PHYSICS 536
GENERAL INSTRUCTIONS FOR LABORATORY

A. INTRODUCTION

A teaching laboratory has special problems. You cannot assume that components and instruments are working correctly. A preceding student may have returned a faulty item to storage without recognizing the problem. Diodes, transistors, integrated circuits, and electrolytic capacitors are usually reliable Always report suspected instrument problems to the instructor.

Learn the limitations and capabilities of the instruments so that you get good results. The equipment is not fragile, but it can be damaged. The following are common mistakes.

1. Instruments pushed of tables.
2. Dropped scope probes.
3. Ignoring voltage and current limitations of instruments. For example, be sure the analog meter is on the correct scale before it is connected to the circuit.
4. A bright, stationary spot on a scope face will leave a permanent mark.

Since there are a large number of students using the laboratory, everyone must help keep the lab in order.

B. LAB REPORTS.

See the other document posted.

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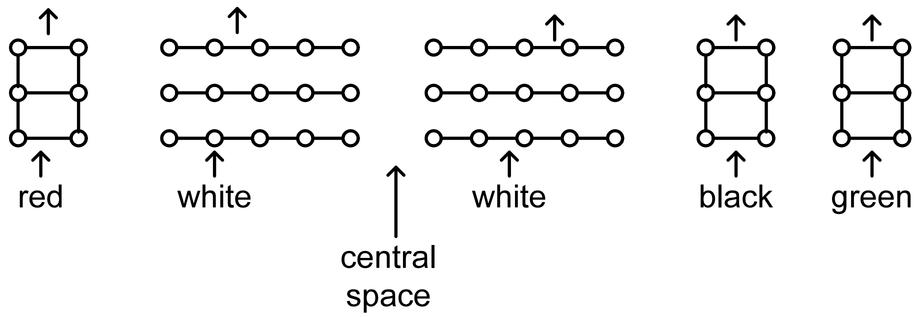
You may include materials of this type if you wish, but it will not improve your grade.

C. GENERAL INSTRUCTIONS.

The general instructions given below will be used in many experiments. They are numbered for easy reference in the experiment instructions. These references are essential, and you should not proceed in an experiment without understanding the assigned instructions. **Instructions that are not needed in the first lab period are marked with an asterisk.** You can study these instructions when they are referenced in subsequent experiments.

1.1 CIRCUIT CONSTRUCTION. Most circuits are assembled using sockets mounted on a metal box. The white sockets running across the short dimension of the board are connected together in sets of five, separated by the center division. Connection errors are the most common problem in the lab.



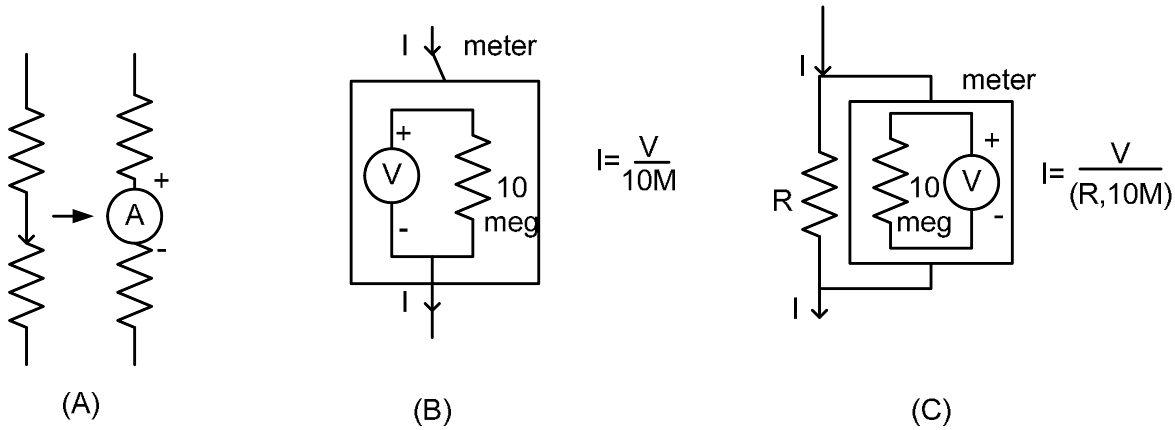
Be sure you understand the socket arrangement, and check the connections first if the circuit does not work. Arrange the circuit similar to the diagram in the instructions to avoid confusion. This also helps the instructor to find errors if you need assistance. In most experiments, it is not necessary to cut leads if the circuit is neat and safe. However, you may cut leads to improve the arrangement of components and avoid accidental contact between components. Some circuits require special component arrangements, which will be specified. Do not force wire into the plug-in sockets. The wire can go between the metal part of the sockets and the plastic wall, which damages the socket. Try wiggling the wire in the socket until it goes in easily. With practice, you can tell when the wire is going in correctly. You should not insert large diameter wire into the sockets, for example, the meter probes. Connect the meter probe to a component lead of a short wire. Large wire can be forced into the socket, but then it will not make good contact when a normal size wire is used.

1.2 VOLTAGE AND COMMON. There are three sets of colored posts with sockets (red, green, and black). The post and all sockets of the same color are connected together. In addition, the black set is connected to the metal box. The red and green are used to distribute voltages, and the black is used as the circuit common.

1.3 SIGNAL CONNECTORS. Two coaxial connectors are mounted on the box. Each has a wire that can be connected to the white sockets. These connectors are used to connect the circuit to the signal generator and scope.

2.1 METERS. There are several types of meters used in the lab; a hand-held digital multimeter and a benchtop digital multimeter. Familiarize yourself with the various measurement options and ranges for each of these options. The best measurements are made when the appropriate range is selected. These meters are described in more detail in the First Laboratory instructions. The clips on the meter leads should be positioned carefully so that they do not cause connections between components.

2.2* CURRENT MEASUREMENTS. A meter must be in series with a component to measure its current, which usually means breaking into the circuit as shown in Part A of the sketch.



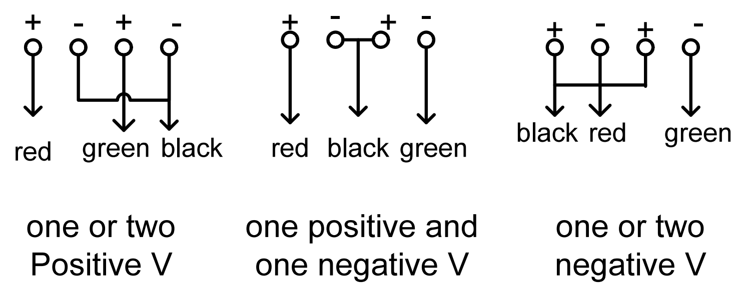
Positive current should go into the plus side of the meter. In the current mode, the meter resistance is low so that the voltage drop across the meter will be small to minimize interference with the circuit. The digital meters can still be used to measure current when it is too small to be observed on the lowest current range. In the voltage mode the meter acts like a 10M resistor, hence a very small current will produce sufficient voltage to be measured. (See Part B of the preceding sketch). For example, a 10^{-9}A current cannot be observed on the most sensitive current ranges, but that current flowing through 10M produces 10mV, which is well within the range of the meters. The large 10M resistance could interfere with the circuit, hence this technique should be used only when the current is small. The current flowing through a resistor R can be determined by measuring the voltage across it (as shown in Part C). When the resistor is large, the internal 10M of the meter must be included in parallel with R to calculate the current.

2.3* VOLTAGE MEASUREMENT. The meter is in parallel with the component for a voltage measurement, hence the meter resistance is very large in the voltage mode. The component and the meter must be treated as a parallel combination, and the meter is negligible if its resistance is much larger than the component resistance. The resistance of the digital meter is 10M. The resistance of the analog meter depends on the voltage range that is used; the resistance is 20K times the full scale voltage. For example, on a 100V scale, the resistance is 10K x 100 = 2M. (The multiplying factor is the full scale voltage, not the observed voltage.)

2.4* AC MEASUREMENTS. In the AC mode a meter measures the effective (or RMS) value of a sine wave. All meters work for 60 cycle, and many meters will work over the whole audio frequency range (20Hz to 20MHz). “True-RMS” meters can be used for nonsinusodial waves, for example to measure the amplitude of noise. Check the meter specifications before you rely on it for anything except 60 cycle sine waves.

3.1 POWER SUPPLY. The power supply has two separate voltage sources in it. The normal limits for each source are 25V and 0.2A. The built-in meter can be used to measure voltage or current for either source. Both sources are protected from excess current. The voltage from the source goes to zero automatically if it is connected to a circuit that draws more than 0.2A. This protection feature can be confusing. You might think that there is something wrong with the source when the voltage drops to zero. However, the fault is most likely in your circuit which draws too much current.

3.2 VOLTAGE SOURCE CONNECTIONS. Each source creates a voltage between a pair of post on the front of the power supply. There is no internal connection between the sources or to ground. The three common connections for the posts are illustrated below. The colors refer to the posts on the circuit board. Black is circuit common.



3.3* USUALLY THE SOURCE should be adjusted to the correct voltage before it is connected to the circuit. Otherwise a component could be damaged before it was adjusted properly. The voltage sources should be turned-off before the circuit components are changed.

4.1 THE SIGNAL GENERATOR can provide sine or square waves over a wide frequency range (10Hz to 10MHz). The frequency can be read from the generator dial; it is not necessary to measure the frequency on the scope. The amplitude is controlled by the push buttons which are marked with the effective (RMS) value of the sine wave. The peak-to-peak amplitude is 2.8 times the effective value. A continuous amplitude adjustment is included. The amplitude of the signal from the generator should be independent of its frequency. The output resistance of the generator is 50 ohms, therefore any load that is comparable to 50 ohms will reduce the signal amplitude when the load is connected.

4.2 THE GENERATOR provides a second signal labeled “1 volt”, which is its effective amplitude. This signal is not affected by the amplitude controls, hence it is useful as a trigger source in some experiment.

4.3 OBSERVE INPUT AND OUTPUT. It is good practice to observe the input and output signal in an experiment. Some unexpected effect at the input might spoil the measurement if you set the input signal and then did not recheck it. Connect the signal from the generator to a “T” connector on channel A of the scope. Then the signal can be carried on to the circuit with a second cable. It is not necessary to have the input signal on the scope display at all times, but it can be observed easily by switching input channels.

The T can be disconnected form the scope without affecting the signal going to the circuit if both scope channels are needed to observe signals in the circuit.

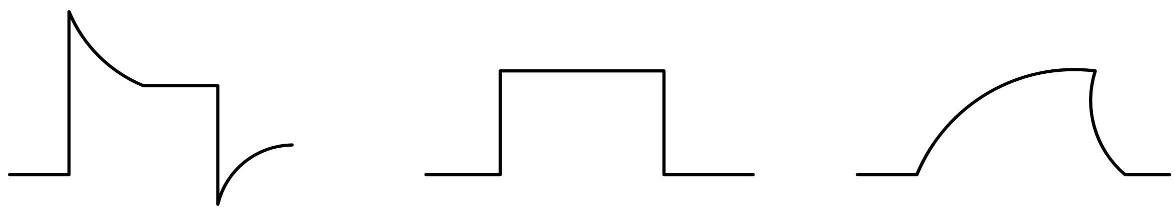
4.4* EXTERNAL SOURCE RESISTANCE. The model used to represent a voltage source has a constant voltage applied to a series resistor (r_s). We create that pattern in real circuits by connecting the signal generator to the circuit through a real resistor R_s. The amplitude of the signal applied to R_s is adjusted (if necessary) to keep it constant.

5.1 OSCILLOSCOPE. The oscilloscope requires more operator skill than the other lab instruments. You will have ample opportunity to become familiar with a scope during the first lab period. Study the written material, experiment with the controls, and ask questions until you can use the scope correctly.

5.2 INPUT OPTIONS. The vertical inputs have three options; AC, DC, and ground. "AC" places a capacitor in series with the signal. The scope displays changed of the input voltage but is insensitive to the average voltage. This mode is convenient for most sine wave measurements. It must be used to observe small variations of large voltages. The capacitor will produce a DC level shift for pulses (see notes Section 3.04).

5.3* DC INPUT. The "DC" mode uses a direct connection rather than a capacitor in series with the input signal. Therefore the scope displays the total voltage relative to its common line. This mode is convenient when you want to observe variations and the voltage relative to a fixed reference. The input is connected first to the reference, and the vertical position control is adjusted until the trace is on a convenient horizontal line. Then the scope input is connected to the signal. The relationship between the signal and the reference is given by the trace relative to the selected horizontal line. The "ground" mode is provided for convenience when the reference is zero volts. This mode switches the vertical input from the front panel to the scope common and opens the connection to the front panel inside the scope after the vertical position is adjusted. When the zero volt reference is set, the vertical position of the scope can be used as a DC voltage meter.

5.4 PROBES. The signal can be connected to the scope through a probe or a coaxial cable. The probe has the advantage of adding only a little capacitance to the circuit (<10pf), but it attenuates the signal by a factor of ten. The equivalent resistance of the probe is 10M. The attenuation is necessary to reduce the capacitance at the probe tip as explained in text appendix A and in notes 3.10.2. Amplitude measurements would be very inconvenient if the attenuation of the probe depends on the frequency of the signal. The probe is tested by using it to observe a square wave on the scope. (A suitable signal is provided at a front panel connector on the scope.) If the attenuation is independent of frequency, the square wave will not be distorted as shown below. A capacitor in the probe is adjusted to remove the distortion.



If the ground lead of the probe is not connected to the ground of the circuit, a large 60 cycle signal can be observed on the scope. Unfortunately, the ground leads tend to break inside their insulation, which can produce this effect. Check the ground lead if you see 60 cycle on the scope.

5.5* COAXIAL CABLE. When the signal observed is very small, a probe cannot be used because it reduces signal amplitude by a factor of 10. (Non attenuating probe can be purchased, but we do not use them in lab). For small signals, a coaxial cable is used to connect the scope to the circuit through one of the connectors on the metal box. The disadvantage of the cable is that it adds capacitance to the circuit, typically 20 pf per foot of cable. Since this capacitance can have several adverse effects, a cable should not be used unless it is essential because of small signal amplitude.

5.6* SINE WAVE AMPLITUDE normally is specified as peak-to-peak, because that is the easiest quantity to measure on the scope. If effective or peak values are used, they will be labeled clearly. Adjust the vertical sensitivity of the scope so that the sine wave covers several centimeters on the display to improve accuracy when the amplitude is measured. When both channels of the scope are used, connect them to one signal initially to insure that they have the same gain. Sine wave amplitude measurements are inconvenient when the peaks are far apart. The horizontal and vertical position must be adjusted to get the peaks close to the grid marks on the scope face. It is more convenient to use a slow horizontal sweet to bring the peaks close together so that there is always some peak close to the grid marks. At very slow speed the signal looks like a continuous band across the scope, which is a convenient display for amplitude measurements. However, you must change the sweet to check the form of the sine wave often enough that you are sure it is not distorted by some fault in the circuit.

5.6A* THE BREAK FREQUENCY is determined by observing the "gain" (v_o/v_i) as a function of signal frequency. (v_i and v_o are the amplitude of the input and output signals respectively.) The gain is constant in the "mid-frequency" region, but it decreases by 30% at the "break" frequency. Use a mid-frequency signal to adjust the vertical gains of the scope until the v_o amplitude is three divisions and the v_i amplitude is 3 divisions (leaving one division to separate the two signals). The fine gain knobs can be adjusted because we are interested in the change in v_o/v_i, not the actual amplitudes v_o and v_i. Change the input signal frequency until v_o drops from 3 to 2.1 divisions, i.e., by 30% which is the break frequency. If the signal generator is working correctly, the amplitude of v_i will be constant when the frequency is changed. Nevertheless, it is good practice to monitor the input signal. (The amplitude of v_i will appear to decrease above 1MHz because of the high-frequency attenuation in the model 1222 scope. This attenuation is the same in both scope channels, hence it does not affect the ratio v_o/v_i. The most convenient way to deal with this scope attenuation is to increase the amplitude of the signal from the generator to maintain the three division display of v_i on the scope). When the break frequency measurement is completed, return the vertical fine gain adjustments to the calibrated position, so that the scope is ready for actual (rather than relative) amplitude measurements.

5.6B* PULSE TIME CONSTANTS. You can use the time for a pulse to change by 60% to measure the pulse time constant.

when $\left(1-e^{-t/\tau}\right)=0.6,\ \tau=1.09t$ $\left(1-e^{-t/\tau}\right)=0.6,\ \tau=1.09t$

Adjust the scope so that the pulse amplitude is five divisions, and the horizontal trace is on a line three divisions below the scope center. Then "t" is the time for the pulse to rise to the scope center.

5.7* CONTINUOUS VERTICAL GAIN. This adjustment is a common source of error. A previous user may have left the control in the uncalibrated position, so get in the habit of checking before you make measurements. The continuous control can also be rotated accidentally if the concentric knobs on the gain control are improperly mounted. If you observe this condition, report it to the instructor.

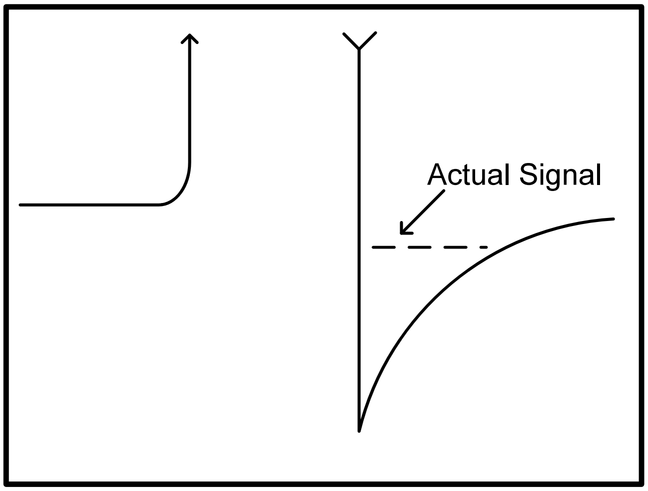
5.8* DUAL TRACE. Dual trace permits you to see two signals on the scope at the same time. Before making measurements, the same signal should be observed on both channels to be sure that they have the same gain. The trigger is taken from the A channel, or external trigger can be used.

5.9* SUM AND DIFFERENCE. The signals applied to the two input channels can be added inside the scope and displayed. One channel can be inverted so that the display is the difference between the two input signals. Some scopes only provide the differential mode, so the inversion is automatic. On others the inversion is manual.

5.10* EXTERNAL TRIGGER. "Internal" trigger is normally used so that the horizontal sweep is started by the observed signal. However, time relations can be effected in this mode by variations of the observed signal. This problem is avoided my carrying a stable signal from the generator directly to the trigger through the "external" connector. The "1V" sine wave from out generator is suitable. The trigger level and slope controls have their usual functions in the "external" mode.

5.11* PHASE MEASUREMENTS. Use the step and continuous controls to adjust the sweep until one complete cycle covers eight horizontal divisions. Then each division represents 45° of phase shift.

5.12* OVERLOAD DISTORTION. A large input signal can deflect the oscilloscope trace off of the screen. If the input signal is very large (approximately 10 times larger than can be displayed), the trace will be distorted when it returns to the scope face. The trace will go in the opposite direction to the signal and then return exponentially to the correct position, as shown in the following sketch.



When it is necessary to observe small voltages shortly after a large voltage, a limiter must be used to prevent the large voltage from overloading the scope.

6.1* METER AFFECTS CIRCUIT. The observed quantities can be affected by the measuring instruments. For example, suppose a 10M meter is used to measure the voltage across a 1M resistor. The meter current is a substantial fraction (1/10) of the current flowing through the circuit resistor. Therefore, the circuit is altered during the measurement to a parallel combination of 1M and 10M. If this change is significant for the circuit, the observed voltage must be corrected to obtain the normal value for the circuit without the meter. When a series meter is used to measure a current, the effect of voltage drop across the meter must be considered.

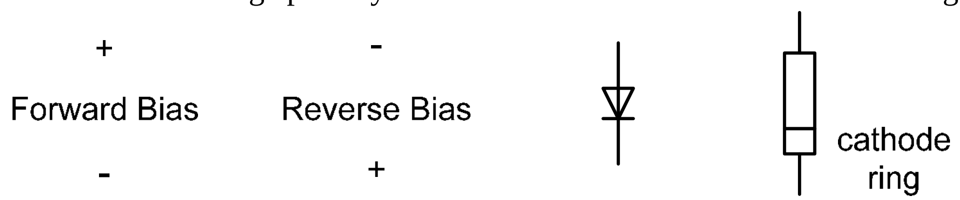
6.2* SCOPE AFFECTS CIRCUIT. A scope probe adds resistance and capacitance to a circuit. The scope input resistance is 1M, but the probe raises this to 10M. The probe capacitance is between the observed point and common. Although the probe capacitance is small (≤10pf), it is often comparable to the stray capacitance in the circuit. Stray capacitance can be the dominant factor for high-frequency signals, hence the probe can have a major effect. The observed quantity can be corrected for the effect of the probe, but the effect of a cable is much worse. A coaxial cable only three feet long can have 100pf of capacitance, which would destroy the high-frequency performance of most circuits. Probe or cable capacitance is not important for low-frequency signals.

7.* RESISTOR COLOR CODE. You can save time by learning the resistor color code. It is posted in the lab and described in Appendix C of the text. Appendix C gives other useful information about resistors.

8.1* DISK CAPACITORS. A whole number means that the unit is picofarads (pf $=10^{-12}$f). A decimal fraction (e.g. 0.01) is in mircrofarads. (uf$=10^{-6}$f). See Text page 19 for more data or capacitors.

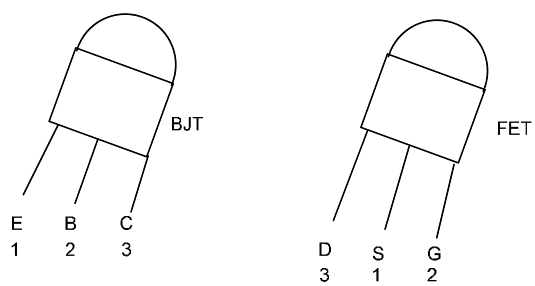
8.2* ELECTROLYTIC CAPACITORS. Most capacitors of 1 uf and larger are polarized because they are electrolytic. The proper voltage polarity is marked. The capacitors are good conductors if the voltage is applied with the wrong polarity. The circuit will not work, and the capacitor can be damaged if the current is large.

9.1* DIODE POLARITY. The symbol for a diode and the usual package are shown in the following sketch. The cathode end of the diode is marked with a ring around one end of the diode case. The voltage polarity for forward and reverse conduction is also given.



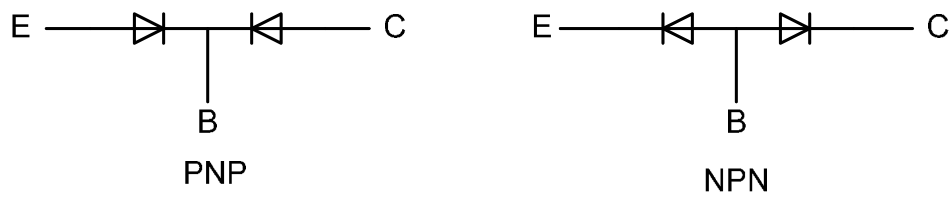
9.2* DIODE TEST. Semiconductor devices usually work correctly or they don't work at all; partial failures are unusual. Therefore, a simple conductance test is adequate using the analog meter on the highest resistance scale. The leads should be connected as if the diode was a resistor. In the resistance mode, and internal battery, the meter, and the external diode are in series. The meter should indicate high conductance for reverse bias (to the left). The voltage polarity supplied by the meter should be obvious by the dramatic difference in conductance. If you are uncertain, the voltage that the meter supplies to the leads can be measured with another meter of the scope. (The battery polarity is not standardized because it is unimportant for resistances.)

10.1* TRANSISTOR PINS. The lead arrangement of the transistors we use is shown below.



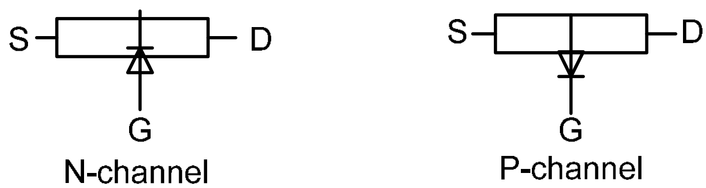
The numbers indicate correspondence between parts. For example, the emitter (1) of the BJT has the same function as the source (1) of the FET. Notice that the pin order is quite difference for the BJT and FET, hence you must rearrange a circuit when these transistors are interchanged.

10.2* BJT TESTS. The conductance test described above can also be used for transistors. The polarity of the two types of BJT's shown is below.



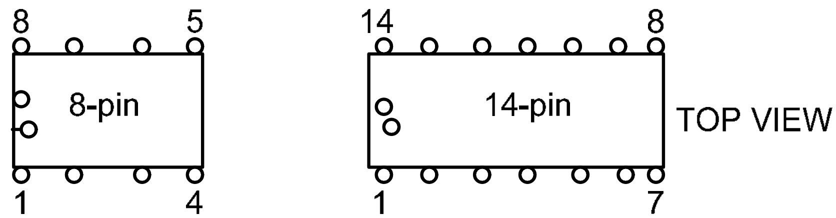
The BJT should be checked on the medium resistance scale. (On the high resistance scale, the emitter-base junction will conduct in both directions because the meter battery voltage is too large. The meter battery is too small on the low resistance scale.)

10.3* JFET TESTS. The gate-to-channel junction should be tested on the high resistance scale like a diode. The source or drain lean can be used for the channel. The polarity of the two types of JFETs is shown below.

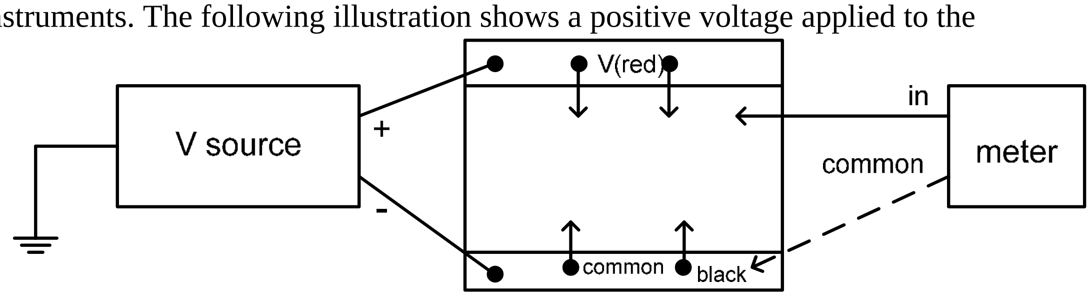


The channel between the source and drain should act like a resistor. Connect the gate to source using one of the clips on the meter lead. Then connect the other lead to the drain. Use the x100 meter scale. The resistance of the channel should be approximately 200 ohms or less because v_{gs}=0. The channel is not polarized.

11.* The arrangement of the IC pins is shown in the top view below. A notch or a small circle are used to distinguish the two ends.



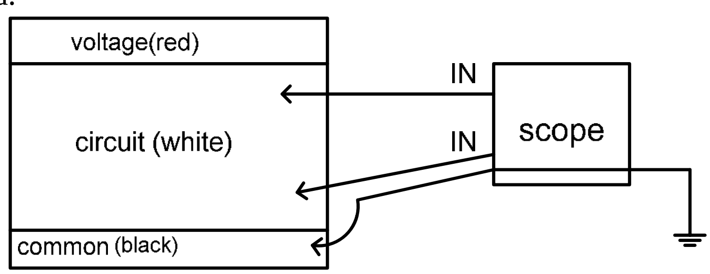
12.1* A COMMON REFERENCE is needed between voltage sources and measuring instruments. The following illustration shows a positive voltage applied to the



circuit through the red terminals. The negative terminal of the source must be connected to the circuit common, which is the black terminals and the metal box (see GI-1.2). A voltage in the circuit can not be measured by connecting the input lead of the meter to a point in the circuit. The meter-common and circuit-common also must be connected as shown by the dotted line.

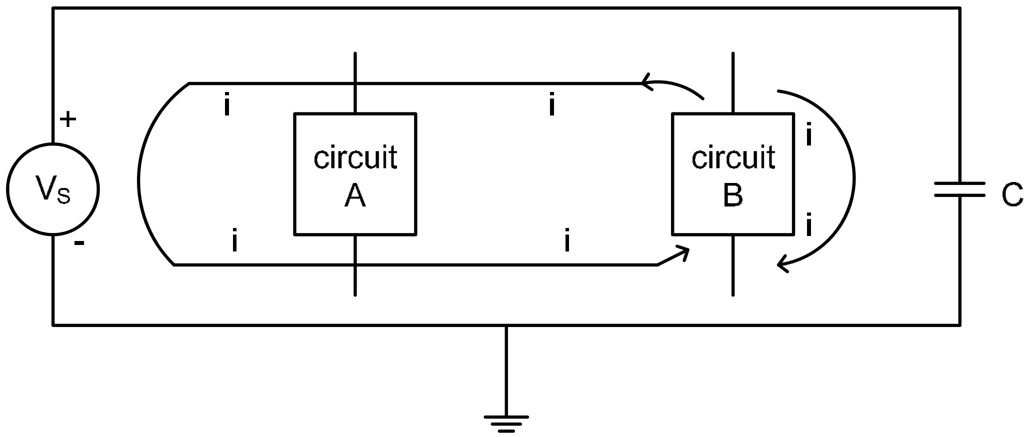
12.2* GROUND. When the metal box is sitting on the table by itself, it is as the same potential as the earth. There is sufficient conduction through the table and building to remove and charge from the box. Under normal conditions, this situation is unchanged when the voltage source is attached! The voltage source created a potential between the positive and negative terminals, not between terminals and ground. The charge from the source flows around a closed loop (out through the positive terminal and in through the negative), so none is collected on the circuit or the box. However, there is a potential flaw in the system. A leak through the electrical insulation in the voltage source can produce a potential between the source and ground. This is prevented by providing a good path from the source to ground through the third wire on the AC plug. When the source is protected in this way, the voltage between box and earth is not affected by the presence of the source. A wire between circuit common and ground is not needed, although it does no harm.

12.3* AN OSCILLOSCOPE is shown in the next illustration. The common of the scope must be connected to the circuit common. If two probes are used, only once connection to common is needed.



(Although this is satisfactory for our lab, a connection to common should be used for each probe when high-frequency signals are observed). The scope is grounded through the third wire of the AC plug to protect against leakage in its power supply. The scope common is grounded through the scope, hence the circuit common also is grounded through the scope.

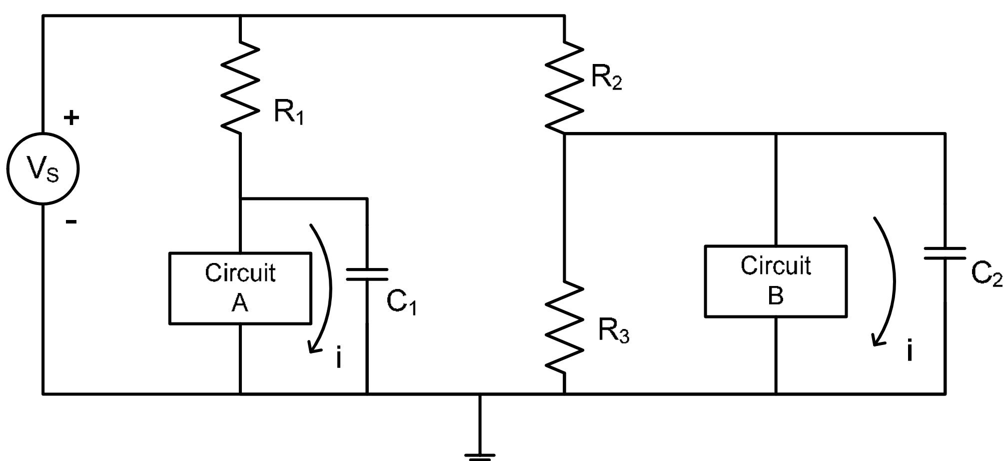
13.1* BY-PASS CAPACITORS. One voltage source usually is connected to several parts of the circuit as shown below. Current always flows around closed loops. If C were not present, the current from part-B would have to flow completely around part-A to complete a loop. For DC and low frequency, current from part-B does no effect the voltage across part-A, because the voltage source and connecting wires have negligible resistance.



At high frequency, however, the inductance of the long wires creates impedance, and the long path serves as an antenna to send and receive high-frequency noise. A by-pass capacitor from the voltage line to common solves the problem by providing a short, local path for the high-frequency current, it also should have a by-pass which provides the shortest practical closed loop. The capacitor should be large enough that it presents negligible impedance for the frequency range it must handle.

In lab, a 0.1uf capacitor should be connected from the voltage distribution lines (red and green) to common. Usually one capacitor at the post edge of sockets is sufficient for each voltage line. (For the red line, connect the capacitor to a white socket and then continue to the common with a direct wire.) However, if the circuit oscillates, you should connect a capacitor to ground from a point on the power line very close to the transistor. By-pass capacitors usually will not be shown on lab circuit diagrams to help you develop a habit of including them in circuits.

13.2* BY-PASS CAPACITORS WITH RESISTORS. Another illustration of short AC loops is shown below. R_1 is included with the C_1 by-pass to direct the high-frequency current from circuit-A.



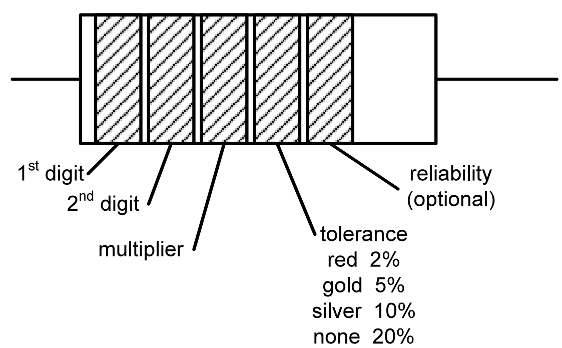
The capacitor provides the low impedance path and the resistor inhibits the current from going onto the voltage line where it could interfere with the other circuits. R_1 and C_1 also act as an AC voltage divider to prevent noise on the voltage line from affecting circuit-A. R_1 can be replaced by an inductor if low DC resistance is needed between circuit A and the voltage source. Circuit-B requires a lower DC voltage than is supplied by the source. The lower voltage is obtained using a resistor divider (R_2 and R_3). Any current from circuit-B must run through R_2 and R_3, which changed the voltage across the circuit. The C_2 by-pass can minimize the voltage caused by AC currents from circuit B. If the average current from circuit-B is constant, the voltage divider plus by-pass is as good as a separate voltage source.

14.* THE DC CONDITIONS of a circuit always should be checked before AC measurements are begun. DC voltage measurements are the easiest way to find a fault in a circuit. AC measurements can be very confusing if the DC conditions are not correct.

IMPORTANT LAB INFORMATION

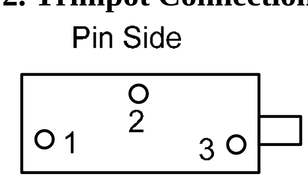
1. Resistor Color Code:

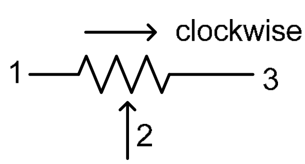
Digit	Color	Multiplier	Number of zeros
	Silver	0.01	-2
	Gold	0.1	-1
0	Black	1	0
1	Brown	10	1
2	Red	100	2
3	Orange	1k	3
4	Yellow	10k	4
5	Green	100k	5
6	Blue	1M	6
7	Violet	10M	7
8	Gray		
9	White		



Example: red-yellow-orange-gold is a 2,4, and 3 zeros, or 24k 5%, resistor

2. Trimpot Connections:





$$102 = 10 \times 10^2 = 1K$$
$$503 = 50 \times 10^3 = 50K$$

3. Capacitor Labels: Unfortunately there are many ways to specify the amount of capacitance.

A. Ceramic disk: Number before "m" specifies capacitance.

$C < 10^{-9}$ f: 10 m = 10ρf = $10x10^{-12}$ f.

$C > 10^{-9}$ f: 0.01m = 0.01 μf = 0.01 x 10^{-6} f.

B. Monolithic (small square): 104 K or 104 M = 0.1μf;

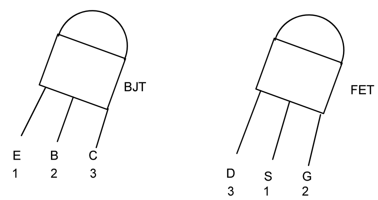
105 = 1μf = 10^{-6}f.

C. Orange cylinder: always μf; e.g., 0.01 = 0.01μf = $0.01x10^{-6}$f.

D. Blue electrolytic: always μf; e.g., 1-12V = 1 μf, 12 V max.

4. Lead Connections for BJT and FET.

TRANSISTOR PINS. The lead arrangement of the transistors we use is



The numbers indicate correspondence between parts. For example, the emitter (1) of the BJT has the same function as the source (1) of FET. Notice that the pin order is quite different for the BJT and FET, hence you must rearrange a circuit when these transistors are interchanged.