EE3 Introduction to Electrical Engineering

LABORATORY MANUAL

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Department of Electrical Engineering
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Acknowledgements

I would like to acknowledge and thank the many people who have contributed to the re-design and development of EE3. In particular, the Chair of the Department of Engineering, Professor Frank Chang was instrumental in providing the resources of staff and funding necessary to develop the new course.

Professor Greg Pottie developed the new lecture format and content of the course and greatly assisted in the development of the laboratory part.

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Dr. Michael Briggs is thanked for his generous insight into the changes that needed to be made to improve the program based on his experience with the previous EE3.

Previous students of EE3 gave us many suggestions that we have attempted to include in the re-design of this important "Introduction to Electrical Engineering."

Finally, I thank the Elenco Corporation for the generous use of their copyrighted materials.

-Prof Oscar Stafsudd, 2012

Student Albert Liu contributed much to Version 1.9, both in providing constructive ideas and in seeing that the changes were implemented.

-Dr. Michael Briggs, 2015

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EQUIPMENT AND DEVICES

Introduction

The purpose of this laboratory is to provide the student with experience in using the basic measurement tools and an opportunity to apply these tools to a term project. The subject areas include:

1. Multi-meters
2. Power supplies
3. Function generators
4. Oscilloscopes
5. Spectrum analyzers
6. Transducers

Safety

All students taking this laboratory course are advised to take and pass the Laboratory Safety Course provided by UCLA. Details of how to enroll in this course are listed on the next page for reference and will also be provided to you at the first lecture.

The instructor of your laboratory will demonstrate safety features in the laboratory itself such as emergency exits, etc. at the first meeting.

If the student chooses a project which involves soldering, and/or use of the Student/Faculty Machine Shop, additional safety and equipment training will be given before the student uses the equipment.

Loose clothing and unprotected footwear (such as open-toed sandals) are not permitted in the laboratory or machine shop.

Food and drinks are not permitted in the laboratory.

Sign and turn in the following certificate when you have successfully taken and passed the required safety course.

LABORATORY SAFETY TRAINING:

The lab room location is Engr IV, 18-132-J.

UCLA in general requires Lab Safety Training BEFORE beginning Research & lab courses; although for the EE3 lab in particular the training requirements are somewhat relaxed since the lab room does not contain the kind of significant hazards that other campus laboratories do. Please refer to details posted at:

Hyperlink: Lab Safety Training (Worksafe Login)

OR https://worksafe.ucla.edu/

You MUST log in, or you will get nowhere. After you have logged in, click on Course Catalog. Expand the Online Course Catalog, You will see LAB-LSFC-OL Laboratory Safety Fundamentals in the list. Click on it, then Launch, to get started.

If you have any questions or comments regarding laboratory safety, please contact the EH&S Hotline at 310-825-9797 or via email at: laboratorysafety@ehs.ucla.edu

For EE3 lab sections it is sufficient to take the EH&S Lab Safety Fundamental Concepts course, at your convenience, anytime during the quarter that you can work it into your schedule. In the meantime, you may browse an online copy of the UCLA lab safety manual:

Hyperlink: UCLA lab safety manual

OR https://www.ehs.ucla.edu/doc/safetyhandbook.pdf/view

Lab Safety Course registration info:

Here is a link to where you can find lab safety training course registration information. Please sign up for the **Lab Safety Fundamental Concepts** course.

Hyperlink: training course registration

OR https://www.ehs.ucla.edu/training/schedule

Emergencies:

The EE3 lab`s emergency phone (land-line) campus extension, located in the stock room, is 7-5277.

Dialing 911 from the lab room`s phone will go directly to the campus Police Dept; whereas, 911 dialed from a cell phone will first go to a regional emergency center and then unnecessary time will have to be spent forwarding that call back to the campus Police Dept. The campus Police Dept can be dialed directly from a cell phone using the

UCLA campus emergency phone number: 310-825-1491.

Multi-Meters

The multiple function meter, more commonly referred to as the multi-meter, is the most basic of electrical measurement devices. These meters occur in two basic types: the analog multi-meter (AMM) and digital multi-meter (DMM). Although the two types perform similar measurements, their methods differ and their limitations are quite different.

Analog Multi-Meters (AMMs)

[See Appendix B for additional information.]

At the heart of all analog meters is a current measuring device (see Figures 1a and 1b). The meter works as follows: the current passing through a coil produces a torque due to the magnetic field across the coil. This torque then acts against a spring and moves an indicator hand. Typical meters require 10^{-1} to 10^{-5} amperes to deflect the indicator hand to full scale. The mechanism is generally mechanically delicate and does not like physical shocks, i.e. dropping. The accuracy is on the order of 5-10%. The electrical equivalent circuit is shown in Figure 2 where the resistance of the coil and its connections are lumped into R_i (the internal resistance of the meter).

FIGURE 1a: ANALOG MULTI-METER

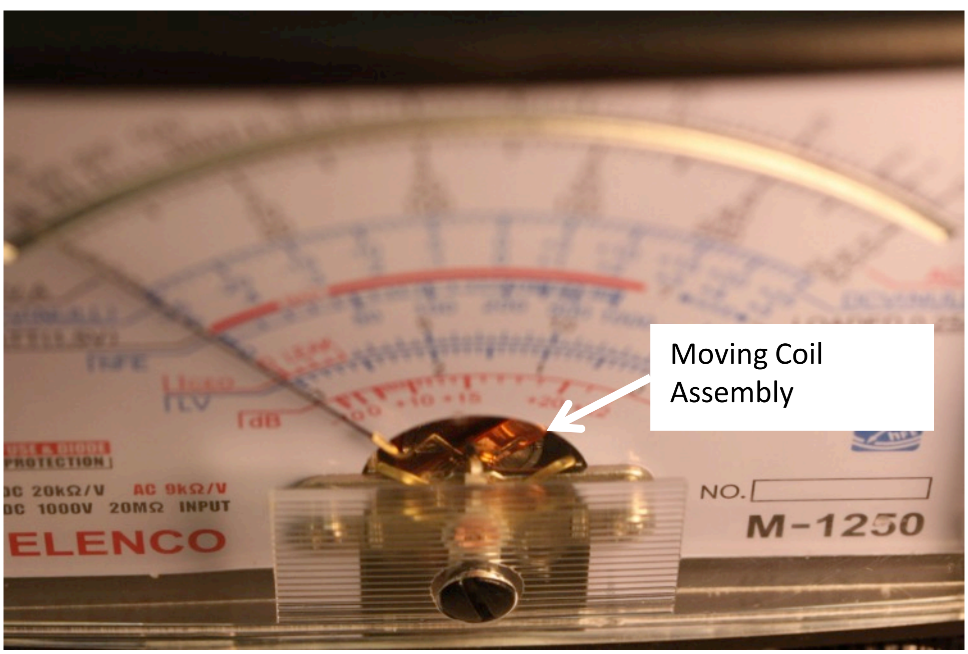


FIGURE 1b: ANALOG MULTI-METER CLOSE-UP
(POINTING OUT MOVING COIL ASSEMBLY)

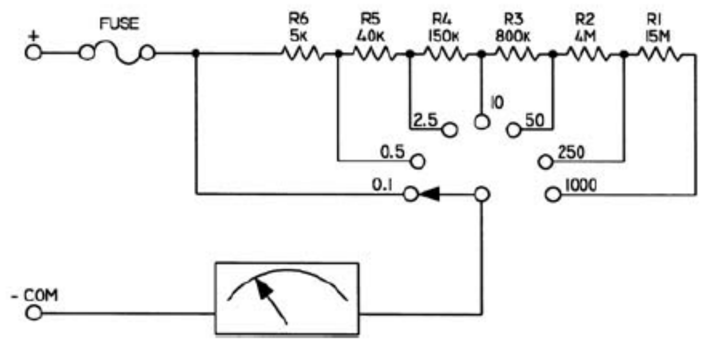


FIGURE 2: ANALOG MULTI-METER VOLTAGE READING CIRCUIT

To change the full scale voltage range of the instrument, a multiple position switch places successively higher resistor values in series with the meter movement.

$$V_{\text{full scale}} = I_0 \,(R_{ex} + R_{int})$$

where R_{int} is the resistance of the coil and R_{ex} is the externally added scale factor resistance. I_0 is the full scale current.

NOTE: most analog meters will indicate the total resistance, i.e. (R_{ex} + R_{int}) to achieve a given full scale voltage and is usually given in ohms/volt = $1/I_0$. The larger this value (ohms/volt), the less the meter will influence the measurement process. It follows that this requires a more precise and delicate and thus higher priced device that is more easily damaged.

Figure 3 shows the typical circuit used to measure resistance with an analog meter. To measure a resistor, one must first short circuit the two measurement terminals or probes. The ohms adjust resistor R_{ohm} is then adjusted to get a full scale reading of the meter. The resistor to be tested is then placed in the circuit. The meter reading is then given by:

$$\text{Meter Fraction of Full Scale} = R_{int} / (R_{int} + R)$$

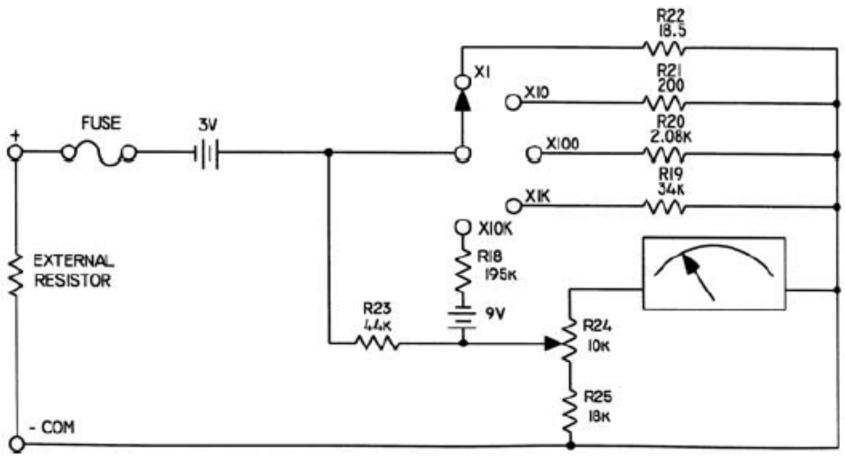


FIGURE 3: RESISTANCE MEASURING CIRCUIT

In principle, resistance can be measured from 0 – infinity. Of course, the readings at large values are not very accurate. The scale is also quite non-linear (see Figure 4 for a typical example). The maximum utility of the measurement is when R ~ R_{int}. Therefore, a meter will have multiple values of R_{int} to be selected.

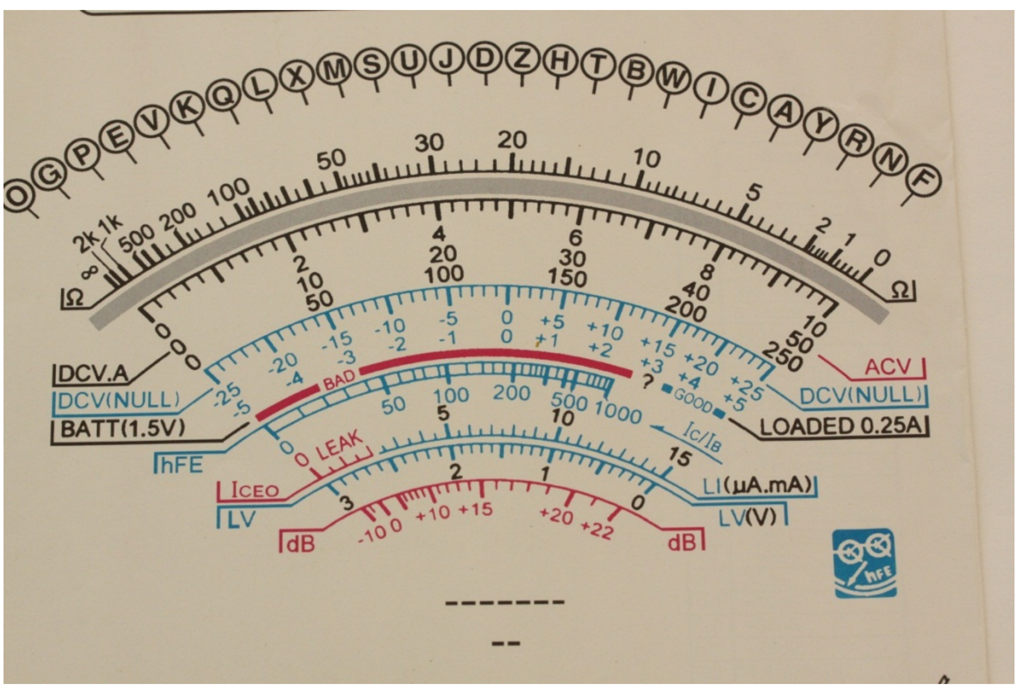


FIGURE 4: ANALOG METER SCALE

An analog meter can also be used to measure current. To do this, the meter's terminals are placed in series with the current to be measured (Figure 5). Note that if one does not wish to perturb the circuit by the measurement process, then the resistance, R_{int}, should ideally be 0 ohms. Since this is not possible, one must consider the effect of the R_{int} resistance on the circuit. Typically, if R_{int} << the resistors in the circuit, there will be a negligible effect on the accuracy of the measurement.

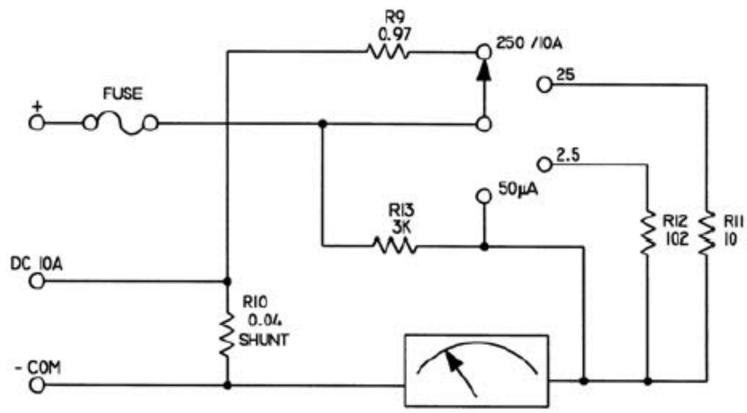


FIGURE 5: CURRENT MEASURING CIRCUIT

Digital Multi-Meters (DMMs)

[See Appendix C for additional information]

Digital multi-meters currently dominate the market. Their advantages over analog meters include:

1. Increased accuracy. Analog meters are typically no better than a few percent accurate. Even very low cost digital meters are 0.1% or better in accuracy.
2. Mechanical ruggedness. Analog meters have delicate mechanical meter movements which tend to be easily damaged by dropping, etc.
3. Higher input resistance than possible with analog meters. Typical values exceed 10^7 ohms.
4. Lower cost for better performance.

Digital multi-meters always measure potential differences, i.e. Voltage. Whether they are functioning as DC voltmeters, AC voltmeters, resistance measuring meters, current meters, etc., the actual measurement is "potential". This is in sharp contrast to analog meters which always measure currents.

In "current mode", the measurement terminals (input) of the DMM are shunted with a resistor and the voltage drop across the resistor is then measured by the meter. The range of the current measurement is changed by changing the value of the resistor. If, for example, the voltage measuring device has a range of 0-2 volts, then a shunt resistor of 1 ohm would cause the range to be 0-2 amperes. Increasing the resistance value to 10 ohms would result in a 0-0.2 ampere range and so on.

Resistance is measured by a DMM by putting a precision constant current source at the measuring terminals. Then, a resistor connected at the terminals will produce a voltage drop proportional to both the resistor value in ohms and the current source in amperes. A significant advantage of this method of resistance measurement over the AMM is that the readout is linear as long as the current source remains ideal. The 0-2 V measurement meter with a 1 micro-ampere current source becomes a 0-2 mega-ohm device. By changing the value of the constant current source, the range can be adjusted.

The measurement method employed by DMMs is to compare the voltage to be measured to internally generated voltages. The internal voltage is changed until a match of sufficient accuracy is achieved. Because the external voltage to be measured is compared, it is possible to make the effective input resistance reach extremely large values and therefore not interfere with the accuracy of the measurement. Typical DMMs in the voltage measurement mode have effective input resistances in the 10 to 400 million ohm range. This makes them “almost ideal” voltage measurement devices.

Two basic digital measurement methods are used in most DMMs. They are (1) the integrator method and (2) the successive approximation method. The integrator method compares the external voltage to be measured (V_m) with the voltage on a capacitor. A constant current source is connected to the capacitor and a digital timer is simultaneously started. The voltage on the capacitor V_c = q/c where q is the charge on the capacitor in coulombs and c is the capacitance in farads. The charge at T=0 is set to zero and the charge at time T is $Q = \int_0^T Idt$. For a constant current I, the charge at time T is q = I·T and therefore the voltage on the capacitor is given as V_c = I·T/C. The voltage V_c is a linear function of time. When the comparator circuit detects that $V_c = V_m$, the timer is stopped. The digital value of the time represents the voltage that was measured. In reality, the measurement is a bit more complicated if capacitors are not perfect and suffer from various problems. To minimize the non-ideal nature of capacitors, the circuit actually measures the time to charge the capacitor and then to discharge it in order to make the measurement more accurate. Such circuits easily achieve 1/1000 accuracy.

Successive approximation types of DMMs can achieve higher accuracies and high speeds. In this type of digital meter, voltages produced by a digital to analog converter (DAC) are compared sequentially with increasing accuracy. The internal voltage is produced by changing the value of resistors switched across a constant current source. The internal voltage starts at $V_{Max.}$ If the external voltage to be measured, V_m is greater than V_{Max} then the instrument displays “over range”. If the external voltage is smaller than V_{Max} then the internal voltage is changed to V_{Max}/2.

The voltages, external and internal, are compared again. If the external voltage is smaller than V_{Max} /2 then the internal voltage is reduced to V_{Max} /4. If the external voltage is greater than V_{Max} /2 then the internal voltage is increased to ¾ V_{Max} . This process is repeated. Each successive comparison doubles the accuracy to which the external voltage is being approximated by the internal voltage (which is digitally controlled). Eight successive comparisons yield an accuracy of 1/256 or 0.4%. It should be noted that 12 bit and 16 bit systems (digital to analog converters) are very common. Such devices can be used to produce DMMs with 1/4096 (0.025%) and 1/65536 (0.0015%) accuracy.

Function Generators

Function generators are time dependent voltage sources. They fall into two distinct types: analog and digital. **In this class, we will only be using digital function generators.**

Analog function generators of the simplest type produce sinusoidal and square waves, i.e. waves whose voltage as a function of time are given by $V(t) = V_0 \sin(\omega t)$ in the case of sine waves or waves that alternate between $\pm V_0$ with a minimum of rise and fall time (see Figure 6). Frequently, triangular waveforms are also available in analog function generators. A triangular wave rises linearly for $-V_0$ to $+V_0$ and the falls linearly from $+V_0$ to $-V_0$ successively.

FIGURE 6: **DIGITAL** FUNCTION GENERATOR

These waveforms can easily be produced by relatively simple analog circuits. More complex waveforms such as modulated or gated repetitive sine, square, or triangular waveforms can also be easily produced. However, for arbitrary functions of time, one should use a digital function generator.

Digital function generators are based on Digital to Analog Converters (DACs) as are some digital multi-meters. A series of numbers stored in a memory is sent sequentially into a DAC. The DAC's output as a function of time is then determined by the array of numbers stored in the memory. The series of voltage outputs produced by the DAC can be used to approximate any arbitrary function limited only by the speed of the DAC and the size of the memory. This series can be repeated to give a repetitive function or occur as a single occurrence.

The NI myDAQ has such an arbitrary waveform generator included as one of its functions. Each type of function generator (analog and digital) has its advantages and disadvantages so both systems continue to be popular and in production.

Power Supplies

The laboratory is equipped with Tektronix dual power supplies, which have variable output voltages and current limits (Figure 7). These supplies act as almost perfect voltage sources. That is, they supply a constant output voltage regardless of current demand up to the pre-set current limit at which point they behave as current sources supplying a fixed current even into a short circuit – zero ohms!

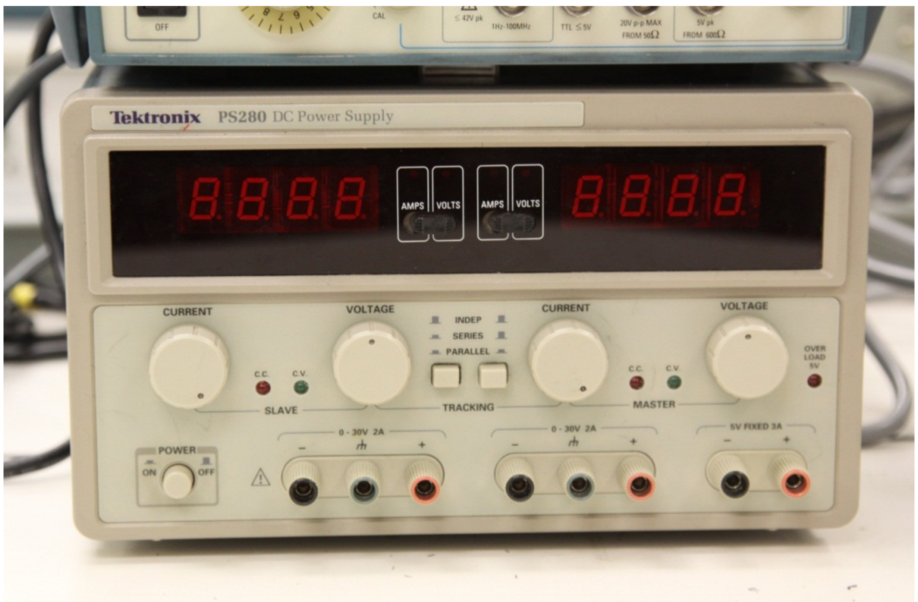


FIGURE 7: DC POWER SUPPLY

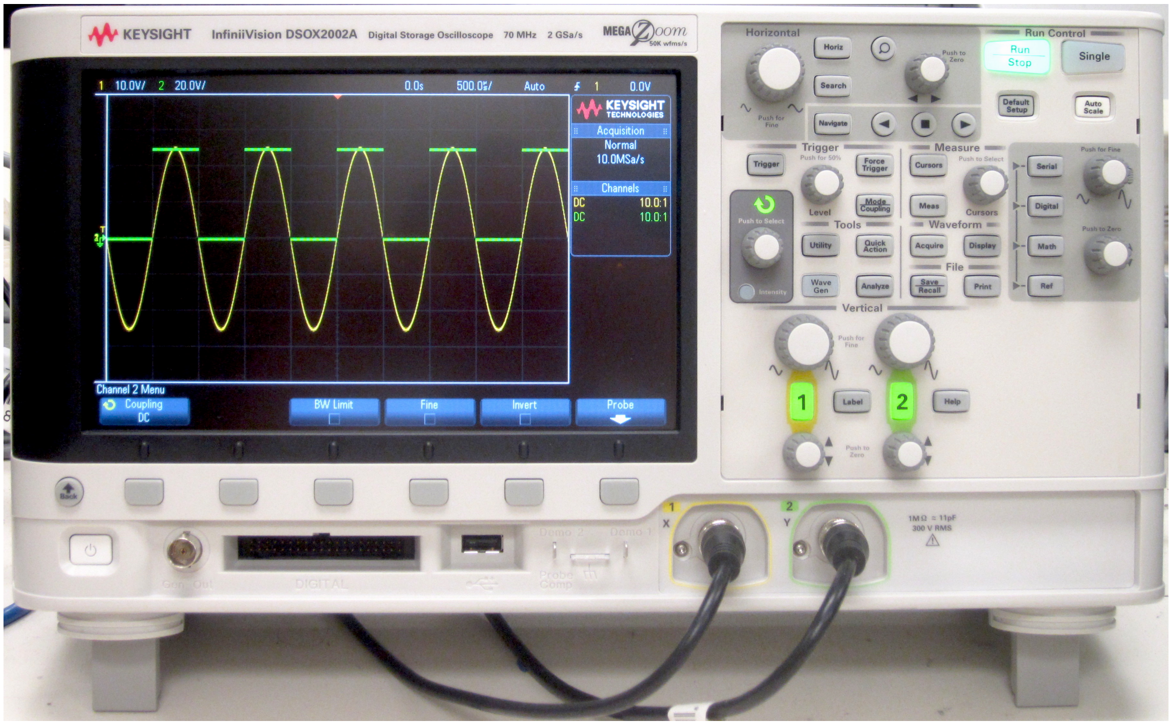
Oscilloscopes

Oscilloscopes allow us to display time dependent waveforms. The original "scopes" were analog devices.

The signal to be displayed was amplified and the amplified signal was then used to displace an electron beam vertically. The displacement was usually accomplished electrostatically. The horizontal path of the beam was determined by a second amplifier circuit. The horizontal position was commonly a linear function of time. Thus, the beam of electrons was positioned horizontally as a linear function of time and vertically by the signal. The electron beam struck a front surface of the cathode ray tube where a phosphor surface was present. The electron impact caused the phosphor to fluoresce (light up brightly). The waveform as a function of time was displayed.

This method was a major step forward at the time, allowing the engineer to visualize the time dependent voltage. Analog oscilloscopes were employed from the 1930's through the end of the 20th century. Digital technology in the form of fast analog to digital converters along with advances in display technologies led to the digital oscilloscope, which has become the dominant technology today.

The typical digital oscilloscope still amplifies and perhaps conditions the signal.



The time dependent signal is then converted to digital information by an analog to digital converter (ADC). The sampling rate is continuously deposited in a FIFO (first in – first out) memory. The memory is a certain number of addresses long (typically 4096 or larger). When new data comes from the ADC, it is placed into *address 1* while data in that address is displaced to *address 2*, *address 2* to *address 3…* with the last *address 4096* discarded. Therefore, at any instant of time, the data in the memory represents 4096 measurements sequential in time.

The digital scope can display this data just as a computer displays images on a screen. Because the data is stored in a memory, a single event can be captured and the process stopped and then displayed as long as the operator wishes! This is an enormous advantage over analog scopes particularly in analyzing transient or single events.

The oscilloscope’s time base controls change the rate of digitization by the ADC and therefore the horizontal display (time axis). If the signal (waveform) is repetitive, then it is desirable to always start the ADC at an equivalent point in the waveform. This is accomplished by the trigger function of the scope. The trigger section can select a given voltage value and sense (increasing or decreasing) of an input to position time = 0 i.e. the start of the ADC memory.

The waveform used to trigger the system is usually the waveform being displayed. However, it can also be from other sources such as power lines or other related waveforms sent to another input channel for the scope.

Because the data is in digital form, many mathematical operations can be performed such as averaging, addition, subtraction, division, etc. of two or more different waveforms. The data can also be transferred to a removable memory allowing the operator to further analyze or archive the data.

Spectrum Analyzers

All spectrum analyzers are based on the mathematical work of Joseph Fourier (1768 – 1830). His work on heat transfer in metal plates (1807) and his later work "Theorie analylique de la chaleur" (1822) laid the foundation for what we call Fourier analysis. He showed that any arbitrary repetitive function can be decomposed into a series of simple oscillating functions. The simplest functions are: sin (ωt), cos (ωt), $e^{j\omega t}$.

There are both analog and digital versions of spectrum analyzers. The most common kind of spectrum analyzer remains the analog type. Analog spectrum analyzers work almost identically as ordinary radio receivers. The signal, a complex time dependent repetitive waveform, is amplified and fed into a nonlinear mixer. A local pure sinusoidal oscillator is also fed in to the nonlinear mixer. The resulting output from the mixer contains many new time dependent terms. One of these terms is of particular interest, i.e. the difference frequency term:

$$A_{dif}(t) = A_{sig}(\omega) \cdot A_{local\ osc} \cdot \sin[(\omega_l - \omega_s)\,t]$$

$$= k\,A_{sig}(\omega)\sin(\Delta\omega t)$$

A narrow band amplifier whose pass band is centered at Δω then amplifies only that term. The output amplitude is then measured. By changing the local oscillator frequency, one can effectively map out the various frequency components A_{sig} (ω). [This is called a "heterodyne" system. Heterodyne detection was first suggested by Reginald Fessenden (1901). The modern heterodyne technique was not invented until 1918 when Edwin Armstrong demonstrated his superheterodyne receiver.]

One of the great advantages of the analog heterodyne system is that one can measure to very high frequencies. The typical laboratory analog spectrum analyzers measure up to 2.9 GHz, i.e. 2.9 x 10^9. Spectrum analyzers are available to over 10^{11} Hz. They do, however, have some limitations. For example, the measurements are performed at different frequencies sequentially. That is, first one frequency and next a small increment away, etc. Therefore, if the signal changes during the measurement, data can be incorrect. If, for example, a system were frequency hopping first at f_1 and then at f_2, etc., it is possible that neither or both would be recorded!

Another more severe problem occurs at low frequencies. This is because all mixers produce excess noise at low frequencies, i.e. 1/f noise. The noise floor, the minimum signal necessary for detection, increases by 100,000 when the frequency changes from 1 MHz to 100 Hz in a typical system!

Digital spectrum analyzers operate in a similar way to digital oscilloscopes. The complex waveform is digitized by an ADC and placed in a memory. The data is then analyzed by a digital adaptation of Fourier analysis called an FFT. The data is then plotted.

The principal problem with this method is that very accurate ADCs are necessary and the speed of ADCs limits the frequency response. However, at low frequencies, where analog analyzers fail, digital analyzers are superb. So the two kinds of spectrum analyzers complement each other.

Transducers

The student will be provided with examples of opto-electronic transducers (light ↔ electricity), acousto-electronic transducers (acoustic power ↔ electricity) and electro-mechanical transducers (motors and/or generators: mechanical power ↔ electricity).

Opto-Electronic Devices

Light emitting diodes convert carriers (holes and electrons) in a direct band gap semiconductor into light. When a diode structure (a p-n junction) is forward biased, electrons from the 'n' side are sent to meet holes from the p side. In most semiconductor diodes, there is a high probability that the energy released by the annihilation of the holes by the electrons will be released in the form of light.

Various alloys of 3-5 semiconductors can be used to make diodes with different energy band gaps. It is currently possible to make LEDs that produce wavelengths from ultra violet through the visible and into the infrared, i.e. 250 nm to 10 microns. Those operating from 250-1000 nm are quite efficient in that they can convert about 10% of the electrical energy to light. In comparison, a standard light bulb converts less than 1% of the electrical energy input to visible light. Typical LEDs are seen in Figure 8.

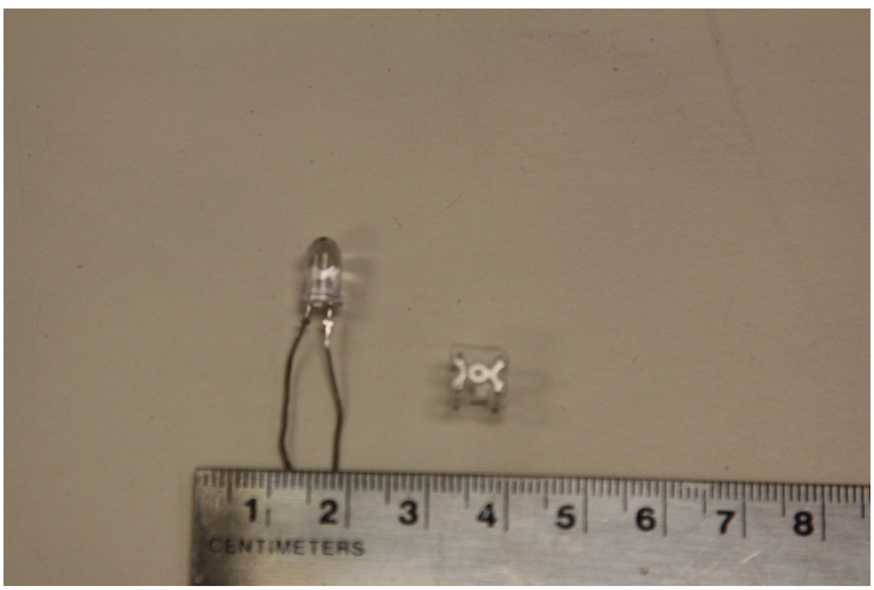


FIGURE 8: LEDs (LEFT: HIGH BRIGHTNESS, RIGHT: HIGH POWER)

Photodiodes perform the reverse function. In this case, the light is absorbed in a semiconductor and thereby generates electron-hole pairs. This, in turn, generates a photo-voltage in a p-n junction or a change in conductivity if the diode is reverse biased. The most common photodiodes are made of silicon (an indirect bandgap semiconductor which can efficiently generate carriers but cannot create light). However, the ease of device fabrication and low cost of silicon devices mean that most photodiodes are made of that material (Figure 9). Large area p-n junction devices can be used to generate useful amounts of electrical power from sunlight, i.e. solar cells (Figure 10).

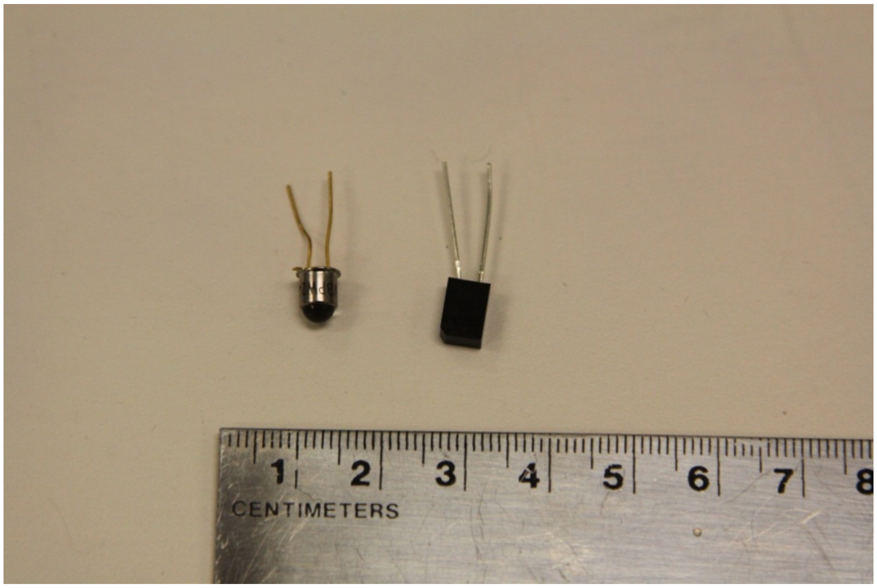


FIGURE 9: SILICON PHOTODIODES

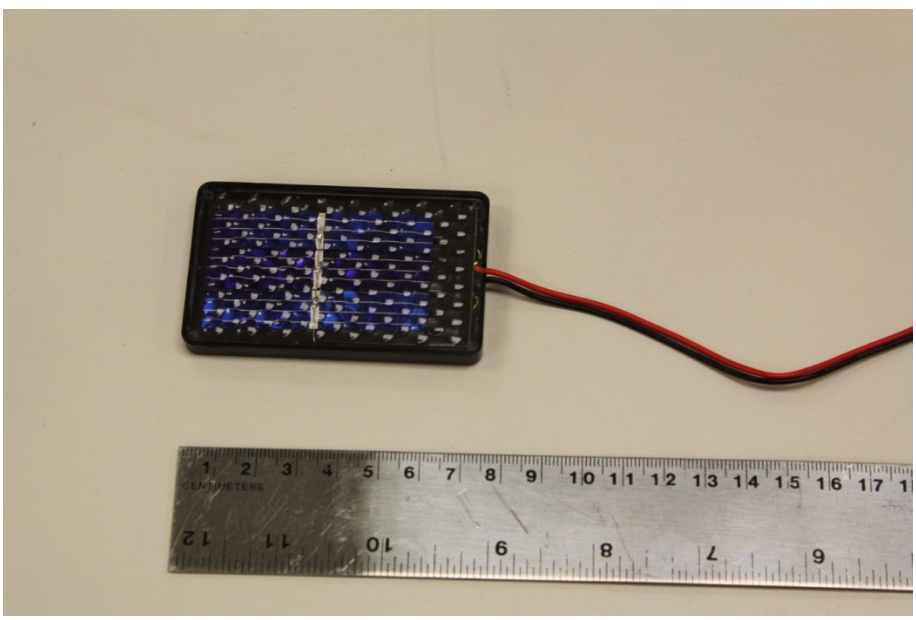


FIGURE 10: SOLAR CELL (400 MILLIAMPERE, 0.5 VOLTS)

Acousto-Electronic Devices

Electrical power can be converted into sound (acoustic power) by a number of methods. Magnetic forces generated by time dependent currents running in a coil which is in turn subject to a large magnetic field move the diaphragm of most loud speakers. Piezoelectric actuators can also be used to move diaphragms and therefore launch acoustic waves.

Piezoelectric types of transducers are particularly useful at high frequencies. The reverse procedures allow devices to be acoustic sensors, microphones, etc. In these cases, the acoustic field (sound) moves the diaphragm and a voltage is produced by the moving coil or the piezoelectric element.

Electro-Mechanical Devices

One of the most useful electro-mechanical devices is the motor and its corollary, the generator. The inventor of the motor, Michael Faraday (1791-1867) pioneered the conversion of electrical energy to mechanical (the motor) (1831) and mechanical energy to electrical energy (the generator). While these devices currently occur in many different formats, we will study one of the simplest forms of these devices – a D.C. (direct current) motor/dynamo. In this device, permanent magnets are fixed in a circle around the inside of a cylindrical steel can. They alternate in polarity, i.e. N-S-N-S. The simple type of motor (known as a "can motor") powers many common devices such as electric razors, electric windows in cars, etc. The rotor or armature is free to rotate on bearings in the outer case. The rotor has a series of projections (see Figure 11) called poles that are in turn wrapped with wire. As current passes through the wire, a magnetic field is produced. Like magnetic poles, i.e. N-N or S-S, repel each other and unlike poles N-S or S-N attract each other. Therefore, the motor rotor will rotate to minimize these magnetic forces.

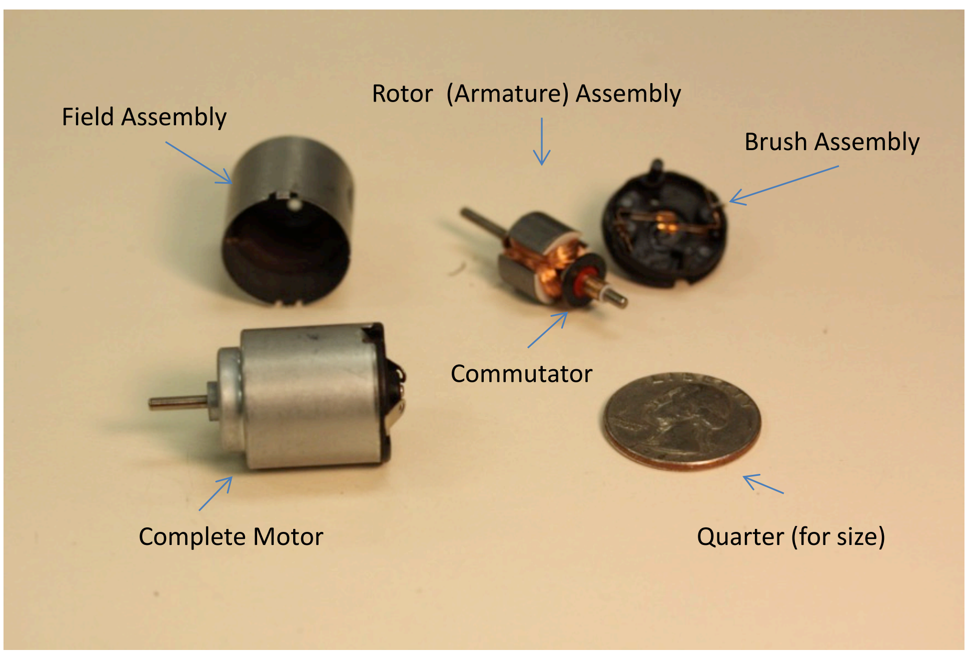


FIGURE 11: MOTOR ROTOR

As soon as the minimum force angular position is reached, the current in the rotor is reversed. This reverses the polarity of the rotor's magnetic field and it continues to be forced into rotation. The process is repeated again and again as the shaft rotates. The timing of the reversal of the current is accomplished in the "can motor" via a mechanical system called a commutator. The commutator consists of sliding electrical contacts (brushes) and cylindrical (split) contacts on the rotor shaft usually made of copper or a copper alloy.

The conversion of electrical energy into mechanical energy in the simple motor can exceed 80% for this low cost device. More sophisticated motor designs actually exceed 90%.

In the reverse process, that of converting mechanical energy to electrical energy, the rotor is not energized and is mechanically rotated by external forces. As the rotor poles pass the fixed magnets, a magnetic field is induced in the rotor poles. As the rotor turns past the fixed magnets, the magnetic flux in the rotor poles rises and falls, reverses direction and rises and falls again and reverses once more. The process is repeated continuously as the rotor turns. The changing magnetic flux in the rotor poles induces a potential in the coils wrapped around the poles. That induced potential is carried to the commutator and from there to the external electrical connections.

If a resistor is connected to these output connectors, current will flow and energy will be deposited in the resistor. Therefore, by applying mechanical forces to the armature, the device now operates as a dynamo converting the mechanical energy to electrical energy. Similar mechanical to electrical energy conversion efficiencies are achieved in these devices.

These types of devices are found in everyday equipment such as emergency radios with hand cranks, flash lights with hand cranks, etc. The simple low cost and useful motor does have a significant problem with respect to lifetime due to mechanical wear in the commutator structures. The problem is eliminated by A.C. motor systems whose lifetimes are typically limited only by the life of the bearings in the device. Even higher efficiencies, i.e. 95% + are practically achieved in these A.C. systems.

LABORATORY SESSIONS

Week 1: Multi-Meters and Power Supplies

In this laboratory, we will explore the use of DMM and AMM multi-meters in the measurement of resistance, voltage sources and current sources.

Resistors

Typical low power resistors are in the form of cylindrical objects with axial leads or connectors. The resistor value is usually indicated by a series of 3 color bands with most times a 4th band representing the resistor's tolerance.

	digits		multiplier	tolerance	
	band 1	band 2	band 3	band 4	
black		0	1	1%	brown
brown	1	1	10	2%	red
red	2	2	100	5%	gold
orange	3	3	1 000	10%	silver
yellow	4	4	10 000		
green	5	5	100 000		
blue	6	6	1 000 000		
violet	7	7			
grey	8	8	0.1 gold		
white	9	9	0.01 silver		

http://www.matrixtsl.com/courses/ecc/uploads/resistorcolor4band.png

Sometimes, as many as 6 bands may be used.

The most basic carbon composite resistors have 3 bands: the first two bands represent the resistor value and the 3rd band is the power of 10 multiplier for that value. The assumption is that the tolerance is 20%.

Four stripe resistors use the 4th stripe to indicate tolerance. For tighter tolerances, i.e. greater accuracy, a 5 band color code is used, but no specific convention is rigorously followed by manufacturers. High accuracy resistors are frequently marked numerically rather than using color bands.

The physical size of the composite resistor indicates its power dissipation ability. Common composite carbon resistors have power ratings ranging from 1/16th to 2 Watts.

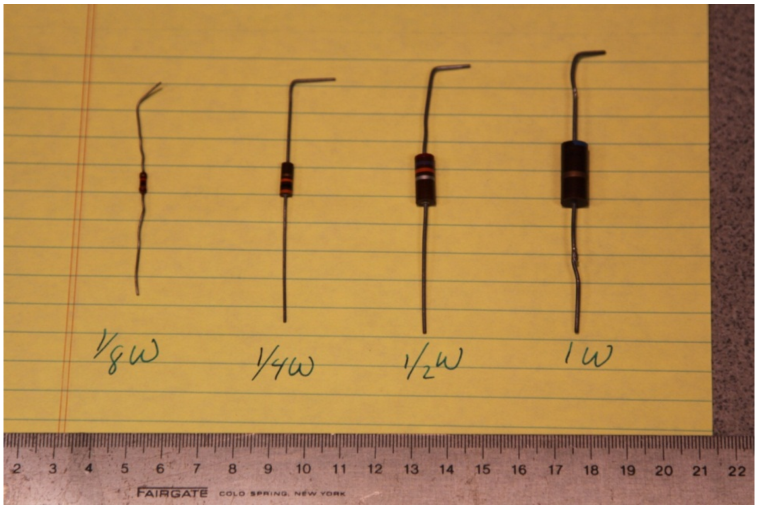
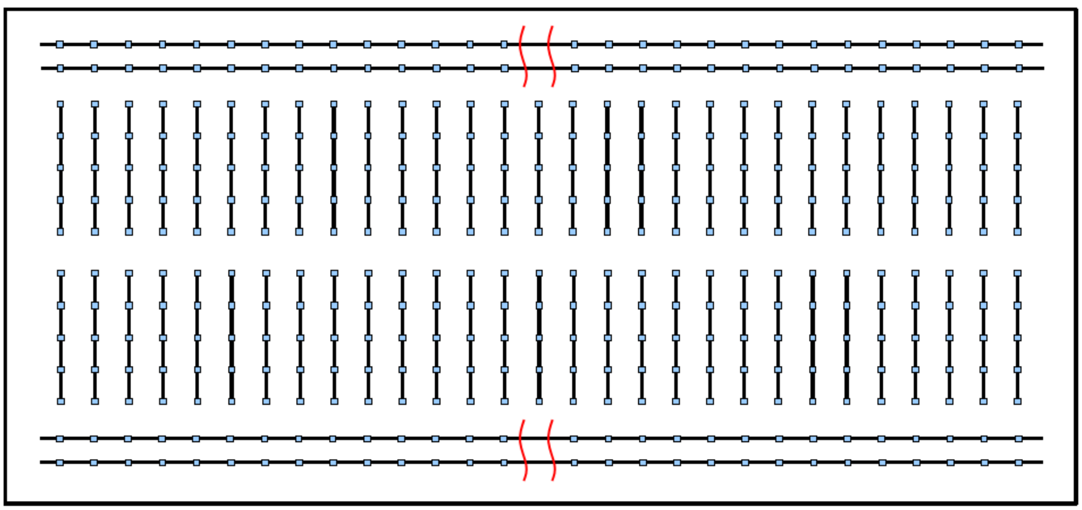


FIGURE 1-1. VARIOUS POWER RATED RESISTORS

Breadboard Interconnection Diagram:



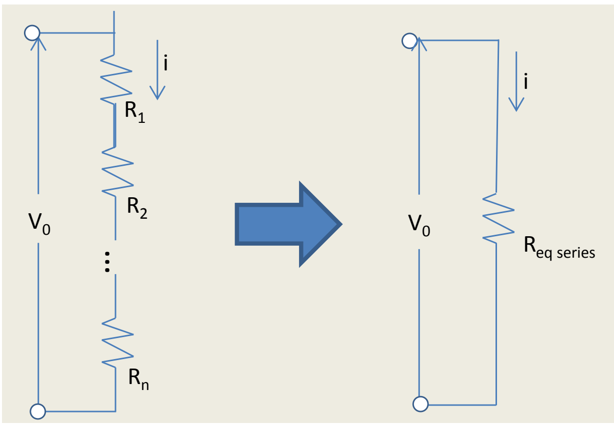
For our labs, your electrical components will be placed into breadboards. A breadboard will have exposed holes for your components to be inserted. As shown above, holes are electrically connected internally into rows and columns.

WARNING: in some breadboards the horizontal strips may be disconnected at the position of the red markings, i.e., the horizontal strips on the upper left will not be electrically connected to the strips on the upper right. The same goes for the horizontal strips on the bottom.

Series and Parallel Combinations of Resistors

If resistors are placed in parallel or series, their behavior with respect to current and voltage can be exactly replaced by a single resistor. Consider the following situations:

Series



From the left diagram:

$V_0 = iR_1 + iR_2 + \cdots iR_n$

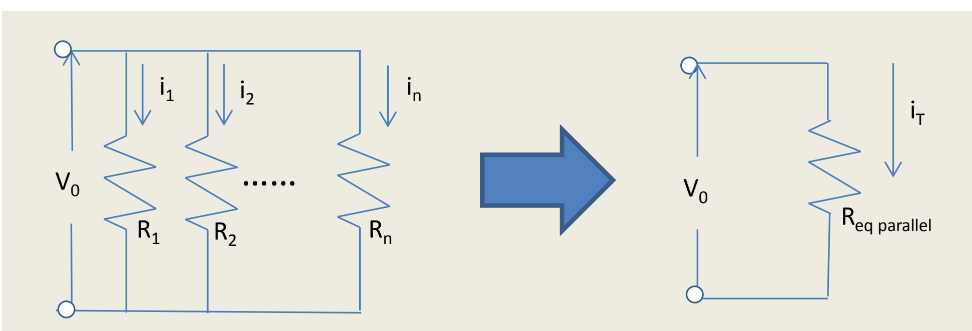
So $V_0 = i\sum_{i=1}^{n} R_i$, or $\frac{V_0}{i} = \sum_{i=1}^{n} R_i$

From the right diagram:

$V_0 = iR_{eq\ series}$, or $\frac{V_0}{i} = R_{eq\ series}$

Therefore, $R_{\text{EQ,Series}} = \sum_{i=1}^{n} R_i$

Parallel



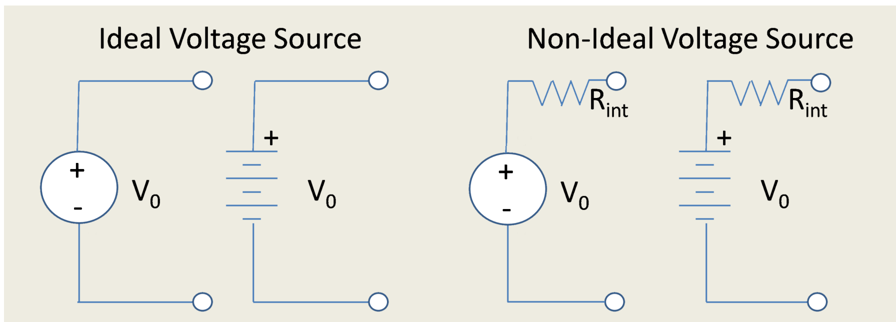
From the left diagram: $i_T = i_1 + i_2 + \cdots + i_n = \frac{V_0}{R_1} + \frac{V_0}{R_2} + \cdots + \frac{V_0}{R_n} = V_0 \sum_{i=1}^{n} \frac{1}{R_i}$

From the right diagram: $i_T = \frac{V_0}{R_{eq\ parallel}}$ Therefore, $R_{\text{EQ parallel}} = \frac{1}{\sum \frac{1}{R_i}}$

Voltage Sources

Voltage sources are either ideal or non-ideal. An ideal voltage source is usually represented as shown below: a circle with + and – signs and a voltage value or a series of long and short lines [this representation comes from original diagrams of a battery]

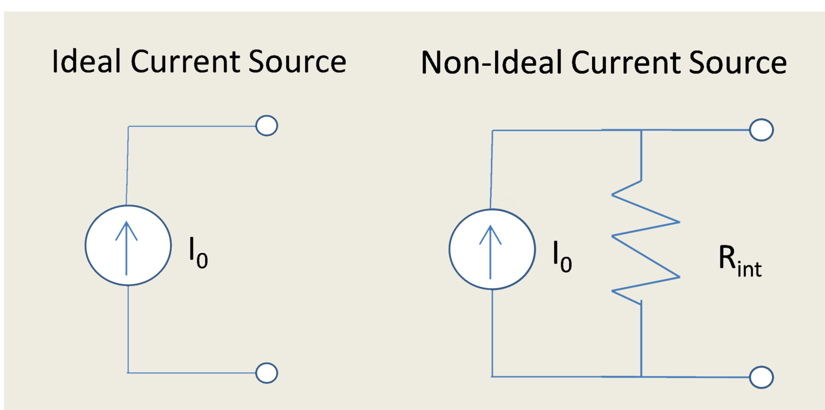
An ideal voltage source would produce a constant potential difference regardless of the current it needs to supply. Real or non-ideal power supplies are represented as an ideal source and a series resistance R_{int} the equivalent internal resistor. The non-ideal voltage source approaches 'ideal' as $R_{int} \rightarrow 0$.



[The Non-Ideal Voltage Source is also called a Thevenin Source]

Current Sources

Current sources also occur in ideal and non-ideal types. An ideal current source delivers a constant current no matter what voltage is required. They are usually shown by a circle with an arrow showing the direction of the current.

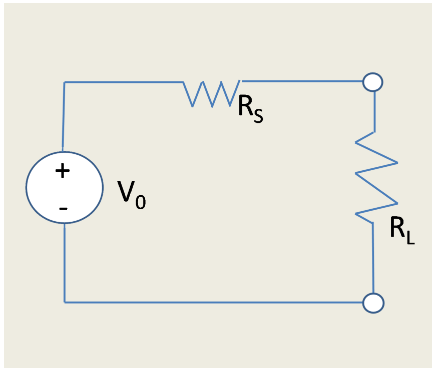


[The Non-Ideal Current Source is also called a Norton Source]

Non-ideal sources are usually represented by an ideal source with an internal parallel resistor.

The non-ideal source approaches 'ideal' as $R_{int} \rightarrow \infty$.

One can use a constant voltage source to simulate a nearly ideal constant current source by placing a very large resistance in series, i.e.



The current through the load resistor R_L can be found as:

$$V_0 = i\,(R_L + R_S).$$

Therefore,

$$i = V_0 / (R_S + R_L)$$

If $R_S >> R_L$, then $i \approx V_0/R_S$ (a constant value providing $R_S >> R_L$).

We will not have you perform current source experiments at this time because **current measurements are the easiest way to destroy a meter**.

Week 1 Prelab

Briefly answer the following questions.

Name:

1. Identify the resistors:

UID:

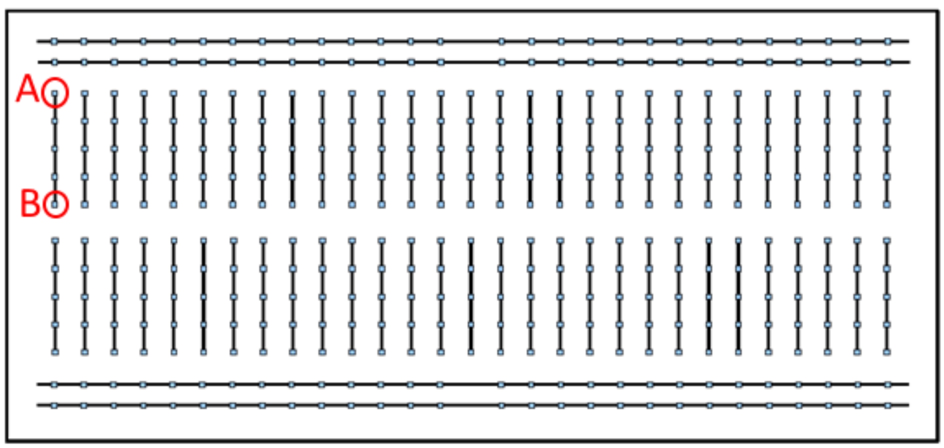
Yellow-Violet-Orange-Gold

____Ω with a tolerance of +/- ____%.

Brown-Black-Yellow-Silver

____Ω with a tolerance of +/-____%.

2.



If a resistor is inserted into the breadboard with one leg at point A and one leg at point B, what resistance will an ohmmeter measure for that resistor? Why? What should you do instead to measure the proper resistance?

3. Draw the following diagrams

(a) Ideal voltage source

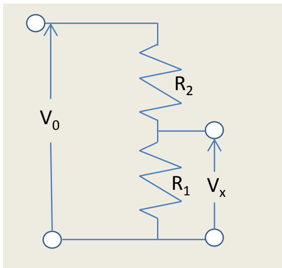
(b) Non-ideal voltage source

(c) Ideal current source

(d) Non-ideal current source

4. Prove the voltage and current divider equations: They are basic and very commonly used equations that you should memorize for use in all your future electronics courses.

Voltage Divider

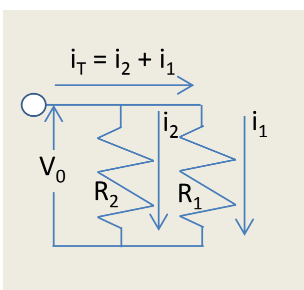


Problem: show that

$V_x = V_0 R_1/(R_1+R_2)$

YOUR SOLUTION HERE:

Current Divider



Problem: show that

$I_1 = i_T R_2/(R_1+R_2)$

YOUR SOLUTION HERE:

Week 1 Prelab End

Multi-Meter Measurements

1. Pick 6 resistors with different color codes. If your resistors have 5 bands, consider only the first four bands. Measure their values with your DMM. Compare their stated values and tolerances (color code) with your measured multimeter results.

WORK SHEET HERE: $\frac{\text{MEASURED-MARKED}}{\text{MARKED}}(100\%)$

Resistor #	Marked	DMM Measured	% Deviation from Marked
R_1	3300, 5% tolerance	3230	2.12
R_2	1000, 5% tolerance	990	1
R_3	6800, 5% tolerance	6700	1.47
R_4	100, 2% tolerance	100.4	0.4
R_5	47 000, 10% tolerance	50400	7.2
R_6	15 000, 5% tolerance	14800	1.3

Is the % Deviation greater or less than the indicated tolerance?

ANSWER HERE:
The % Deviation is always less than the indicated tolerance.

2. If you look at a standard list of 20% resistors available, you will see 1000 ohms and 1500 ohms but not 1200 ohms. Why? If you look at 5% resistors, would the results be different? Why? [A listing of resistor values can be found on the wall of the laboratory.] Hint: Think about what tolerance means and how it differs from measurement error.

ANSWER HERE:
1200 is within the 20% deviation of the 1000 Ohm resistor and the 1500 Ohm resistor, making a standalone 1200 Ohm resistor unnecessary. With 5% resistors, the range of resistance values would look like this: 950-1050, 1425 - 1575. Since 1200 is now excluded from the deviation range, 1200 should be its own resistor.

3. Pick two resistors that are approximately two orders of magnitude different, i.e. 1,000 Ω and 100,000 Ω, or 22 Ω and 2,200 (See Figures 1-2, 1-3, and 1-4.)
   a. Measure them carefully. Note their actual values rather than the color code indicated value.

WORK SHEET HERE:

R_1 Color Code Value: 100 000 Ohms R_1 Measured Value: 99, 000 Ohms

R_2 Color Code Value: 1000 Ohms R_2 Measured Value: 990 Ohms

b. Measure them in series and parallel connections.

WORK SHEET HERE:

R_{Series} Value: 100 000 Ohms $R_{Parallel}$ Value: 981 Ohms

c. Compare your measurements with the calculated values. Your calculated values should be calculated using the individually measured values from part a. Note: in series, the larger value dominates the measurement.

WORK SHEET HERE:

R Series Resistance Calculated: 99, 990 Measured: 100000 % difference 0.01

R Parallel Resistance Calculated: 980.2 Measured: 981 % difference 0.082

d. In the parallel connection, which resistor dominates and why?

e. In the series connection, which resistor dominates and why?

ANSWERS HERE:

d. The 990 Ohm resistor, because it offers the path of least resistance so most of the current flows through it, and so the DMM registers a resistance that is very close to 990.
e. The 99 000 Ohm resistor, because it accounts for a vast majority of the resistance that the current encounters and thus the DMM registers.

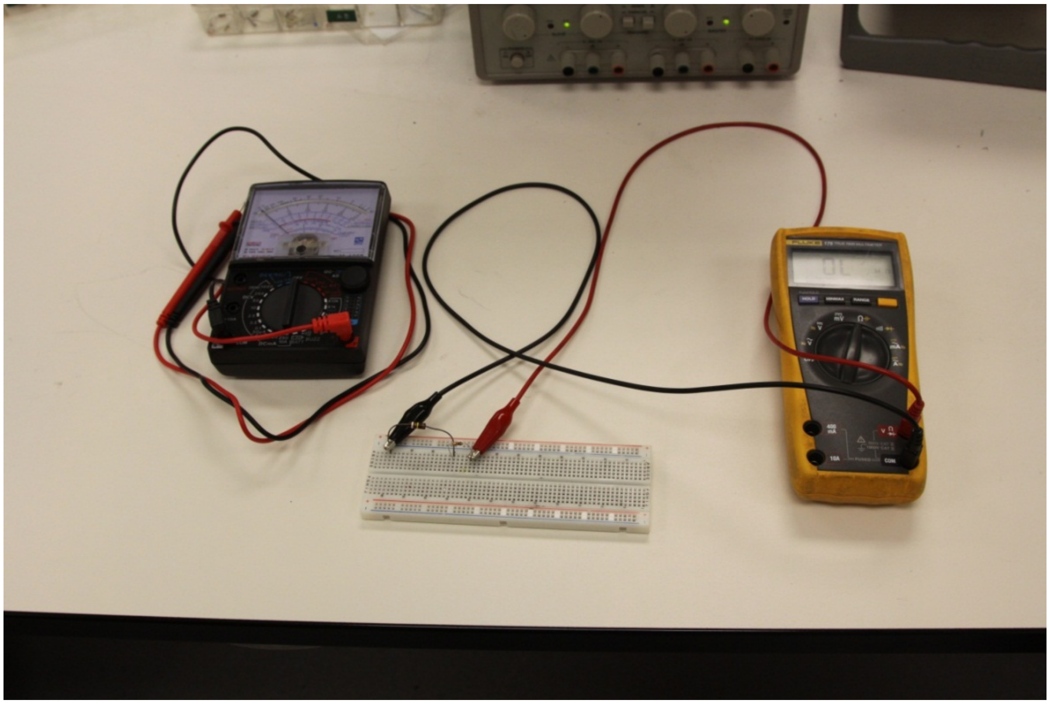


FIGURE 1-1. MULTIMETERS CONNECTED
TO RESISTOR ON PROTO-BOARD
[Left side: Analog Multimeter   Right side: Digital Multimeter]

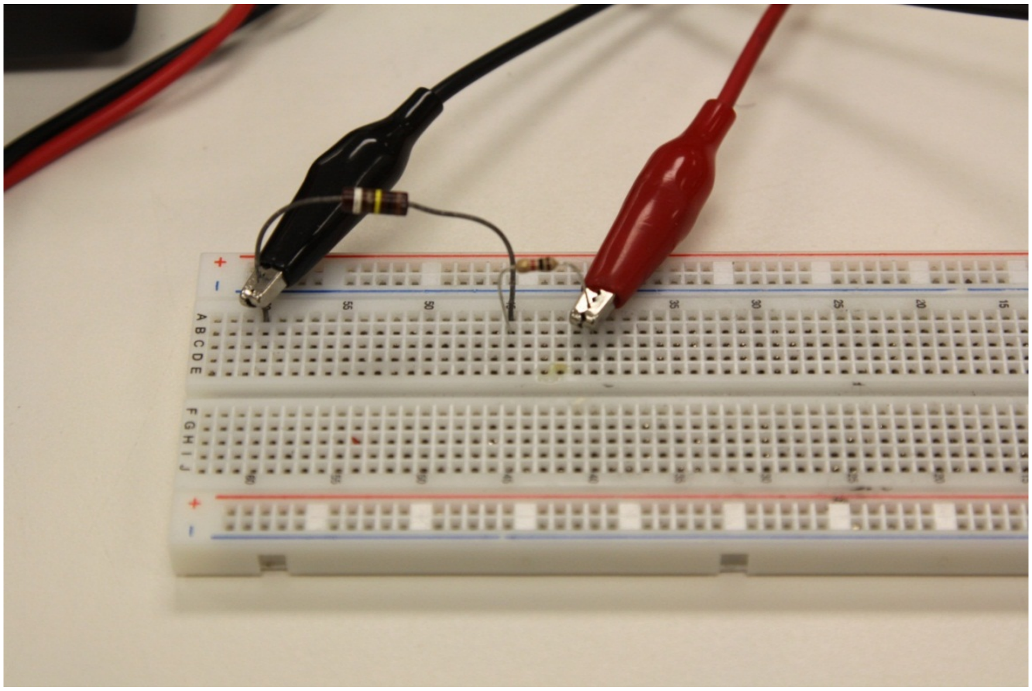


FIGURE 1-2. RESISTORS CONNECTED IN SERIES ON PROTO-BOARD

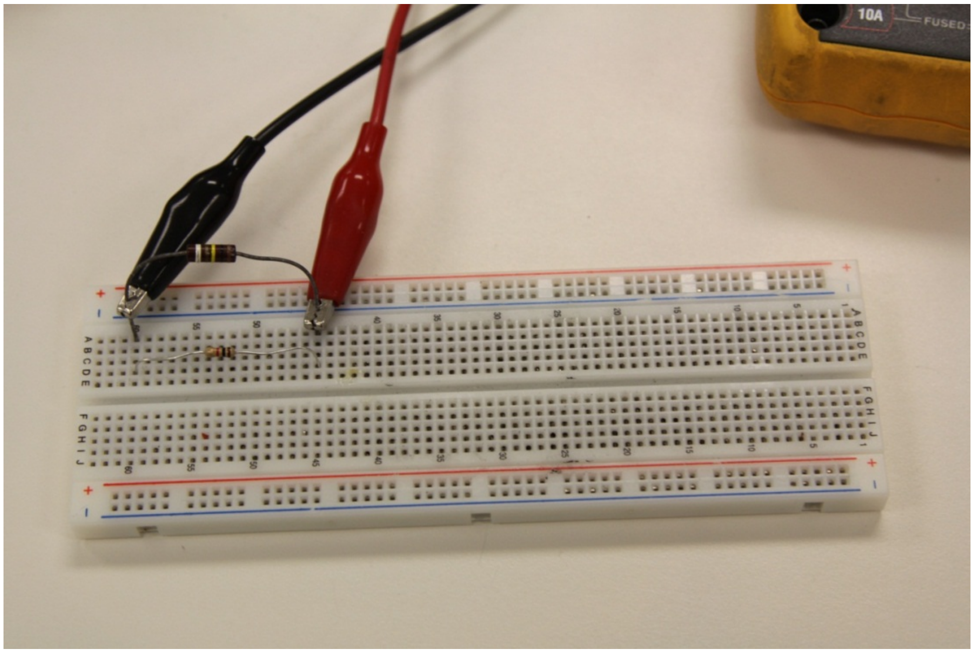
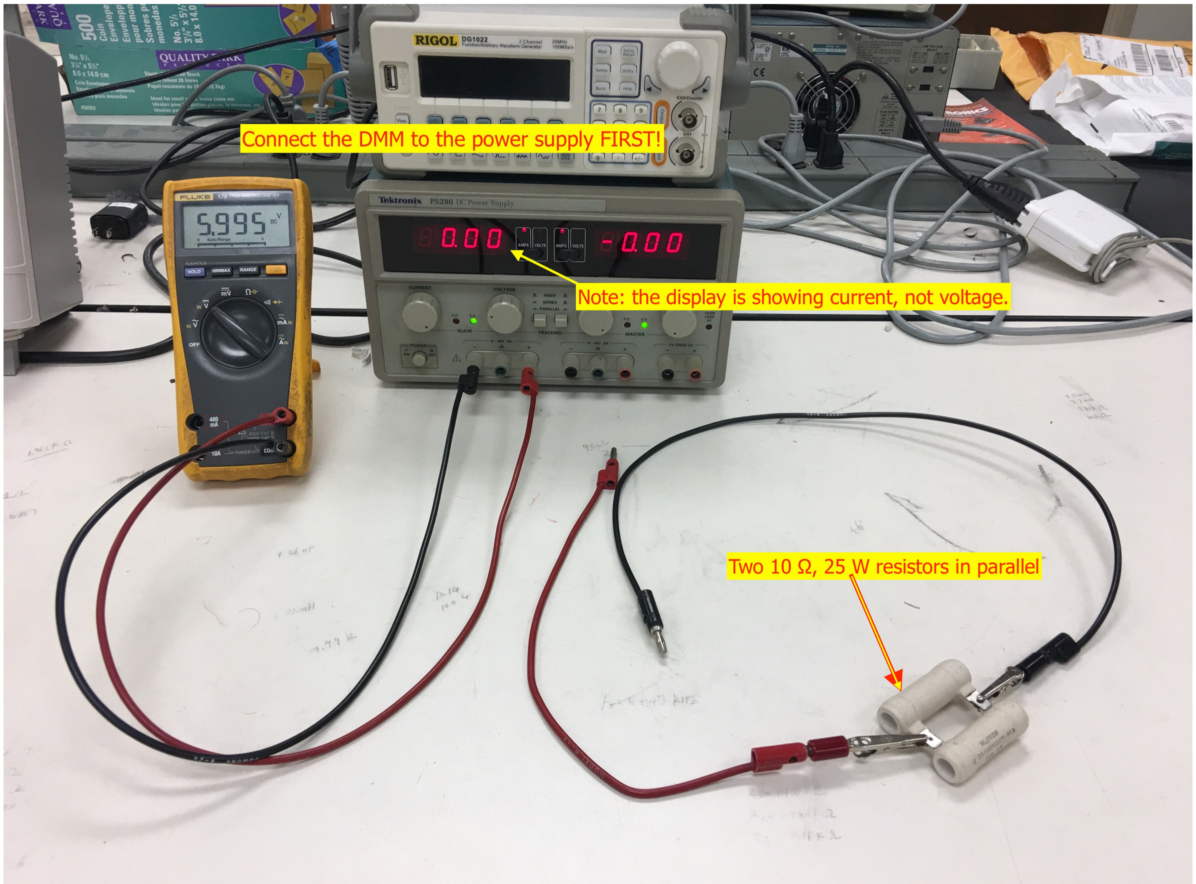


FIGURE 1-3. RESISTORS CONNECTED IN PARALLEL ON PROTOBOARD

Source Measurements

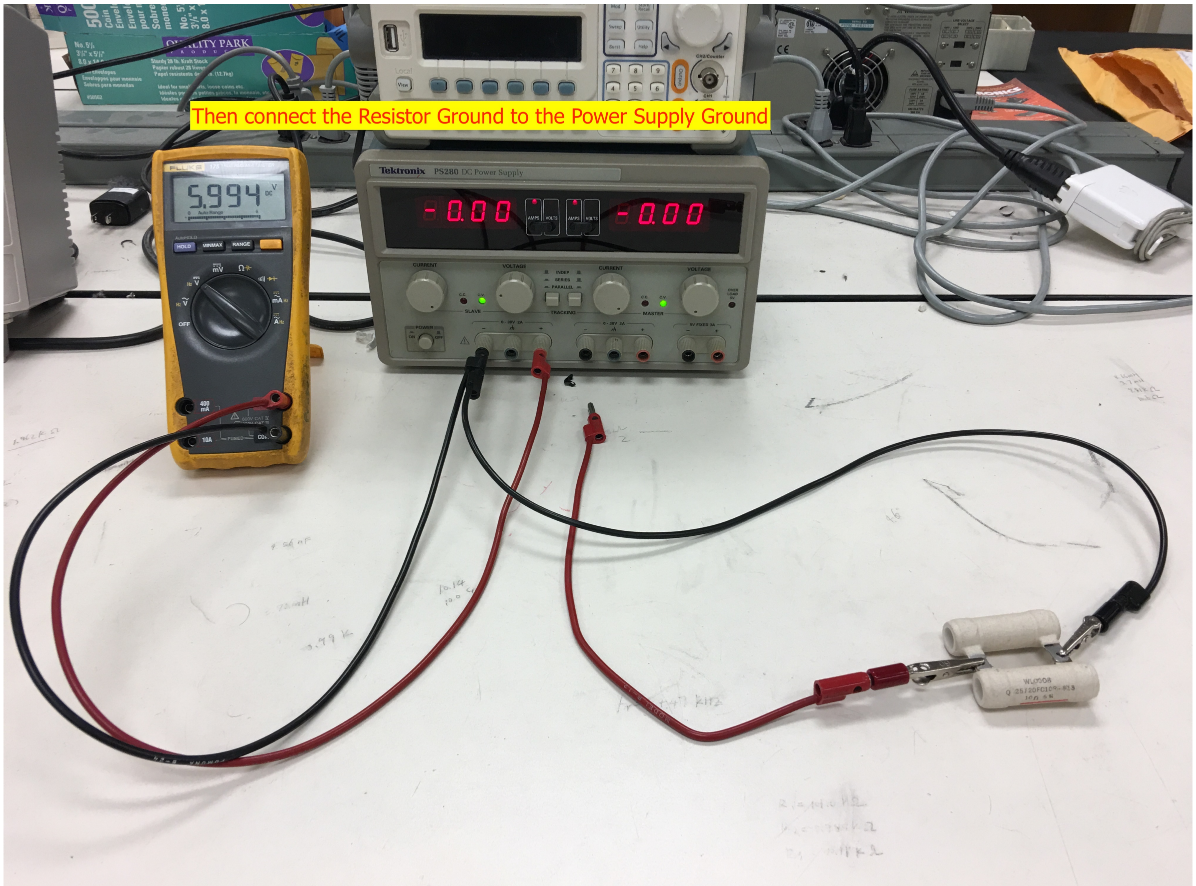
The Tektronix dual power supply you will be using can operate as a near ideal voltage source or a near ideal current source. When the green light is on (CV) it is a Controlled-Voltage source, and when the red light is on (CC) it is a Controlled-Current source.

To test the voltage source, refer to the following figures:

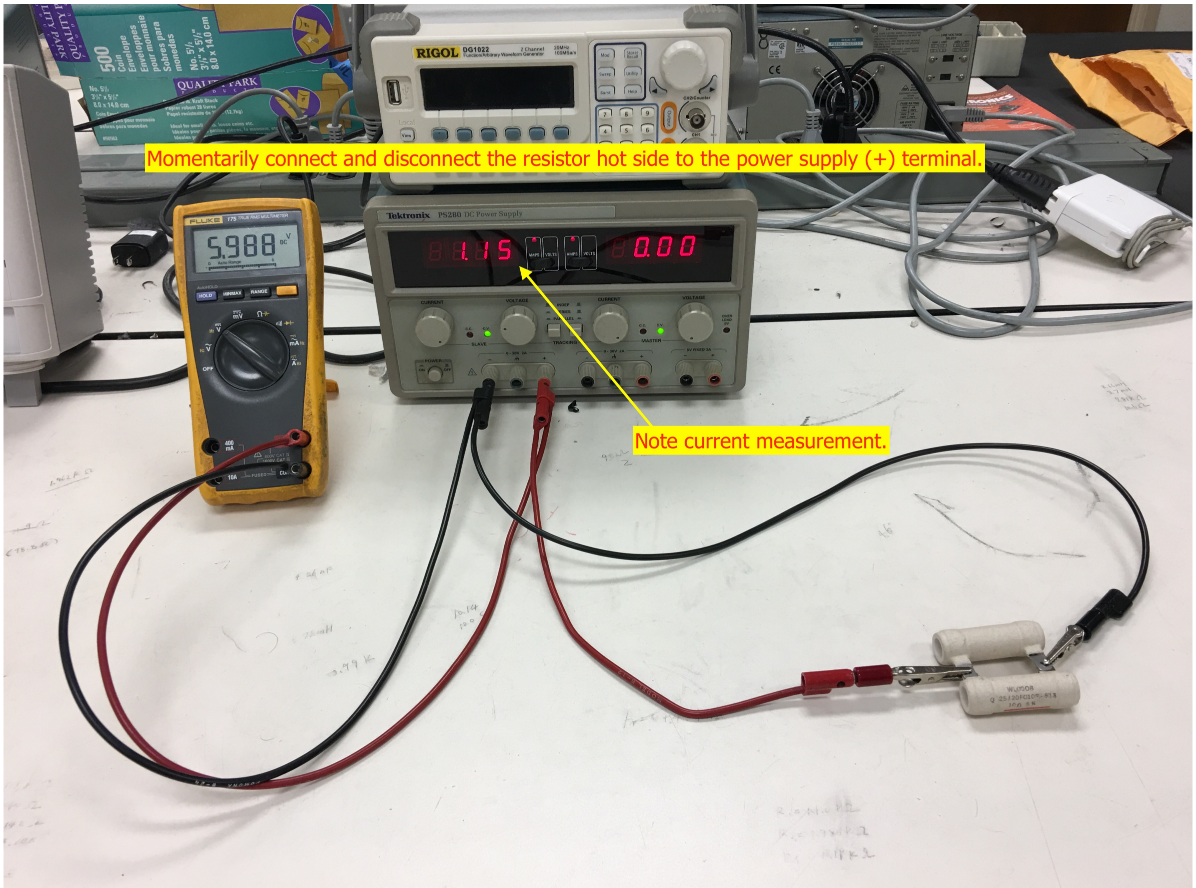


1. Set the DMM to read DC volts.
2. Using the left side of the power supply front panel, connect the positive terminal of the DMM to the positive terminal of the power supply. Do the same for the negative terminal.
3. Slide the switch on the power supply front panel to the left to display current.
4. Turn the current limit to full right (clockwise).
5. Set the output to ~6 volts as indicated on the DMM.
6. Be sure that the DMM display shows <u>three numerals to the right</u> of the decimal point.
7. Set up the 5 Ω resistor by connecting two 10 Ω resistors in parallel as shown in the above picture.

By observing the following picture, connect the 5 Ω resistor ground (black lead) to the power supply ground. Leave the resistor hot side (red lead) disconnected.

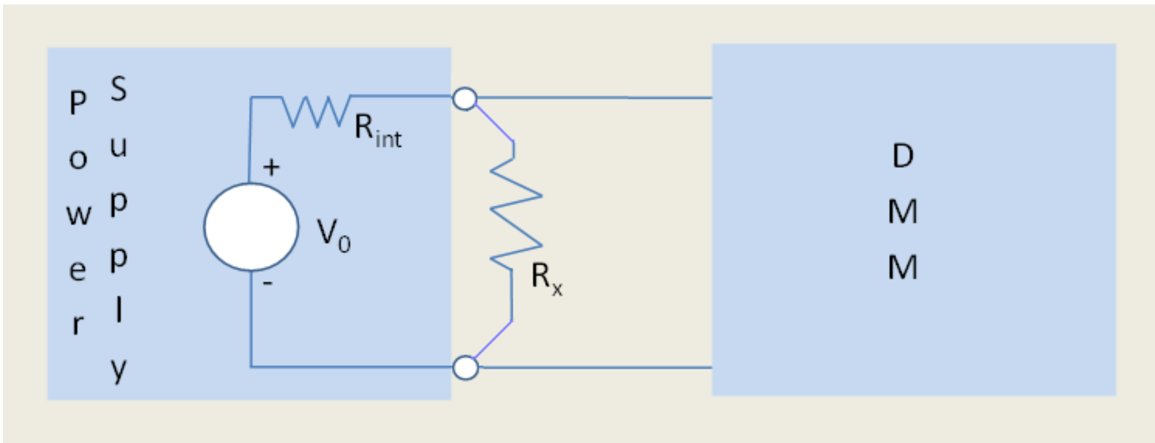


Now, by observing the following picture, momentarily connect and disconnect the resistor hot side (red lead) to the power supply (+) terminal. Note: the resistor will dissipate energy and could get quite HOT!! Take care not to burn yourself. Record the DMM readings in the worksheet below when connected and when disconnected. The difference between the two readings should be a few millivolts.



Measuring Internal Resistance of a Power Supply

Observe carefully the small change in the output voltage that occurs when the 5 Ω resistor (Rx) is connected as shown below. From the change in this voltage, calculate the internal resistance of the voltage source. The circuit equivalent to the above pictures is:



(The DMM input resistance is extremely large compared to R_x !)

WORK SHEET HERE:

Unloaded voltage (i.e. without 5 Ω resistor): 6.011 Volts

Loaded voltage (with 5 Ω resistor): 6.008 Volts

Voltage shift: 0.003 Volts

Calculate internal resistance: (Hint: The voltage divider equation will be useful here)

```
I = V/R = 6.008/5 = 1.202 Amps

V(shift) = IR(int)
R(int) = V(shift)/I
       = 0.003 V/ 1.202 A
       = 0.002 Ohms
```

Unloaded and Loaded Voltage Dividers

We will investigate the effect that loading has on a voltage divider circuit. Loading, as you recall from lecture, is the demand for current from a voltage source. That demanded current has an effect on the performance of the circuit. We will be measuring the amount of that performance change.

You will need the following components:

1 KΩ resistors (2)

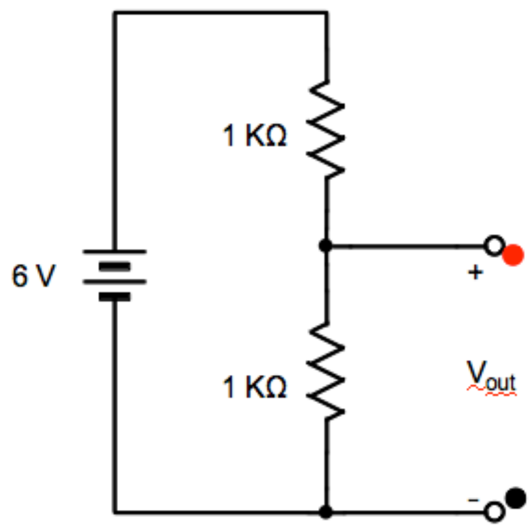
3.3 KΩ resistor

Breadboard

DMM

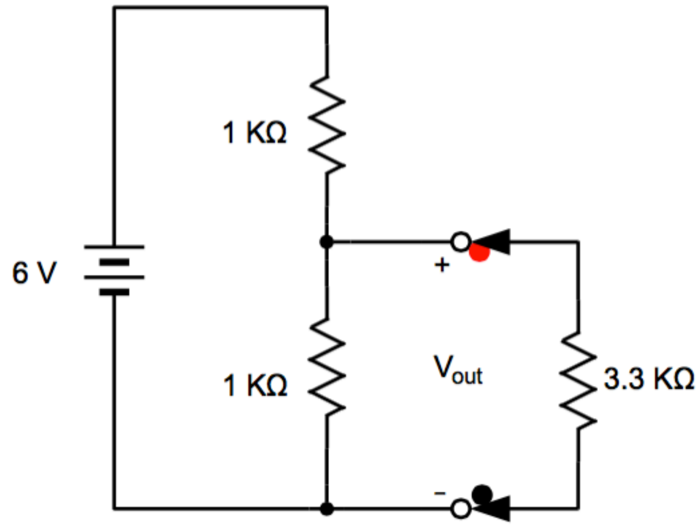
Tektronix DC Power Supply

1. Construct the voltage divider circuit as shown below. This is an <u>unloaded</u> voltage divider.



2. Measure V_{out} at the red and black dots. Record the value here __3.003 V__ .

3. Now load the circuit by attaching the 3.3 KΩ load resistor across the lower 1 KΩ resistor, as shown below. The 3.3 KΩ resistor is now demanding current from the voltage divider.



4. Measure the new V_{out} as in Step 2. Record the value here: 2.606 V
5. Fill out the following table:

	UNLOADED VOLTAGE DIVIDER	LOADED VOLTAGE DIVIDER
V_{out} (measurement)	3.003 V	2.606 V
$V_{upper1K}$ (calculation)	2.997 V	3.396 V
I_{total} (calculation)	0.003 A	0.0033 A

How does the increase in total current affect the output voltage of the loaded voltage divider circuit?

The increase in total current actually reduces the output voltage of the loaded voltage divider circuit.

Validation of Kirchhoff's Laws

In this lab, we will be showing that Kirchhoff's Laws are actually true with the Digital Multimeter (DMM).

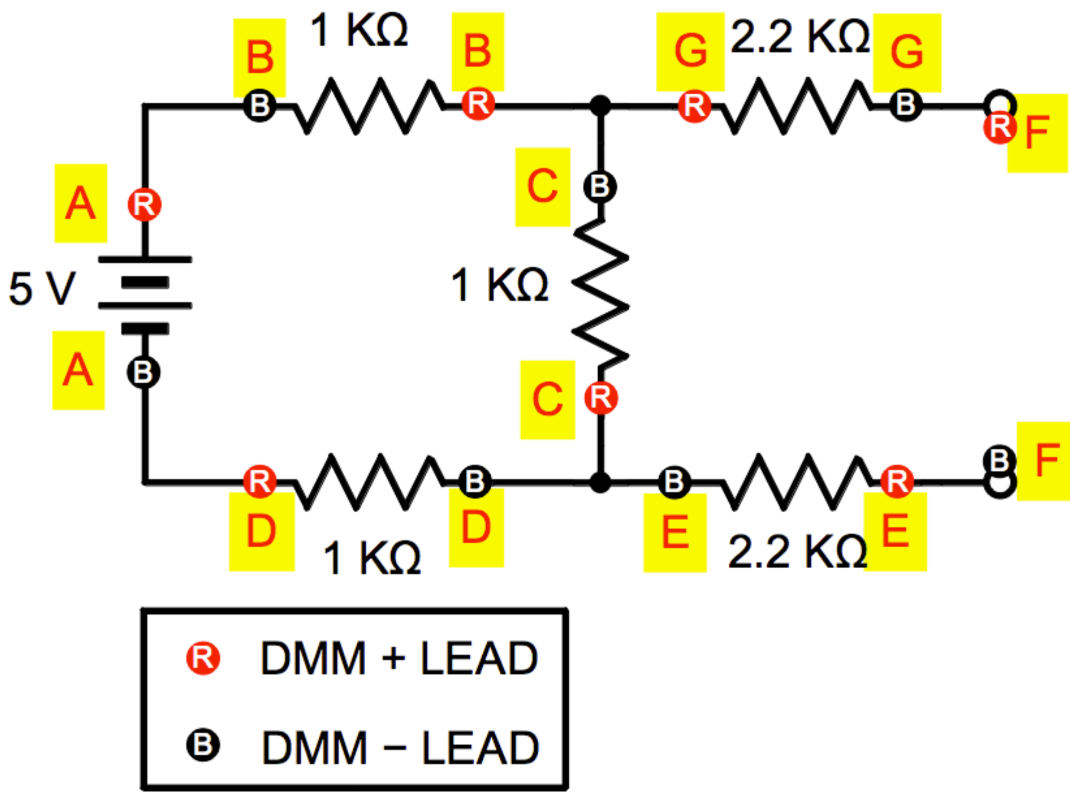
In addition to a DMM and the power supply, you will need the following components:

1 KΩ resistors (3)

2.2 KΩ resistors (2)

Breadboard

1. Construct the following circuit using the power supply, breadboard, and resistors:



2. Using the DMM, and following the polarities indicated, take DC voltage measurements A through G. Fill in the blanks on the next page.

MEASUREMENT	VALUE
A	5.00
B	-1.67
C	-1.67
D	-1.67
E	0
F	1.67
G	0

3. Add measurements A through D. Put your answer here: -0.01 V

4. Add measurements C, E, F, and G. Put your answer here: 0 V

5. Now, use a jumper wire to connect the two open circles (at Measurement F).

6. Repeat measurements A-G.

MEASUREMENT	VALUE
A	5.00
B	-1.78
C	-1.45
D	-1.78
E	0.72
F	0
G	0.72

7. Using Ohm's Law, calculate the ABSOLUTE VALUE of the current through resistors B, C, and G (answers in "CURRENT" column in the table below). Also, using the Passive Sign Convention, determine whether the current through each resistor is entering or leaving the B-C-G node connecting the three resistors ("CHOOSE ONE" column).

RESISTOR	CURRENT	CHOOSE ONE	
B	1.78 mA	☐ LEAVE	☒ ENTER
C	1.45 mA	☒ LEAVE	☐ ENTER
G	0.33 mA	☒ LEAVE	☐ ENTER

8. Using [a] the Passive Sign Convention rule** (see footnote) and [b] the NVA convention that currents leaving the node are positive, attach the + or – sign to the currents and **add them up to see if KCL holds**. NVA rule: currents leaving the node are marked +; currents entering the node are marked −.

9. Put your sum here: 0 Amps

Discuss your answers to Steps 3, 4, and 9. In particular, did you validate Kirchhoff's Laws?

Yes, we did validate Kirchoff's Laws. We observed that a closed loop will have a net voltage change of 0 Volts (or close to 0, there is room for measurement error here), and that the current entering and exiting at a node should sum up to 0 Amps.

Week 1 Lab End

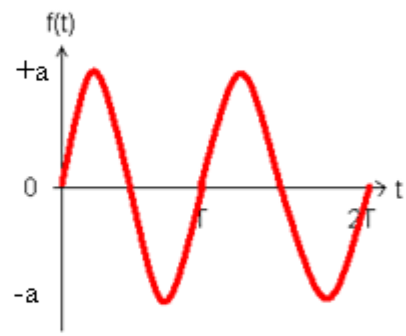
** The Passive Sign Convention says, among other things, that the positive end of a resistor is where the current always enters. Conversely, the negative end of a resistor is where the current always leaves.

Week 2: Oscilloscopes and Function Generators

RMS of a periodic signal is calculated by first squaring the waveform, then taking its mean over its period, T, then taking the square root. Its definition using the calculus is

$$\text{RMS} = \sqrt{\frac{1}{T}\int_0^T f^2(t)\,dt}$$

As an example, we will derive the equation for RMS/Vpp for a sine wave. You will be asked to derive the equation for square waves and triangular waves in the pre-lab.



First, $f(t) = a\sin\left(\frac{2\pi t}{T}\right) \rightarrow RMS = \sqrt{\frac{1}{T}\int_0^T \mathrm{a}^2 \sin^2\left(\frac{2\pi t}{T}\right) dt}$

Using the definition of $\sin^2(\theta) = \frac{1-\cos(2\theta)}{2}$, $RMS = \sqrt{\frac{a^2}{T}\int_0^T \frac{1-\cos\left(\frac{4\pi t}{T}\right)}{2} dt}$

Taking the integral, $RMS = \sqrt{\frac{a^2}{T}\left[\frac{1}{2}t - \frac{\frac{1}{2}\mathrm{T}}{4\pi}\sin\left(\frac{4\pi t}{T}\right)\right]_0^T}$

Evaluating, we get $RMS = \sqrt{\frac{a^2}{T}\left[\frac{1}{2}T\right]}$ (Note that at t = 0 and T, $\sin\left(\frac{4\pi t}{T}\right) = 0$)

Therefore, $RMS = \frac{a}{\sqrt{2}}$, and since $Vpp = 2a$, then $\frac{\boldsymbol{RMS}}{\boldsymbol{Vpp}} = \frac{\mathbf{1}}{\mathbf{2}\sqrt{\mathbf{2}}}$

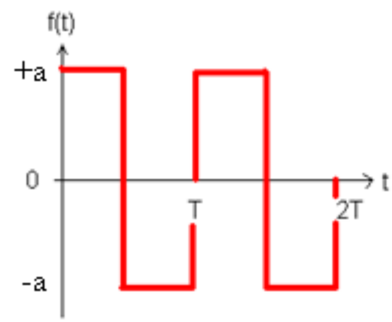
It may for the purposes of your lab helpful to think of RMS in terms of Vpp, like so:

$$RMS = \frac{Vpp}{2\sqrt{2}}$$

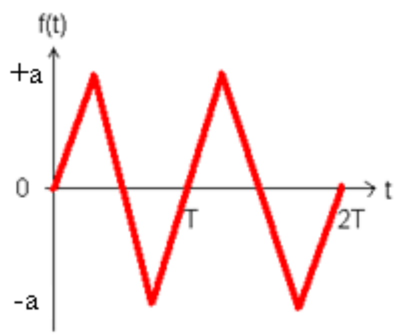
Week 2 Prelab

Calculate the ratio RMS/Vpp for the following signals. Show all your work!
Name:

1. Square Wave: RMS / Vpp = ? UID:



2. Triangular Wave: RMS / Vpp = ?



3. If you see a difference by a factor of 10 between the oscilloscope reading and the function generator setting, where is the first place that you should look? Watch the Probe Setting video (https://youtu.be/dtSuTHIviSo) for the answer.

____

____

4. If you see a difference by a factor of 2 between the oscilloscope reading and the function generator setting, where is the first place that you should look? Watch the Function Generator Output Impedance video (https://youtu.be/-8Dv1oOjD9w) for the answer.

____

____

5. Why would you ever want to use AC coupling on an oscilloscope? Watch the AC Coupling video (See CCLE) for the answer.

____

____

Week 2 Prelab End

Time Dependent Measurements

This week's experiments will give you the opportunity to learn the basic operations of an oscilloscope and a function generator.

Setting up Function Generator and Oscilloscope

1. Turn on both the function generator (Figure 2-1a) and oscilloscope (Figure 2-2).
2. Connect the function generator's CH1 output, making sure that the output is on (press the output button if it is not lit), to the CH1 input of the oscilloscope.
3. Connect the Sync Out of the function generator, on the rear (see Figure 2-1b), to the scope's CH2 or EXT TRIG channel. Keep in mind which channel on the oscilloscope you connected the Sync Out to. We will refer to this as the triggering channel from now on.
4. Note: On the function generator you must output from the function generator's CH1, since the Sync Out is only associated with Channel 1. Enable Sync Out in the function generator's Utility Mode and make sure you are set to your triggering channel (either CH2 or EXT TRIG) in the oscilloscope's Trigger Menu. You can do this by pressing Trigger Menu and then pressing the button next to Source on the display until it changes to your desired triggering channel.
5. Set the frequency of the function generator to sine output (sinusoidal waves) at 100 Hz with amplitude somewhere between 1 V and 10 V.
6. Turn the Horizontal and Vertical knobs until you see a sinusoidal waveform on the display (Figure 2-2) with a square wave generated by the Sync Out. If you do not see either, press CH1 Menu and Trigger Menu on the oscilloscope to turn on the inputs. You can tell that CH1 is on if the pushbutton under the CH1 Vertical Knob is illuminated.
7. Make sure that in the CH1 Menu, your Probe is set to 1x.

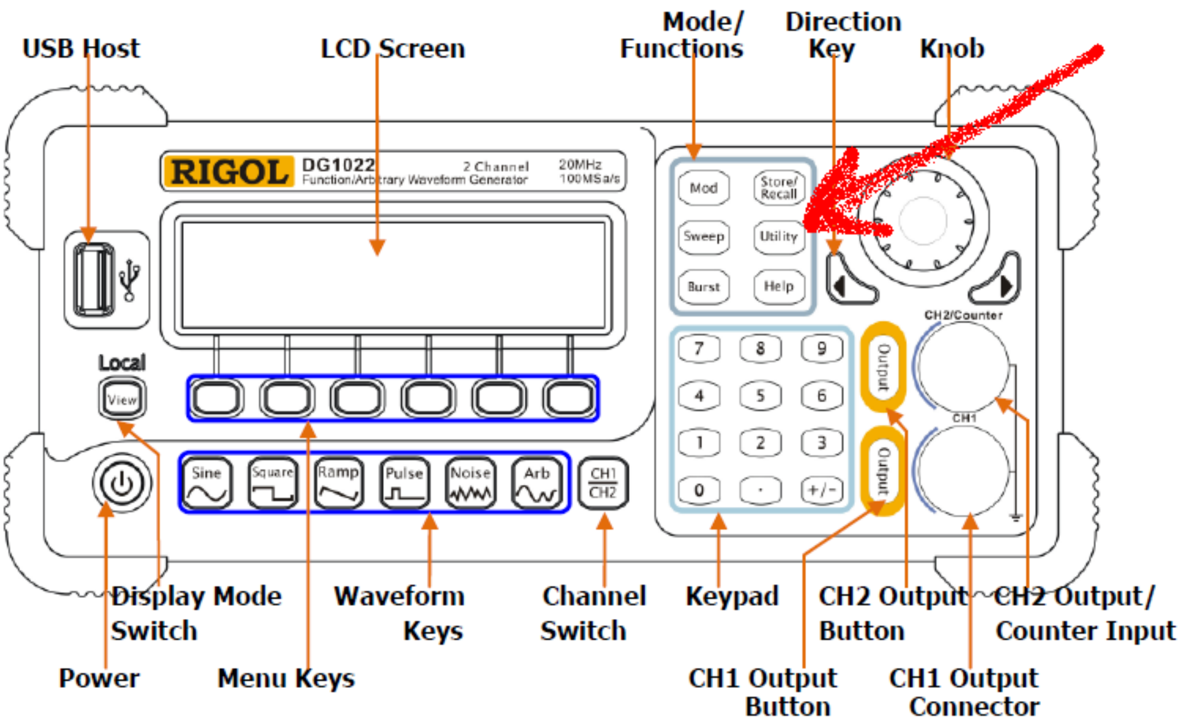


FIGURE 2-1a: DIGITAL Signal Generator (front)

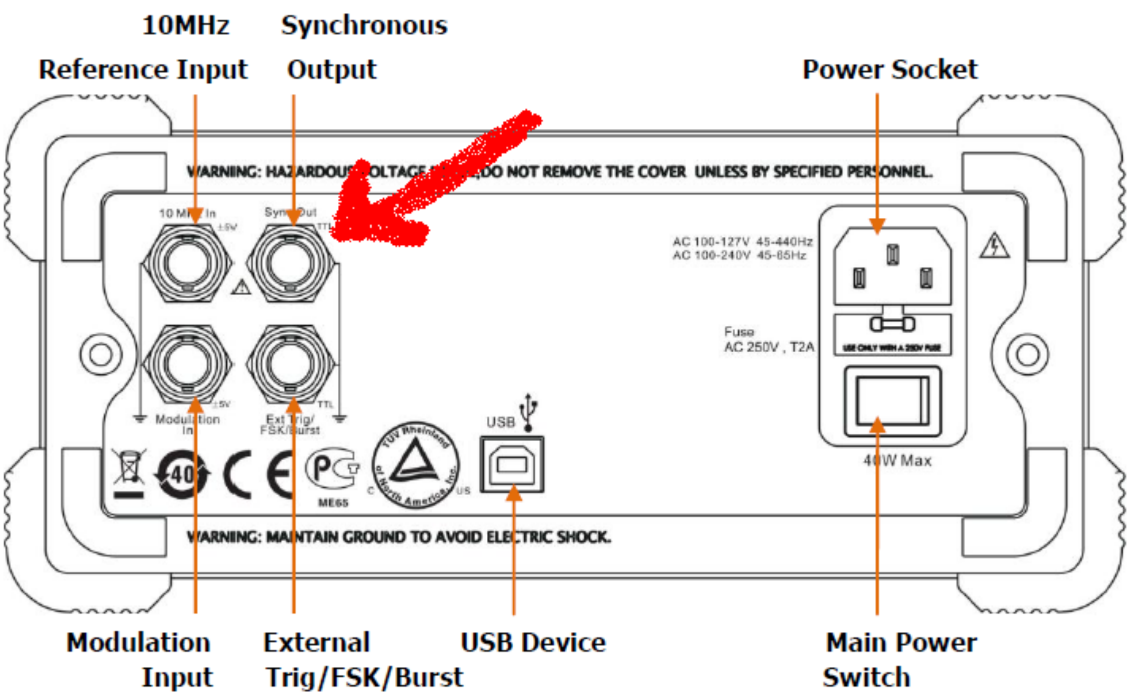


FIGURE 2-1b: DIGITAL Signal Generator (back)

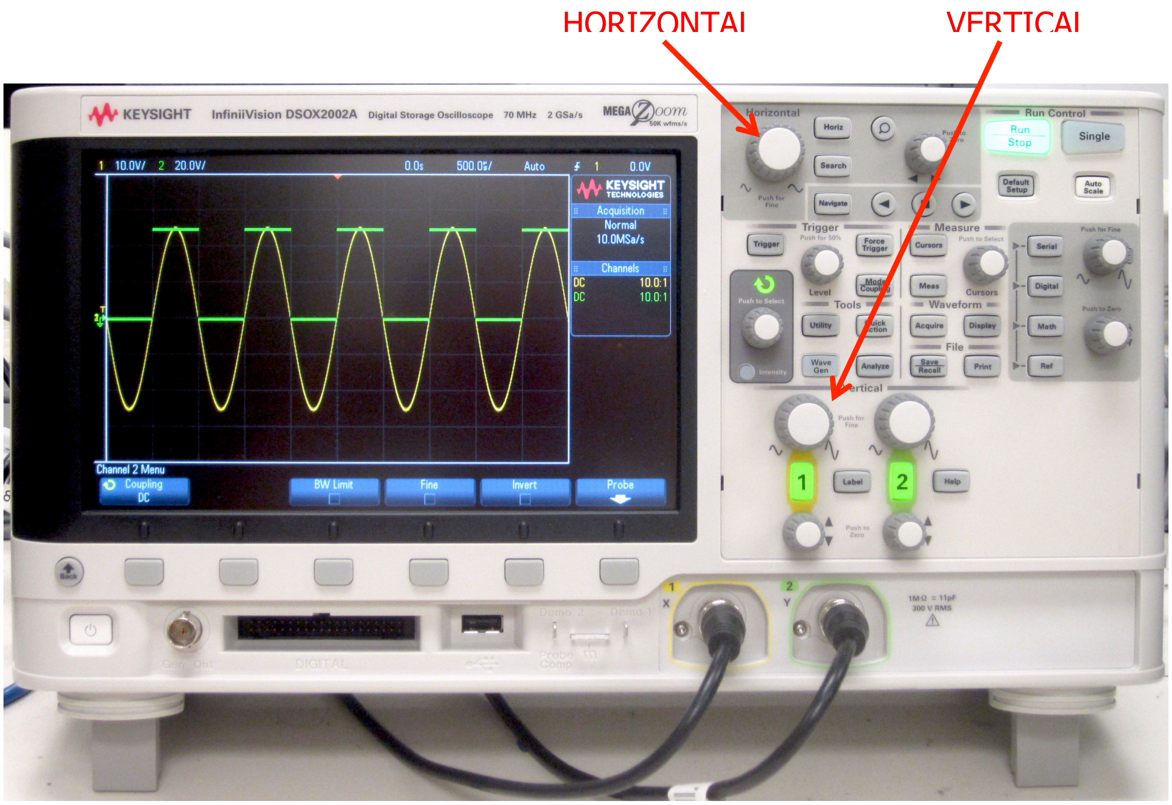


FIGURE 2-2: OSCILLOSCOPE

Understanding Triggering

To understand the trigger function of the scope, select the trigger control. We wish to control the triggering by first selecting the trigger menu and setting the source to be channel 1. With the trigger in Edge mode, the Level knob can now be used to control the voltage level at which the scope will start its measurement, i.e. its time reference point or trigger point. Note: if a trigger voltage point is selected that is outside of the range of voltages on channel 1, then the scope will not display new data and will indicate on the display “not triggered” or “waiting for trigger”, etc.

A small “T” in the left margin indicates the trigger level. Its color indicates which channel has been selected to be the triggering channel. Adjust the trigger level to obtain a stabilized display. The display will now say “triggered” or “running”. Adjust the trigger level and note its effect on the position of the waveform.

Note the level control also allows the slope of the level to be observed. Change the slope (or sense) from increasing to decreasing back and forth to note the effect on the display. Set the trigger level about halfway between 0 and the maximum value of the waveform. Now adjust the voltage level of the function generator and note the position of the “0” time changes with amplitude and that, as the voltage of the function generator gets small, the trigger will eventually fail to work.

Now change the trigger input to your original triggering channel (CH 2 or EXT TRIG, whichever channel the Sync Out of the function generator is connected to on the oscilloscope). Note that the trigger will now remain constant regardless of the magnitude of the sinusoidal signal. This is the prime reason for the use of a sync output.

Beginning the Experiment

Change the mode of the function generator from sine to triangular and then square. Note each of these waveforms. The actual voltage levels can be measured by using the voltage cursor function of the scope. Selecting CURSOR and using the two upper left knobs, measure the Vpp amplitude of a sinusoidal wave, i.e. the peak-to-peak amplitude.

Using your digital multi-meter on the AC voltage settings, measure the voltage of the waveform. Compare the scope and multi-meter indicated voltages. Do this for sine, square, and triangular waves. The following are four sets of similar measurements, comparing the DMM to the oscilloscope. We will measure a low frequency (100 Hz) with 5 Vpp. We will then similarly measure a high frequency (25 kHz) with 5 Vpp.

A BNC T-connector will be useful so that the DMM can be used at the same time as an oscilloscope.

WORK SHEET HERE:

Wave Form	Scope Voltage (CURSOR)	Calc	Meter Voltage (RMS) DMM	Difference (%) Vs Calc DMM
100 Hz	~5 Vpp	Vrms	Vrms	%
Sine:	________	____	_______	_______
Triangle:	________	____	_______	_______
Square:	________	____	_______	_______

If there are differences, explain:

ANSWER HERE:

WORK SHEET HERE:

Wave Form	Scope Voltage (CURSOR)	Calc	Meter Voltage (RMS) DMM	Difference (%) Vs Calc DMM
25 kHz	~5 Vpp	Vrms	Vrms	%
Sine:	________	____	________	________
Triangle:	________	____	________	________
Square:	________	____	________	________

If there are differences, explain:

ANSWER HERE:

Week 2 Lab End

Week 3: Transducers

It is *HIGHLY RECOMMENDED* that you read through this week's lab and familiarize yourself with all the material before attending the lab session—there is a lot of content in this week's lab and understanding the material is critical for success!

Week 3 Prelab

Briefly answer the following questions. Name: UID:

1. Draw the circuit schematic symbol of a diode and label the anode and cathode.

2. When a diode is forward biased, the anode is at a (circle one) higher / lower voltage than the cathode.

3. When looking at the diode itself, what are the two methods for telling which side of an LED is the anode and which side is the cathode?

4. Fill in the blank: When a _______ voltage relative to the _________ is applied to the ________ of an NPN transistor, current is allowed to flow from the ________ to the ________.

5. The small DC motor in the equipment kit can be damaged if more than 3V DC is applied directly across the motor.

   Hence, we should always:

   ____

   Draw a circuit diagram of this connection.

Week 3 Prelab End

Electro-Optic Transducers

Photoconductors

Of the electro-optic transducers we will be working with, only the photoconductor, shown in Figure 3-3, is a linear device. That is, the current versus voltage response is linear and bidirectional. The photoconductor behaves as a resistor whose value changes with illumination.

The photoconductor is governed by the equations

$$R_p = 1 / G_p \quad \text{and} \quad G_p = G_0 + \alpha I$$

where G_0 is the dark conductance ($1 / R_0$). Different types of photoconductors will have different dark conductances. Shining light onto the photoconductor will lower the resistance of the device.

Measure the resistance of the photoconductor in darkness and in bright light.

Photoconductor Resistance In darkness: ______________________________ In bright light: ____________________________

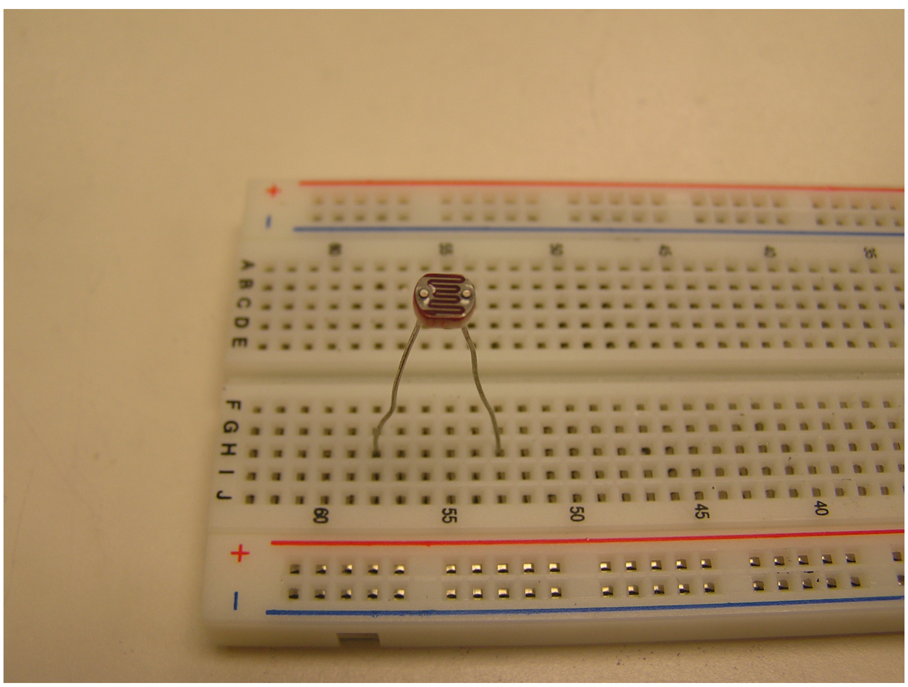


FIGURE 3-3: Photoconductor

Light-Emitting Diodes (LEDs)

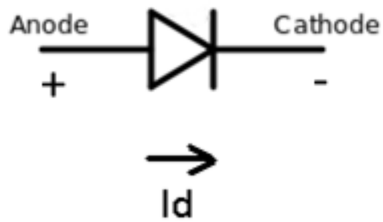


FIGURE 3-4: Diode Symbol

Diodes, also known as p-n junctions, are devices that do not follow Ohm's Law. Diodes have a non-linear relationship between current and voltage. Diodes are typically represented in diagrams by the symbol shown in Figure 3-4. The anode is also called the "positive side" and the cathode the "negative side". We first define I_d, the current flowing through the diode, as flowing from the anode to the cathode. In Figure 3-5, the diode is forward biased—that is, the anode is at a higher voltage than the cathode. We can see that under forward bias, the current-voltage relationship is exponential. In Figure 3-6, the diode is reverse biased, with the cathode at a higher voltage than the anode. The diode allows negligible current to pass under reverse bias.

A reasonably accurate mathematical model of the current-voltage relationship is:

$$I_d = I_0 (e^{V/Vt} - 1),$$

where V_t is known as the thermal voltage and is typically around 0.026 Volts and I_0 is known as the saturation current. The saturation current is typically only a fraction of a microampere.

Under reverse bias, $V \leq -V_t$:

$$I_d \approx -I_0$$

As shown in Figure 3-5, this leads to a constant current (typically negligible and less than one microampere) in the reverse direction under reverse bias.

Under forward bias, i.e. $V \geq V_t$:

$$I_d \approx I_0 e^{V/Vt}$$

As shown in Figure 3-6, this leads to an exponential I-V curve under forward bias. Keep in mind that the slope of a device's I-V curve is indicative of its resistance. In fact, the reciprocal of the slope at a given point is its resistance at that point! Note that at low forward bias voltages, the slope is small, so the diode is operating in a region of high resistance. In contrast, at high forward bias voltages, the slope is large, so the diode is operating in region of low resistance. A forward-biased diode's transition from its high resistance region to its low resistance region occurs around 0.5~0.7 Volts and is known as a diode's turn-on voltage.

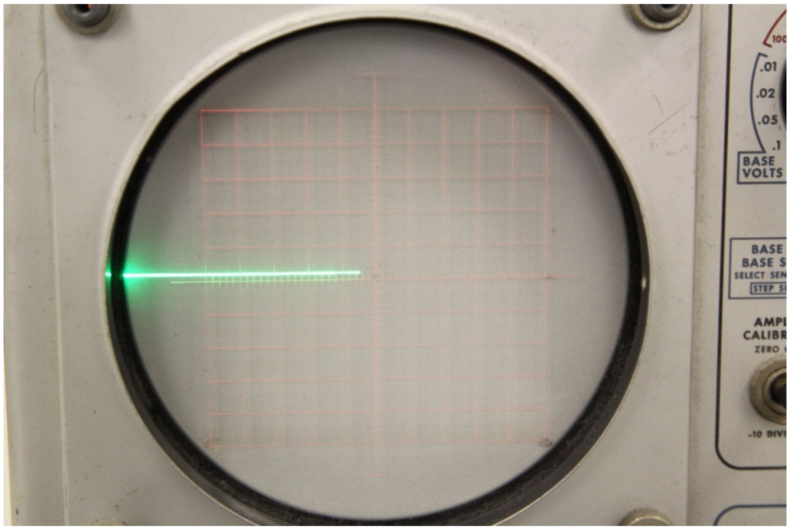


FIGURE 3-5: Diode Reverse Bias Characteristic

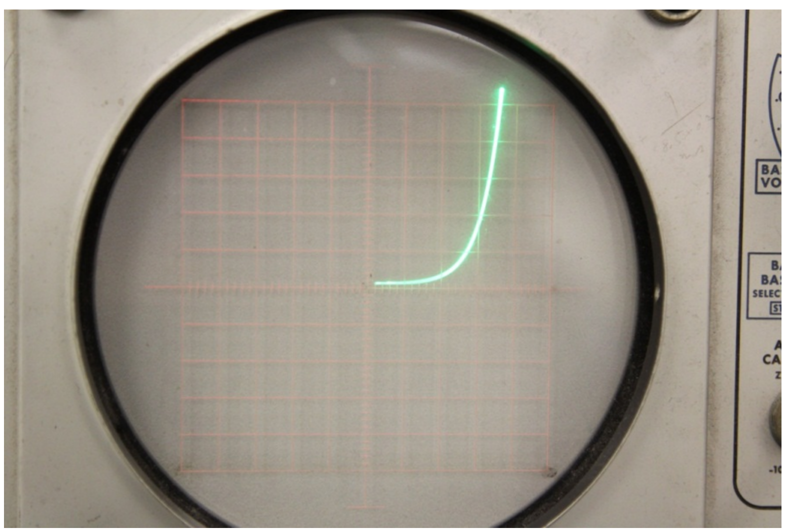


FIGURE 3-6: Diode Forward Bias Characteristic

Note that the power dissipation can be large under reverse bias because the voltage across the device can be quite large (tens of volts) even though the current is small. Under forward bias, the typical voltage is in the order of a fraction of a volt for silicon devices.

To observe the characteristics of diodes, we will be experimenting with light-emitting diodes, also known as LEDs. When a large enough current passes through an LED in the forward direction, the LED will generate light.

There are two ways to tell which side of the LED is the anode and which is the cathode. This is shown in Figure 3-7 below.

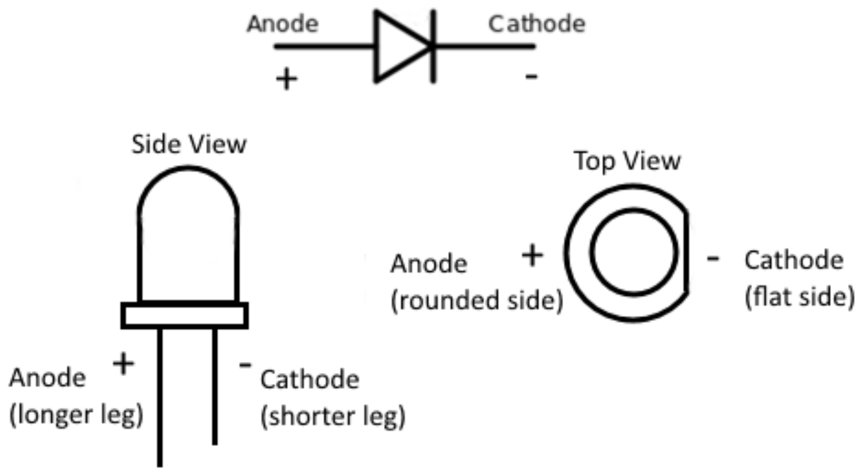
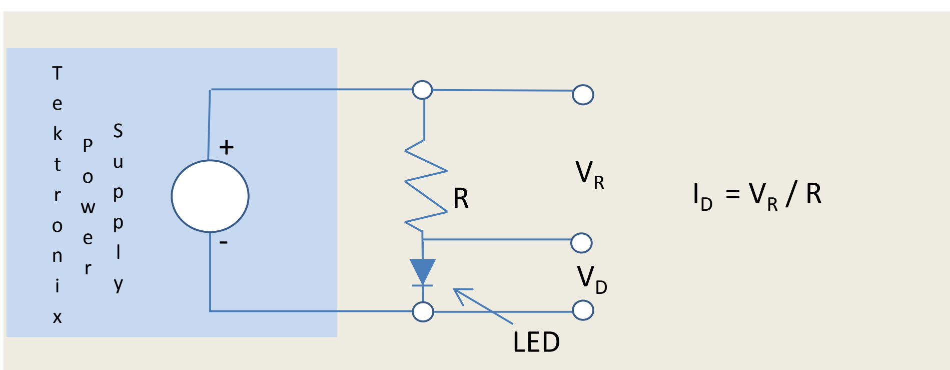


FIGURE 3-7: Physical Diode

NOTE: It is often times unreliable to determine polarity via leg length since component legs can be clipped or twisted. Also, in some IR LEDs, the shorter leg is the anode, but the flat is on the cathode side. Determining which sides are rounded and flat, or using the transistor curve tracer, is more reliable.

To test the current-voltage relationship of diodes, we will employ a **red** LED which can typically stand up to 20 milliamperes. Set up the circuit as below. **We will not reverse bias the LED, as this may break it!**



The 0-20 volts Tektronix power supply should be connected to the LED under test through a 1000 ohm resistor. Thereby, only a maximum of 20 volt/1K-ohm, i.e. 20 milliamperes can flow.

Using a DMM, measure the voltage across the resistor and the voltage across the LED at given power supply voltages. This allows the measurement of the current through the resistor via Ohm's Law. (Note: the potential across the 1K-ohm resistor = 1000 * I_{device}.) Because this is a series circuit, the current through the resistor is the same as that through the LED.

The setup is shown in the Figures 3-8 and 3-9 below:

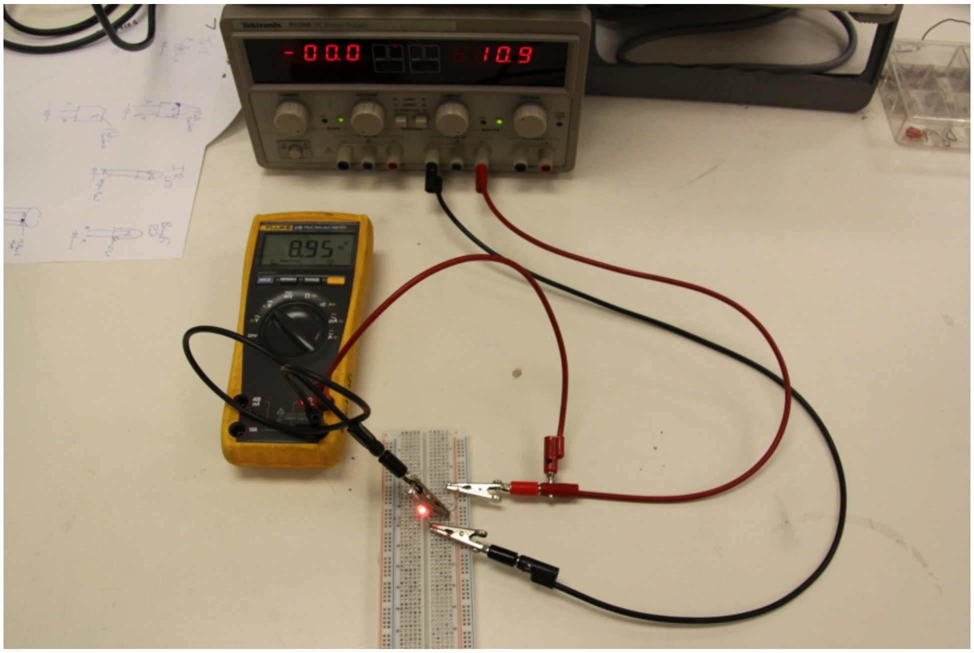


FIGURE 3-8: I VS. V MEASUREMENT SET-UP

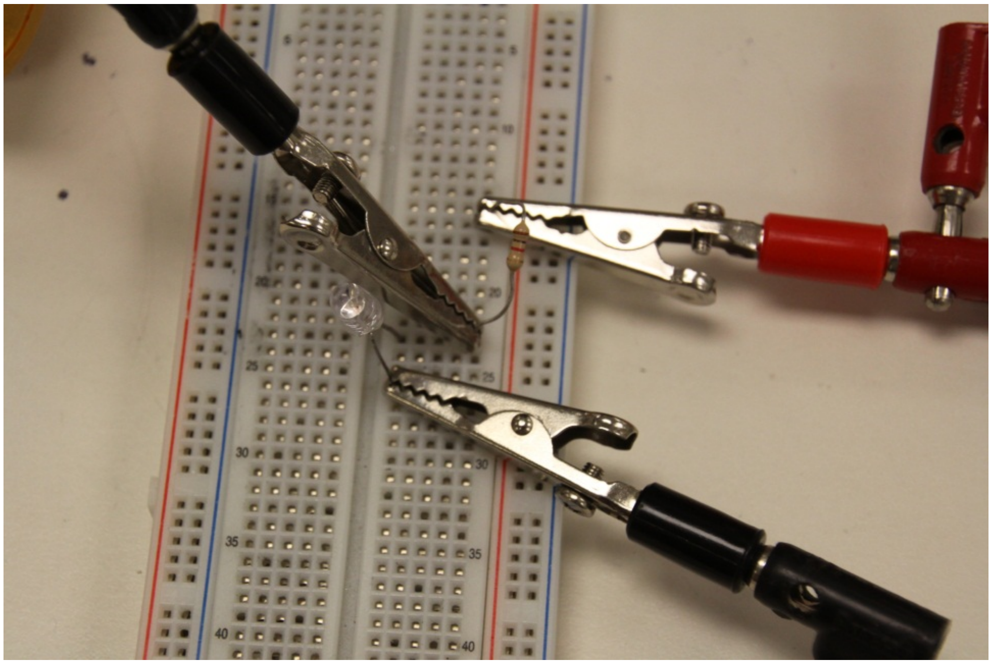


FIGURE 3-9: CLOSE-UP SHOWING LED AND SERIES RESISTOR

WORK SHEET HERE:

Supply Voltage	$Voltage_{Resistor}$	$Voltage_{LED}$	$Current_{LED}$ ($V_{resistor}$ / 1000)
0 V			
0.5 V			
1.0 V			
1.5 V			
2.0 V			
2.5 V			
5.0 V			
10 V			
15 V			

At approximately what LED voltage does the LED turn “bright”? ______________________

Plot the current vs. voltage of the device in the given space below.

ANSWER HERE

Phototransistors

In order to understand how phototransistors work, we will first look at a regular transistor. Transistors are three terminal devices that act as linear amplifiers, or, on a basic level, as switches. In this class, we will primarily be working with Bipolar Junction Transistors, or BJTs, shown in the figure below. BJTs have three terminals labeled base (B), collector (C), and emitter (E). The direction of the arrow points in the direction of current flow. (The symbol and operation listed in Figure 3-10 is for an NPN BJT. You may work with PNP BJTs later for your project, which have a different symbol and operation.)

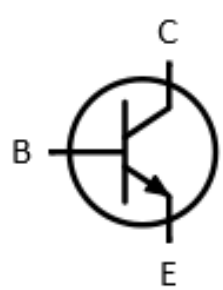


FIGURE 3-10: NPN BJT Symbol

In an NPN BJT, when a high voltage with respect to the emitter is applied to the base, current is allowed to flow from the collector to the emitter. When a low voltage with respect to the emitter is applied to the base, current is no longer allowed to flow from the collector to the emitter. This allows the transistor to act as an electrically controlled switch.

In this portion of the lab, we will work with BJT-based phototransistors. BJT-based phototransistors have an *exposed base* that is sensitive to light. When light shines on the base, the phototransistor allows current to flow from the collector to the emitter.

The visible light phototransistors we use are very similar in appearance to LEDs, shown in Figure 3-11, but have a flat top instead. Note the terminals specified in Figure 3-12.

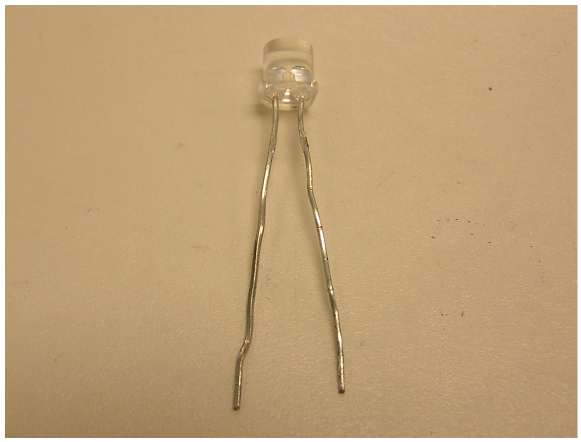
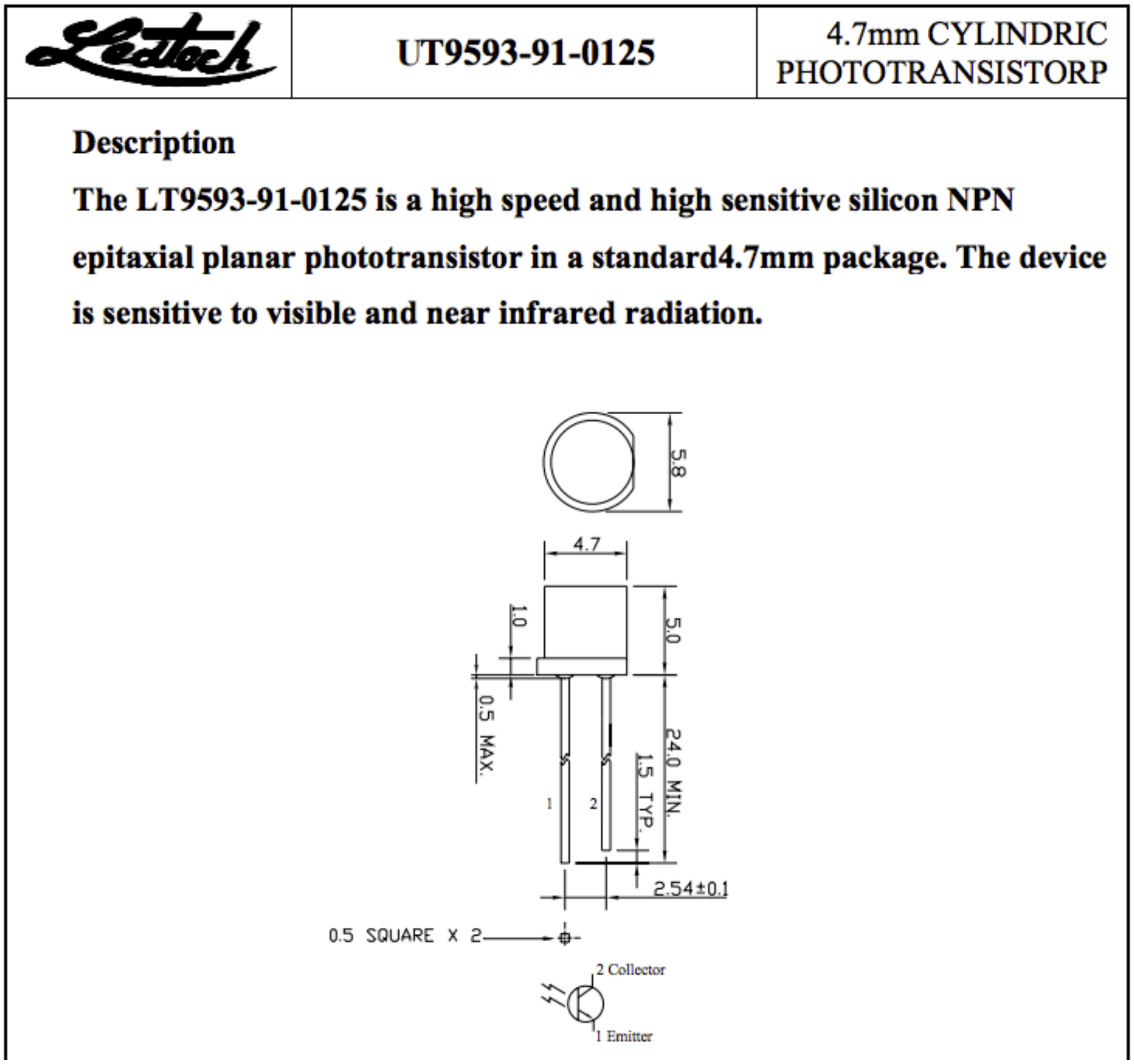


FIGURE 3-11: Visible Light Phototransistor



Ledtech	UT9593-91-0125	4.7mm CYLINDRIC PHOTOTRANSISTORP

Description

The LT9593-91-0125 is a high speed and high sensitive silicon NPN epitaxial planar phototransistor in a standard4.7mm package. The device is sensitive to visible and near infrared radiation.

FIGURE 3-12: Phototransistor Symbol

Set up the circuit measurement as shown in Figure 3-13 and Figure 3-14. Note that the left-hand side of Figure 3-13 is identical to the circuit from the previous part.

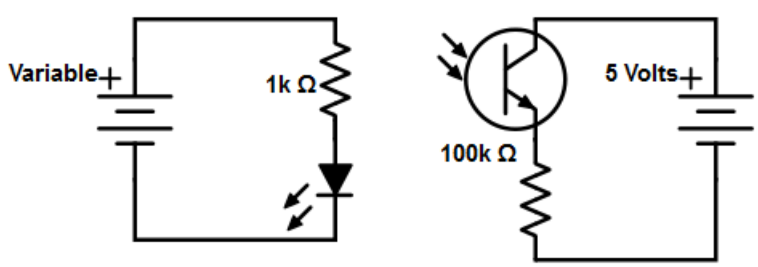


FIGURE 3-13: PHOTOTRANSISTOR EXPERIMENT SCHEMATIC

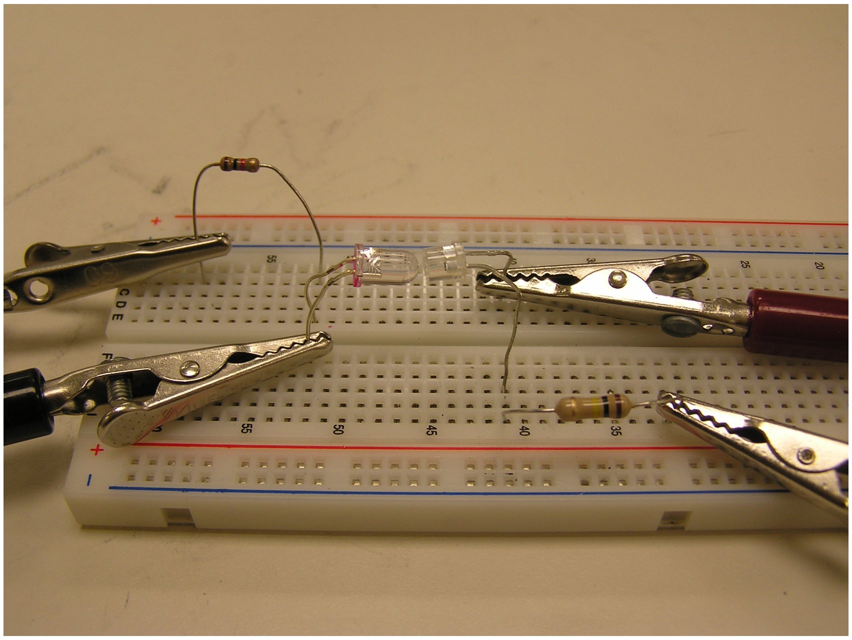


FIGURE 3-14a: PHOTOTRANSISTOR MEASUREMENT SET-UP (LED OFF)

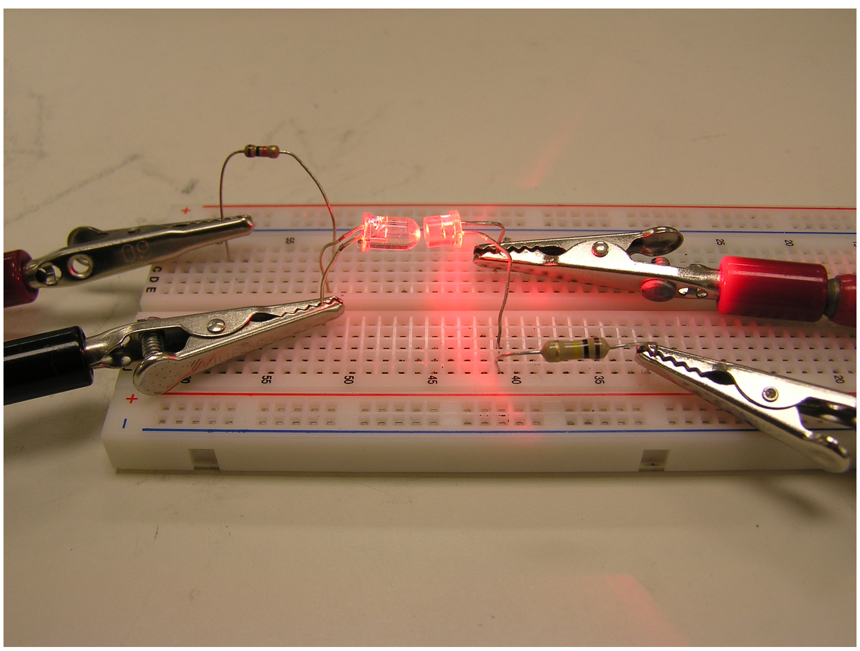


FIGURE 3-14b: PHOTOTRANSISTOR MEASUREMENT SET-UP (LED ON)

Keep in mind that the phototransistor is very sensitive to how directly and closely the LED is pointing at it. You may have to position the LED very close to the phototransistor to get appreciable results.

Measure the voltage across the 100 kΩ resistor when the LED is off. Turn the variable supply voltage to 15 Volts and measure the voltage across the 100 kΩ resistor again.

WORK SHEET HERE: (Use DMM for your voltage measurements only!)		
	Voltage$_{100\ k\Omega}$	Calculated Current$_{100\ k\Omega}$
LED off		
LED on		

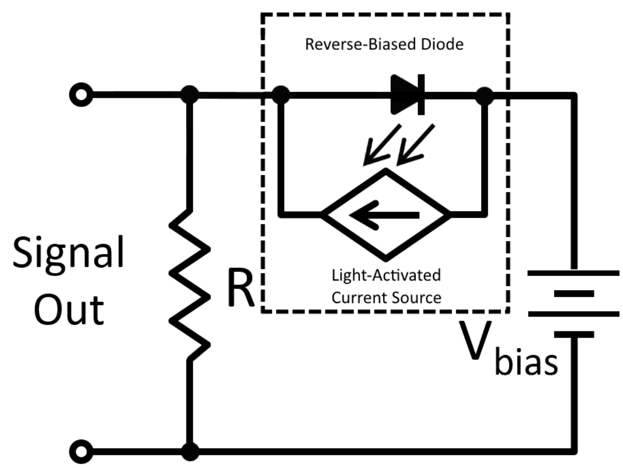
How well does your phototransistor act as a switch? (Ask your TA or mentors for help if you are experiencing difficulty in getting the setup to work)

Photodiodes

The operation of photodiodes is a fairly complex topic matter that you will study more deeply in later classes. As such, we use models in this section to make the information more digestible than it would otherwise be.

Photodiodes are light detection devices designed for high sensitivity and low noise with small areas on the order of 10^{-8} to 10^{-6} cm^2. Care must be taken not to injure these devices.

To understand how photodiodes work, let us take a look at the following circuit.



For the purposes of this class, photodiodes are modeled as a current source in parallel with a diode, as shown in within the dashed box.

When no light is shining on the photodiode, the light-activated current source is off. In this case, the circuit can be reduced to a voltage source in series with a reverse biased diode and resistor. As we know from before, reverse-biased diodes allow a current of $I_d \approx -I_0 \approx 0$ to pass in the reverse direction. Therefore, no current passes through the circuit and there is a corresponding Signal Out voltage of 0 across the resistor.

When light is shining on the photodiode, then a current I_{gen}, which varies with light intensity, is generated by the light-activated current source. We choose a V_{bias} such that $V_{bias} > I_{gen}R$, which will maintain the diode in reverse bias (remember that a diode is reverse biased when the anode is at a lower potential than the cathode). Therefore, the only current passing through the circuit is the generated current I_{gen}, and there is a corresponding Signal Out voltage of $I_{gen}R$.

A simplified model for the photodiode is shown again in Figure 3-15:

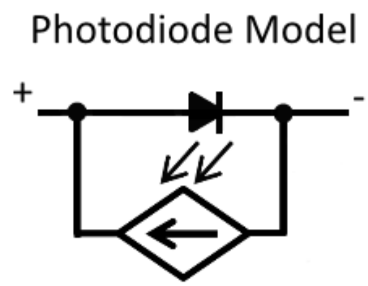


FIGURE 3-15: Photodiode Model

On circuit diagrams, photodiodes are represented by light shining onto a diode. The current source, as is present in our photodiode model, is not shown in the schematic symbol. Note that the location of the anode and cathode in our model and schematic symbol is still the same. We will continue using the model, which will be shown inside a dashed box, in this section of the lab for analyzing photodiode operation.

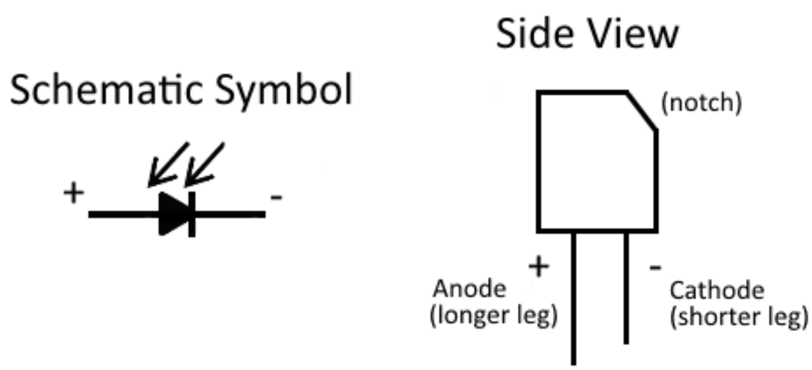


FIGURE 3-16: Photodiode Symbol

The side-look IR photodiodes we will be using in this lab are shown below in Figure 3-17.

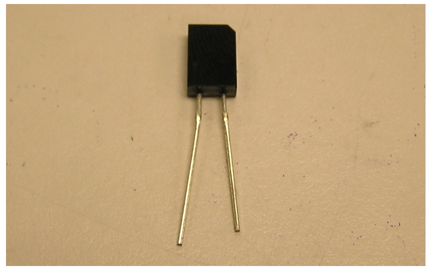
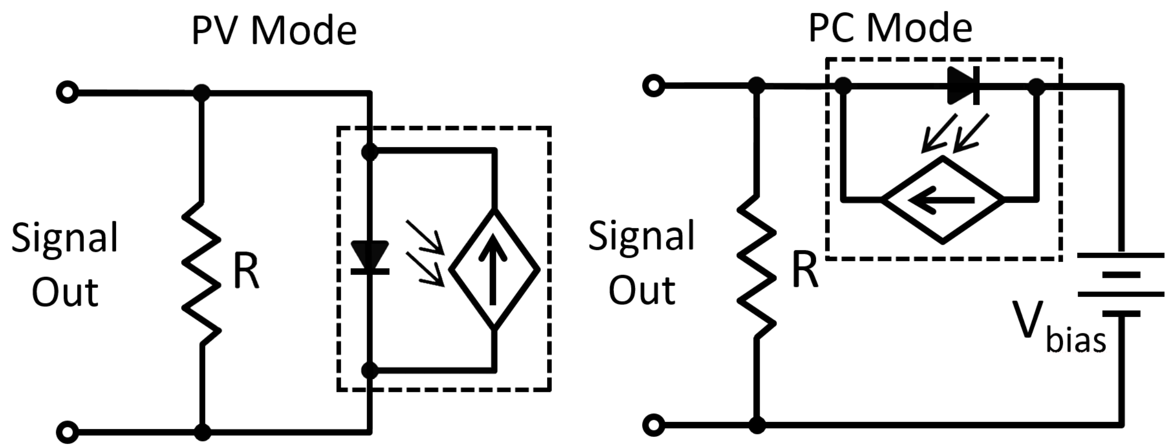


FIGURE 3-17: Side-look IR Photodiode

There are two common photodiode circuits: photovoltaic (PV) and photoconductive (PC) mode. The operation of PC mode has already been discussed in the introduction of photodiode operation.



Unlike PC mode, PV mode lacks a biasing voltage source and consequently operates differently. We will once again consider our photodiode model of a diode in parallel with a current source.

In PV mode, a non-illuminated photodiode will not generate a current and so there will be 0 voltage at the Signal Out. An illuminated photodiode will have a generated current I_{gen} from its light-activated current source, which then passes through the resistor to create a corresponding Signal Out voltage of $I_{gen}R$. In PV mode, we typically operate the diode sub-component in a high resistance region (the voltage across the diode, $I_{gen}R$, is low) so that the current through the diode sub-component I_d is negligible compared to I_{gen}.

Recall that in the LED section, we defined a positive current as current flowing into the anode. In both PV and PC mode, current generated by the light-activated current source will leave the anode of the photodiode, resulting in negative current.

In PV mode, the anode is positive with respect to the cathode due to the voltage drop across the resistor. By the Passive Sign Convention, a negative current and positive voltage give us negative power—the photodiode provides power in PV mode.

Remember that for PC mode, we choose a V_{bias} such that $V_{bias} > I_{gen}R$ so that the photodiode remains in reverse bias, where the anode is negative with respect to the cathode. By the Passive Sign Convention, a negative current and a negative voltage result in positive power—the photodiode consumes power in PC mode. It is straightforward to see that V_{bias} provides power to the photodiode and resistor.

In summary, power is provided by the photodiode and absorbed by the resistor in PV mode while power is provided by the biasing voltage source and absorbed by the photodiode and resistor in PC mode.

Please request the assistance of your TA or mentor to observe the photodiode illuminated characteristic on a curve tracer, shown in Figure 3-18. Note that in Quadrant IV, the photodiode exhibits a positive voltage drop and negative current, which corresponds to PV mode. In Quadrant III, the photodiode exhibits a negative voltage drop and a negative current, which corresponds to PC mode.

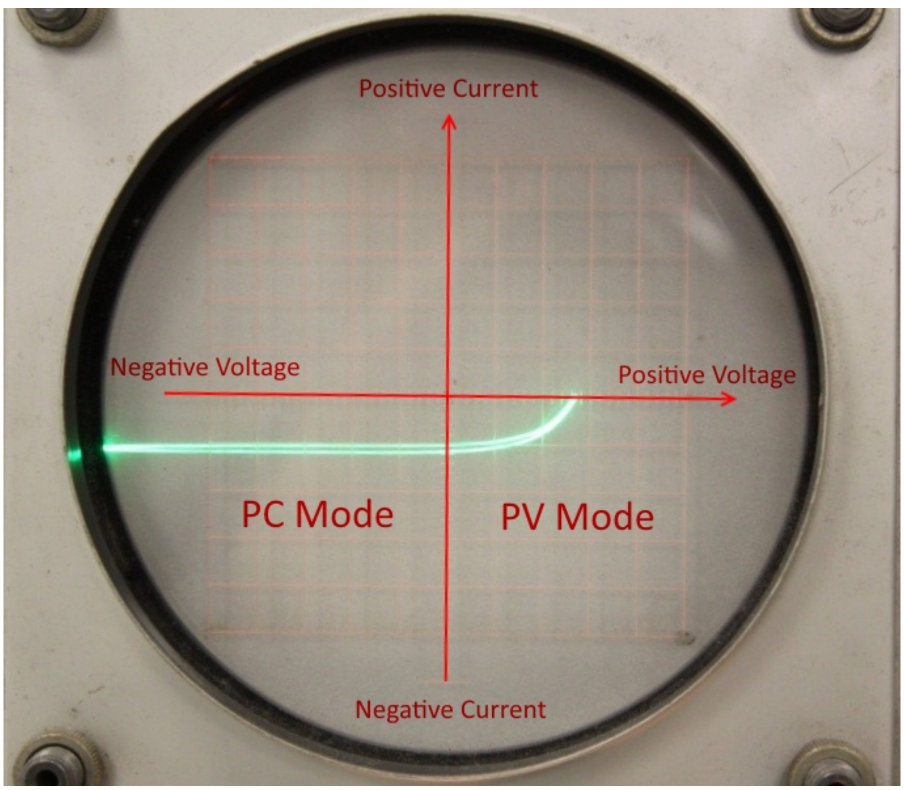
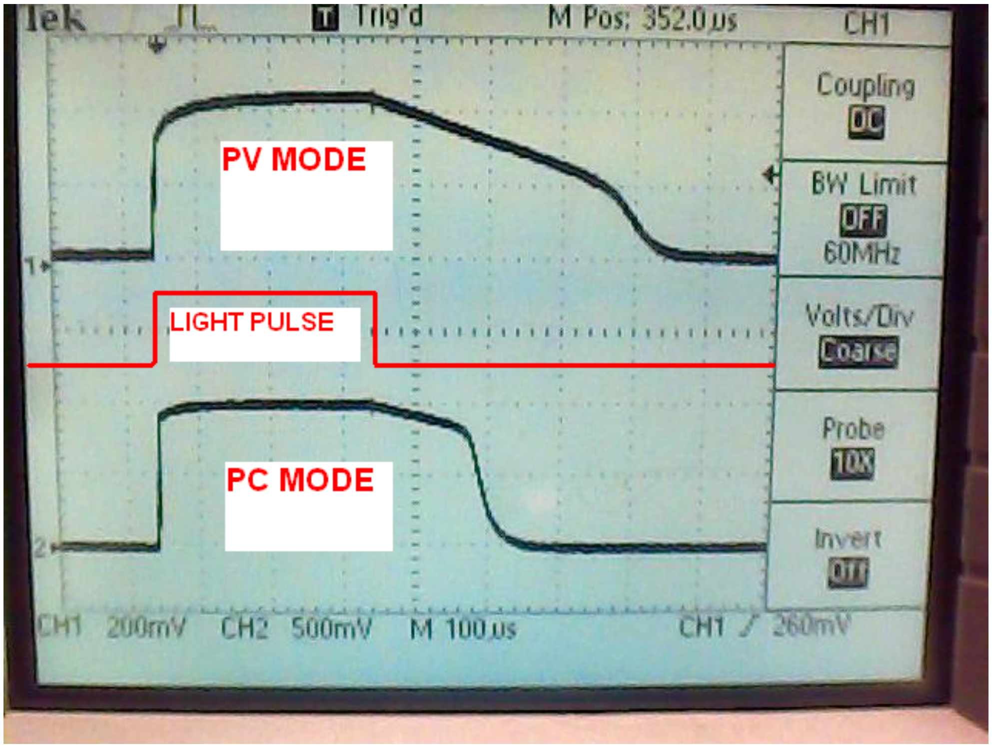


FIGURE 3-18: Photodiode Illuminated Characteristic

PV mode is suitable for power generation such as in solar cells since the power being provided in PV mode comes solely from light. While PC mode is not suitable for power generation since it requires a biasing voltage source to provide power to the circuit, PC mode responds faster to changes in light and has a higher signal to noise ratio (SNR) as shown in the oscilloscope reading below.



What are the advantages of each circuit? Briefly explain.

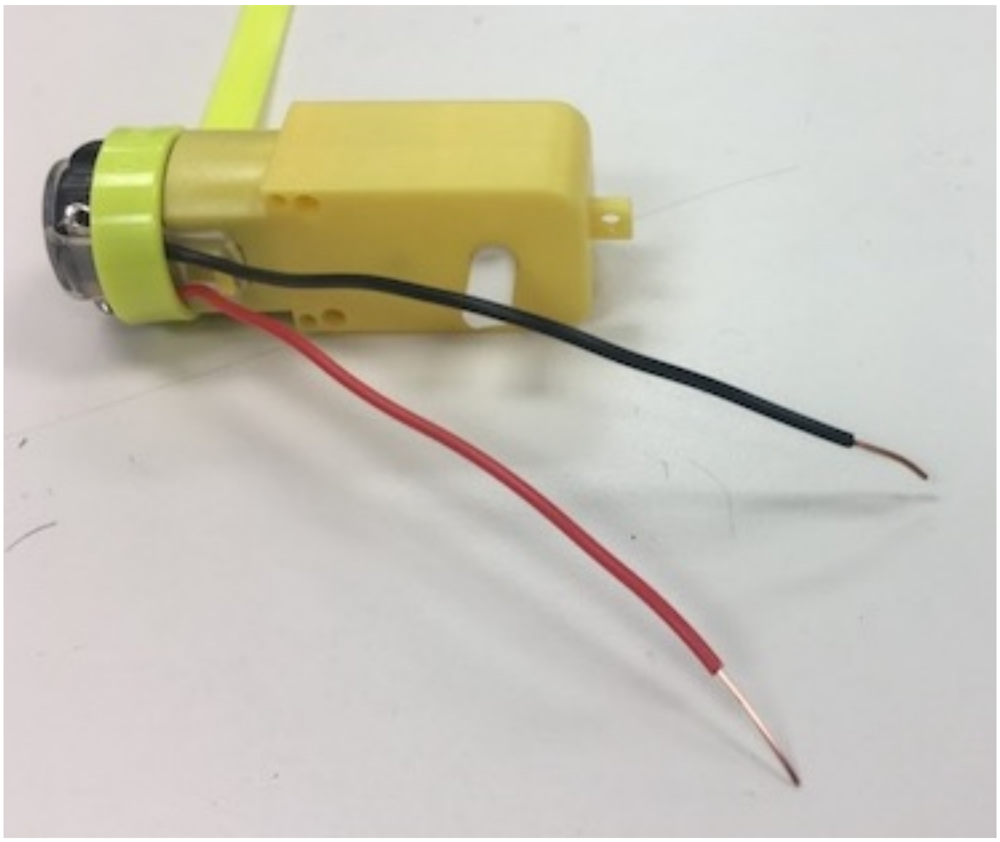
ANSWER HERE:

Electro-Mechanical Transducers

Motors and Generators

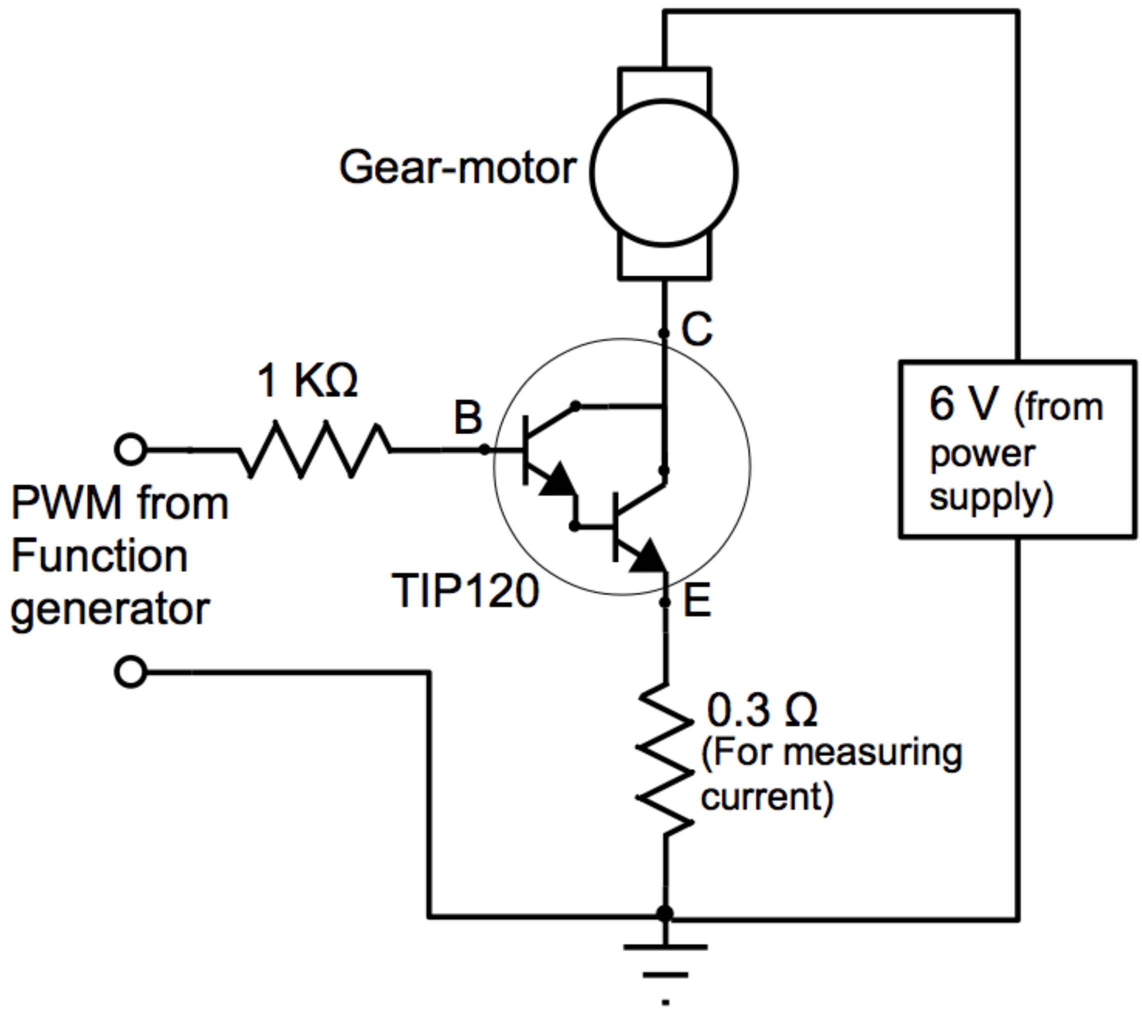
In this section, you will create a circuit that controls the speed of the electrical motor that is in the car that is part of the EE3 project. You will learn that an Arduino microcontroller PWM output pin can control a single TIP120 NPN (Darlington) transistor that will drive the motor. The duty cycle of the PWM signal controls the motor speed.

You will be supplied a copy of the DC gearmotor that is used in the project.



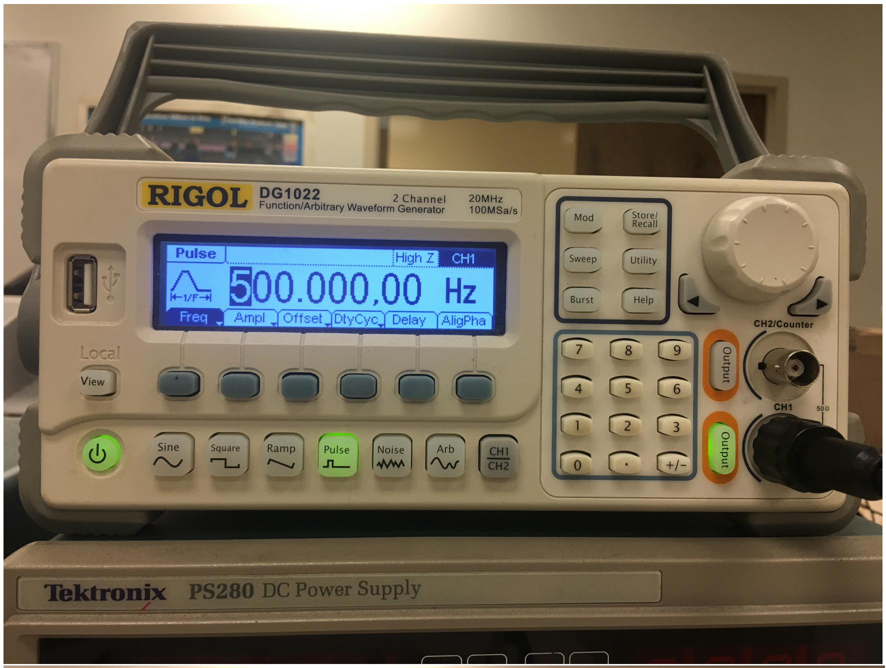
Look up the data sheet for the TIP120 Darlington transistor (google “TIP120 datasheet”). Determine which pin is associated with the emitter, base, and collector.

Hook up the circuit shown below (Do NOT connect the power supply yet):



NOTE: We will measure current <u>indirectly</u> by measuring the voltage across the 0.3 Ω resistor. You will NOT use the 0.3 Ω resistor in your project.

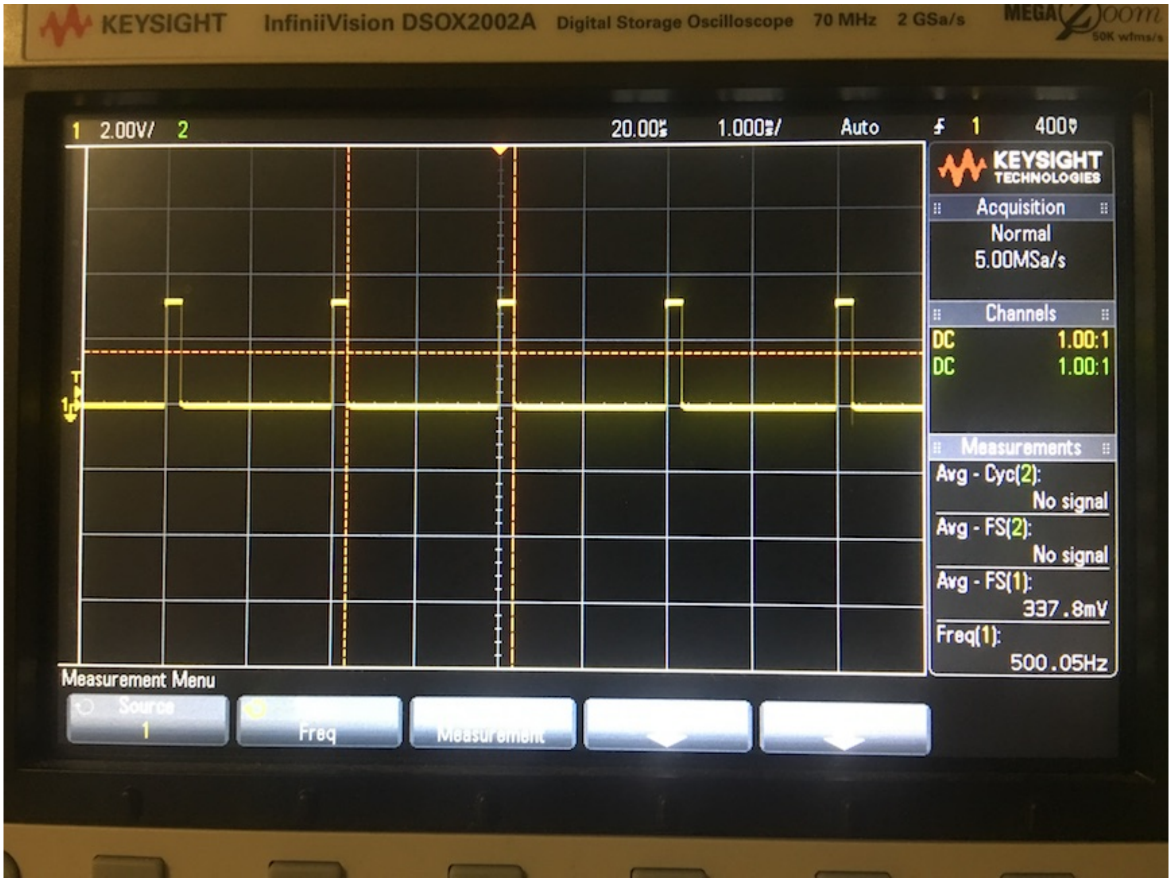
1. The power supply will connect 6 V to the circuit, and provide the current to drive the motor.
2. Set the function generator to provide a pulse train at 500 Hz and to switch between 0 V and 3.3 V (this is similar to the PWM signal from the Arduino Nano).


RIGOL DG1022
2 Channel
Function/Arbitrary Waveform Generator
20MHz
100MSa/s
Pulse
High Z
CH1
500.000,00 Hz
Freq
Ampl
Offset
DtyCyc
Delay
AligPha
Tektronix PS280 DC Power Supply


RIGOL DG1022
2 Channel
Function/Arbitrary Waveform Generator
20MHz
100MSa/s
Pulse
High Z
CH1
3.300 VPP
Freq
Ampl
Offset
DtyCyc
Delay
AligPha
Tektronix PS280 DC Power Supply

.

3. Set the pulse train (use the **Pulse** button; see above picture) duty cycle to 10%.
4. Connect the + and − leads of the function generator to the yellow Channel 1 on the oscilloscope. Adjust the oscilloscope settings to show the PWM signal and confirm that the function generator is correctly set.
5. Make sure that 5 pulses are shown on the oscilloscope screen. Adjust the oscilloscope settings (MEAS button) to show the average voltage from the function generator.



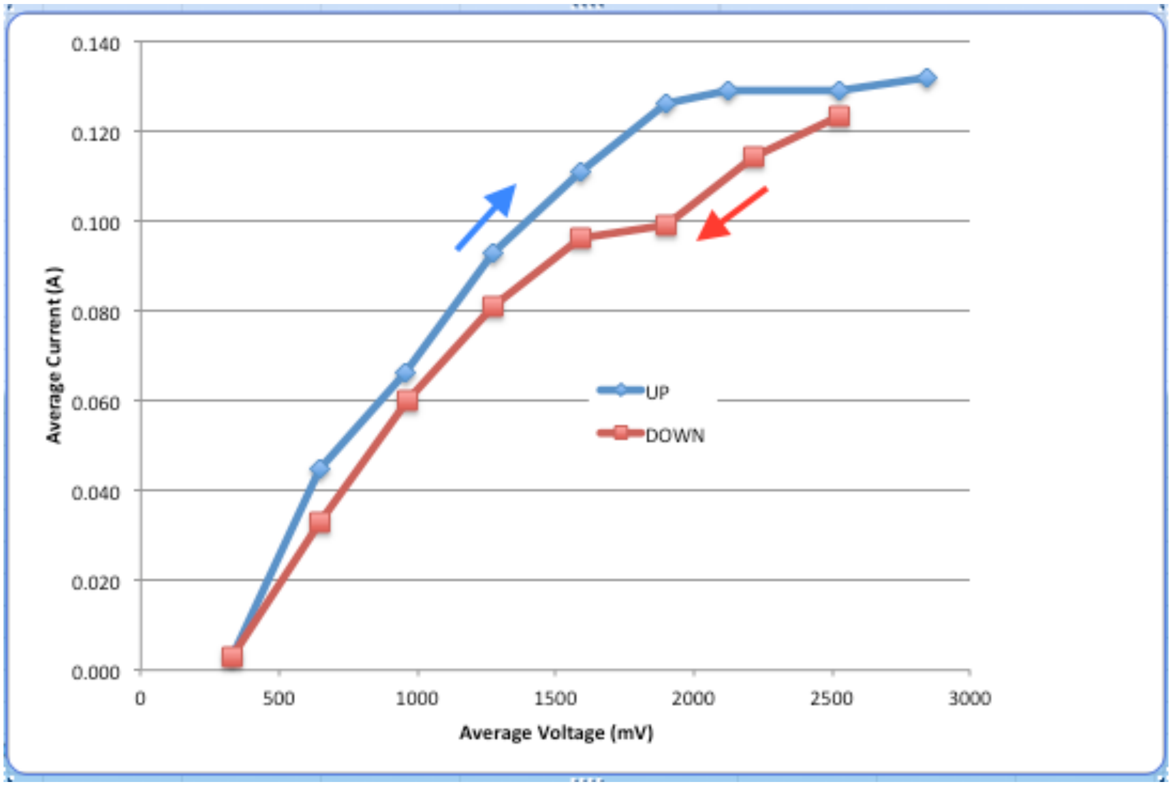
6. Connect the oscilloscope (green) Channel 2 + lead to the top of the 0.3 ohm resistor. Adjust the oscilloscope settings (MEAS button) to measure the average value (FS) of the Channel 2 signal.
7. Connect the power supply to the circuit. The motor should not turn.
8. Increase the duty cycle by 10% increments up to 90%. The motor should start to turn at around 30% duty cycle, and turn faster with increasing duty cycle. At 50% duty cycle, your oscilloscope screen should look something like the picture below.

9. Now decrease the duty cycle by 10% increments back down to 10%. The motor may stop turning at a different duty cycle from that where it started turning on the way up.
10. At each duty cycle setting, record on the work sheet below the average voltages for both channels indicated on the oscilloscope screen.

WORK SHEET HERE:

Duty Cycle %	Average Motor Volts	Average 0.3 Ω MilliVolts
20	________	________
30	________	________
40	________	________
50	________	________
60	________	________
70	________	________
80	________	________
90	________	________
80	________	________
70	________	________
60	________	________
50	________	________
40	________	________
30	________	________
20	________	________
10	________	________

Enter your data into Excel. Create another column where you compute the motor current using Ohm's law, and plot your results (current vs. voltage). You should get something like this:



What voltage and current are required to just start the motor spinning? _____________

Week 3 Lab End

Week 4: NI myDAQ week

Week 4 Prelab

1. **NI ELVISmx Installation:** This lab requires you to use NI myDAQ. To make good use of lab hours, please download and install the required NI ELVISmx software on a Windows machine before the lab. The latest software version as of this lab manual revision can be found online at:

http://www.ni.com/download/ni-elvismx-15.0/5424/en/

If you don't have a Windows laptop, either install Windows in a Virtual Machine or using Boot Camp on a Mac (instructions can be easily found online) or borrow one from the library:

http://www.library.ucla.edu/clicc-laptop-lending-sel-boelter

They contain an older version of the NI ELVISmx that will work just as well.

Using the Elvis program, the NI myDAQ can be launched into modes in which it emulates various laboratory devices. Details on how to do this can be found at the website:

www.ni.com/white-paper/11420/en

2. **LabVIEW and DAQmx Drivers:** For future work, you will likely need to install LabVIEW and DAQmx Drivers, which allow you to write LabVIEW programs that interface with the myDAQ.

NOTE for Mac Users: While LabVIEW and DAQmx drivers can be installed natively on Mac OS, the latest Mac driver only supports LabVIEW 2011 through 2014. Since only LabVIEW 2015 is available through student purchasing links, it is recommended you install LabVIEW on a Windows machine. We make no guarantees on proper operation of LabVIEW 2015 with the latest Mac OS DAQmx Drivers.

The directions for installing and activating LabVIEW will be included in your purchase of LabVIEW either off Studica or UCLA onthehub.

The latest DAQmx drivers as of this revision are listed at the links below. These must be installed *after* LabVIEW has already been installed. See note above for Mac OS.

Windows Drivers (ver 15.1): http://www.ni.com/download/ni-daqmx-15.1/5617/en/

Mac Drivers (ver 14.0): http://www.ni.com/download/ni-daqmx-base-14.0/5060/en/

3. If the myDAQ AI0 is used as an oscilloscope to measure the Ch1 output (non-inverting) of a function generator, how would you connect these two devices? Draw lines to connect them.

F.G. Ch1	myDAQ Analog Input Channel 0
Ground	AGND
Ch1 Output	0+
	0-

4. For a square wave and a sinusoidal wave generated at the same frequency, which waveform requires a higher frequency response from the measuring system? Briefly explain why.

Week 4 Prelab End

MyDAQ NI ELVISmx – DMM

Connect the red and black test probes that came with your MyDAQ into its banana connectors and use your MyDAQ with **ELVIS DMM** instrument to operate as a digital multimeter to measure the output of the digital function generator just as you did back in week 2's lab. For the Keysight oscilloscope use its measurement utility to measure Cyclic RMS.

WORK SHEET HERE:

1 kHz Wave (5 Vpp)	Cyclic RMS Key Scope Voltage	Meter Voltage DMM	Meter Voltage myDAQ/DMM	% Difference (vs Scope) $\frac{\text{DMM or myDAQ-SCOPE}}{\text{SCOPE}}(100\%)$ DMM	% Difference (vs Scope) myDAQ
Sine:	________	________	________	________	________
Triangle:	________	________	________	________	________
Square:	________	________	________	________	________

In particular, does the MyDAQ measurement of sine, square waves and triangular waves behave the same or differently than the digital multi-meter? Why?

ANSWER HERE:

MyDAQ NI ELVISmx – Oscilloscope

Activate the NI myDAQ in **ELVIS Oscilloscope** instrument. Connect both the myDAQ and the Keysight scopes to the digital function generator. Note that the MyDAQ analog inputs are made through its edge connector and are *differential* (just like an OpAmp), with a non-inverting and an inverting terminal, neither of which is connected to the chassis ground of the MyDAQ. However, the function generator, and many other sources, have *single-ended* outputs, where the negative side of the signal is tied to the chassis ground of the source. Here is the main point: merely connecting the signal source {+lead} to the MyDAQ's {+input} and the signal source {–lead} to the MyDAQ's {–input} **is not enough**. You must add a third wire that connects [a] the MyDAQ's {–input}, [b] the MyDAQ's chassis ground (labeled AGND), and, as a result, also to [c] the signal source's chassis ground. This chassis-ground-to-chassis-ground connection is essential to minimize ground loop noise.

Compare the behavior of the lab bench Keysight and your myDAQ oscilloscopes. Start by setting the MyDAQ oscilloscope time base to 10 ms (you should adjust the time base to values that allow the waveform to be seen clearly). Start by measuring the output of the function generator at about 1 kHz and amplitude of 1 – 10 Vpp looking at both sine and square waves. Increase the frequency of the function generator to 1 KHz, 10 kHz, 99 kHz, 999 kHz and 1999 kHz. Note whether the amplitude of the sine waves and particularly the shape of the square waves remain constant. The digital function generator output is in fact constant over this frequency range, so changes in rise and fall time, and/or amplitude with frequency are the result of frequency limitations in your measuring devices. (The output of the analog function generator varies somewhat over this frequency range.)

WORK SHEET HERE:

Frequency	Oscilloscope RMS Voltages			
kHz	Sine (Key)	Square (Key)	Sine(myDAQ)	Square (myDAQ)
1	________	________	________	________
10	________	________	________	________
99	________	________	________	________
999	________	________	________	________
1999	________	________	________	________

Square wave response requires a higher frequency response from the measuring system than sinusoidal waves. As you will see in the spectrum analyzer experiment, square waves can be thought of as being formed from a fundamental sinusoidal wave whose period is the same as the square wave plus higher frequency components (all odd integer multiples, or *harmonics*, of the fundamental frequency) to make up the sharp rise and flat top asso-ciated with the square wave.

Therefore, as your measuring system goes to its high frequency limit, the sharp rise and fall of the square wave will be lost due to the lack of these higher frequency components being accurately displayed. This is known as the Gibbs phenomenon, which you will have a chance to look at later. Plot the sinusoidal frequency response versus frequency for these two oscilloscopes. Use the Bode plot format with the 1 KHz value as the reference. Plot both oscilloscope curves on the same graph. Then create a second plot for the square wave data.

ANSWER HERE:

We define the upper frequency response of a system to be the point at which the amplitude decreases to 70.7% (-3 dB). Using this criterion, can you estimate the frequency response of the myDAQ and the Keysight oscilloscopes? Discuss.

ANSWER HERE:

From these experiments you will observe that the combination of a laptop computer and a NI myDAQ can emulate the common functions of a standalone multi-meter or oscilloscope.

The NI myDAQ will also operate as a function generator. Put the device in function generator mode and test its output using the Keysight oscilloscope. Test various waveforms such as sine, square, and triangular outputs.

Note that the generator can also be used to generate arbitrary waveforms. This will be useful for the various projects that you will choose to work on. In your outside time, please examine this option of generating arbitrary waveforms.

MyDAQ NI ELVISmx – Dynamic System Analyzer (AKA Spectrum Analyzer)

Put the NI myDAQ in spectrum analyzer mode called a “Dynamic Signal Analyzer”. Use the function generator to produce 1 kHz square waves of about 1 V_{pp}. Analyze the spec-trum of this square wave. Compare the frequency components and their amplitudes to theory. That is, only odd harmonics should appear (1 kHz, 3 kHz, 5 kHz, etc.) and the ratio of the various harmonic amplitudes to that of the fundamental should be 1/N where N is the harmonic (1: 1/3 : 1/5 : 1/7 : … etc.).

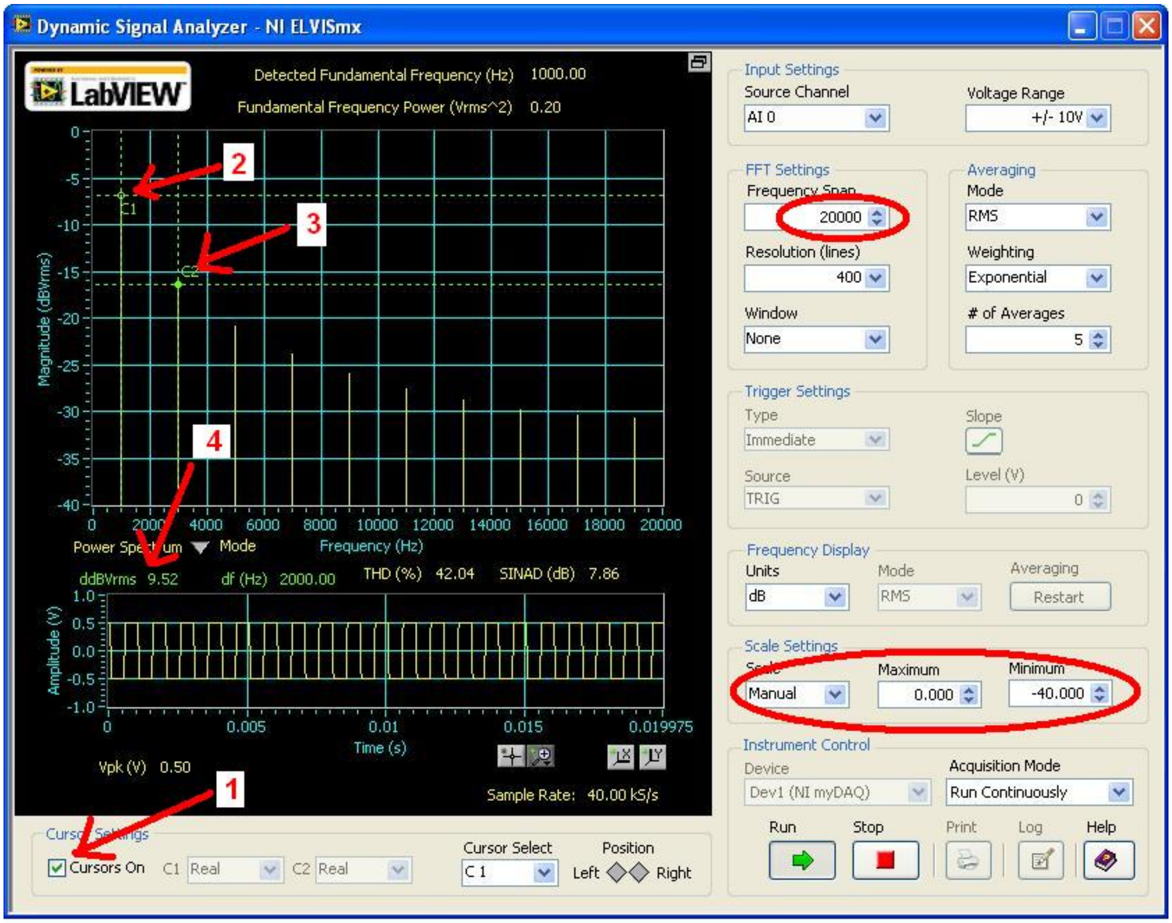
Note again: the dynamic signal analyzer can display the data in both a linear and logarithmic manner, called dB (decibel) defined as a ratio of powers:

$$\text{Bel}=\log_{10}\left(\frac{\text{Power}_{\text{test}}}{\text{Power}_{\text{reference}}}\right)$$

$$\text{dB}=10\log_{10}\left(\frac{\text{Power}_{\text{test}}}{\text{Power}_{\text{reference}}}\right)=20\log_{10}\left(\frac{\text{V}_{\text{test}}}{\text{V}_{\text{reference}}}\right)$$

Take the data both linearly and logarithmically. The logarithm display gives greater detail over a wide dynamic range and is therefore commonly used in engineering.

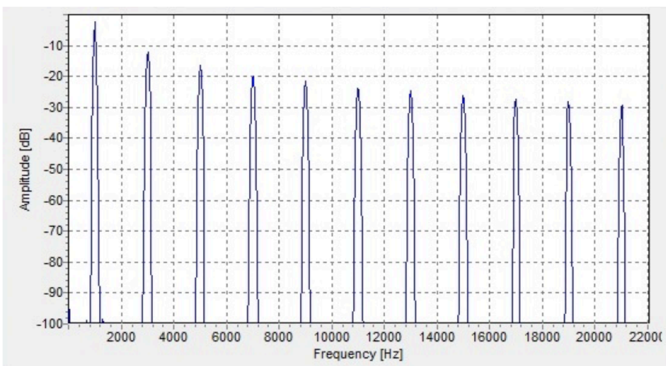
Set the FFT settings / Freq Span to 20 kHz, Frequency Display / Units to dB, and set the Scale Settings / Scale to Manual (Max = 0, Min = -100). Click Run, then click the lower-left corner box “Cursors On,” drag the dashed vertical green line (on the left side of the display) horizontally until it snaps onto the first harmonic, then drag the remaining second dashed vertical line to snap respectively on each of the higher harmonics – one by one. Each time (snapped onto each of the higher harmonics) note and record the value on the left middle indicator in green as ddBVrms (delta dB).



Dynamic Signal Analyzer - NI ELVISmx
LabVIEW
Detected Fundamental Frequency (Hz) 1000.00
Fundamental Frequency Power (Vrms^2) 0.20
Magnitude (dBVrms)
Frequency (Hz)
Power Spectrum Mode
ddBVrms 9.52
df (Hz) 2000.00
THD (%) 42.04
SINAD (dB) 7.86
Amplitude (V)
Time (s)
Vpk (V) 0.50
Sample Rate: 40.00 kS/s
Cursor Settings
Cursors On
C1 Real
C2 Real
Cursor Select
C 1
Position
Left
Right
Input Settings
Source Channel
AI 0
Voltage Range
+/- 10V
FFT Settings
Frequency Span
20000
Resolution (lines)
400
Window
None
Averaging
Mode
RMS
Weighting
Exponential
# of Averages
5
Trigger Settings
Type
Immediate
Slope
Source
TRIG
Level (V)
0
Frequency Display
Units
dB
Mode
RMS
Averaging
Restart
Scale Settings
Scale
Manual
Maximum
0.000
Minimum
-40.000
Instrument Control
Device
Dev1 (NI myDAQ)
Acquisition Mode
Run Continuously
Run
Stop
Print
Log
Help
1
2
3
4

WORK SHEET HERE (SQUARE WAVE ANALYSIS):

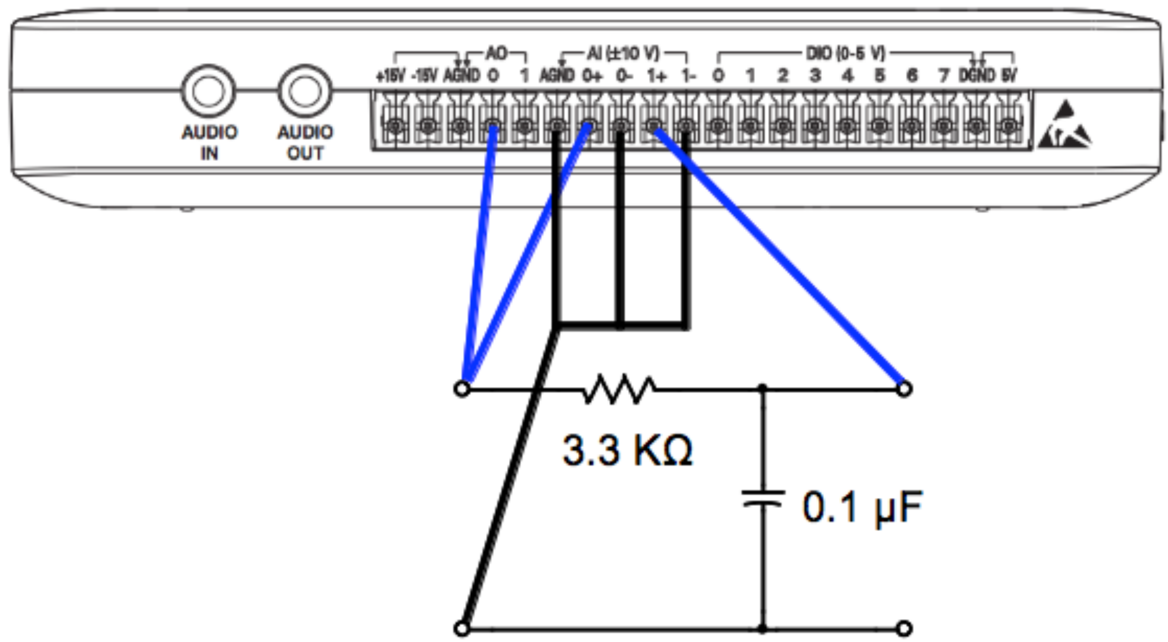
n Harmonic	20 log(Vn / V1)=dBn-dB1 Ratio, in dB (n-th / 1st)	20log(1/n), n=odd; -inf, n=even Theory .
1	0	0
2		
3		
4		
5		
6		
7		
8		
9		
10		



MyDAQ NI ELVISmx – Bode Analyzer

This section shows you how the MyDAQ can generate Bode plots. You will generate the bode plot of a first-order low-pass filter (LPF).

Set up the circuit below on your breadboard and connect it to the MyDAQ as shown.



Note that the AO subsystem drives the filter, and the AI subsystem measures both the input to and output from the filter.

Start the Bode Analyzer and set it up to take 20 measurements starting at 100 Hz and ending at 10 KHz. Take a screen shot (NOT a photograph!) of the result. Calculate:

The theoretical cutoff frequency (-3 dB point) of the filter ________ Hz

The cutoff frequency as measured by the Bode Analyzer ________ Hz

The % difference, using theoretical as the reference.

Offer a list of the causes of the difference. ____

____

____

Four optional, but informative experiments:

1. If the function generator has a symmetry adjustment, then with the function generator set on “triangular output” adjust the wave to be non-symmetrical as seen on the scope. Compare the harmonic structure to the symmetrical waveform.

2. Select a sinusoidal output on the function generator. Use the NI myDAQ to analyze the spectrum. What do you observe? Can you explain the result?

3. Set the function generator to sine wave and observe the spectrum on both linear and logarithmic scales. Is the sine wave generator making perfect sine waves? What do you observe?

   Try this experiment with both an external function generator and the internal myDAQ. Is there a difference? Why?

4. Connect the external digital function generator to the Keysight oscilloscope and generate a square wave. Zoom in on the corner of a square wave where the voltage drops from high to low or rises from low to high. What do you observe?

   Does the “curving” get better or worse as you change the frequency of your square wave? This imperfection in generating square waves is known as Gibbs phenomenon.

Week 5 Pre-Lab:

PROJECT DEVELOPMENT, CONSTRUCTION, AND TESTING

Discuss with your project partner(s) possible projects, decide what you would like to do for your project, and turn in a one-page proposal at the beginning of the lab, based on the form below. Your lab mentors and Teaching Assistant will be of help in selecting an appropriate subject. Here are a few suggestions:

1. LED and Photodiodes
    a. Analysis of the bit stream waveform output by IR remote control
    b. Optical data link (electrical isolation) across a gap of at least a few inches.
    c. Fiber optic communications
    d. Optical rotation direction sensor (CW vs CCW)
    e. Linear position and/or velocity sensing
2. Acoustic Transducers
    a. Ultrasonic sonar distance measurement
    b. Acoustic waveguides
    c. Reflectors
3. Electronic circuits
    a. Audio amplifier with filtering (bass, treble)
4. Solar Cells
    a. I-V current voltage measurements
    b. Power generation
5. Motor Control Systems
    a. Light-activated garage-door opener
    b. Optical- or ultrasonic-controlled draw-bridge
6. NI myDAQ (LabVIEW programming)
    a. Elevator programmed to move to different "floors."
    b. Ultrasonic sonar, with measured distance displayed on your laptop.
    c. See the National Instruments website student project blog for ideas.

Note that basic IC's (operational amplifiers, logic gates) are available in the lab, and you may submit a request (no later than week 7) for a few specialized (low-cost) items that you might need for your project, which the course will procure for you.

A form is provided on the following page to help you prepare a one-page project proposal to turn in at the beginning of lab 5.

EE3 Laboratory Project Proposal

Project team members ___________________________________

____

____

Lab Project Title

____

Project description:

Main objective:

Options:

Parts List (most significant parts):

Our plan for lab activities to be done to have the project working and ready to demonstrate in the lab week 10:

Week 6 activities:

Week 7 activities:

Week 8 activities:

Week 9 activities:

Week 10 activities: Make Powerpoint presentation (find template on course webpage) and demonstration of the project in operation.

Weeks 6-10: Projects

See the pre-lab assignment above.

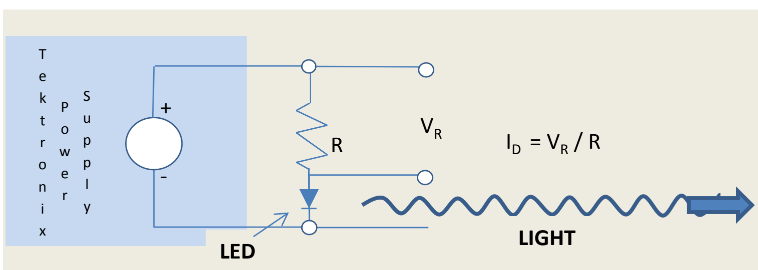
Opto-Electronic Projects (Part 1)

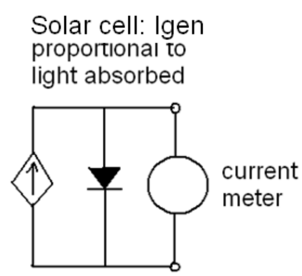
Solar cells are designed to convert light (typically solar radiation) to electrical power. Conversion efficiencies for silicon are 10% ± 5% and the solar radiation level in sunny southern California is about 100 milliwatt/cm^2. In this setup, we will measure the generated current by a basic solar cell.

Solar cells are only used in the forward direction, i.e. for generating power. Be sure to look at the forward characteristic of your single solar cell in the dark and illuminated.

One of the simplest questions that can be of interest is what load value, i.e. resistance will yield the maximum power? And does this change with illumination level?

Using the set-up from Week 3, measure the light output vs. device current. Put a single cell solar cell next to the LED. Connect a multi-meter to the solar cell. Use the meter in "current mode". See the circuit diagram below. Put a shield over your set up to avoid the effects of the laboratory lights. The LED is connected as before.





Below is a picture of an AMM in current mode connected to a solar cell. Note: it is a single cell rated at ½ volt 400 mA. The AMM is used rather than the DMM because it has a lower resistance in current mode.

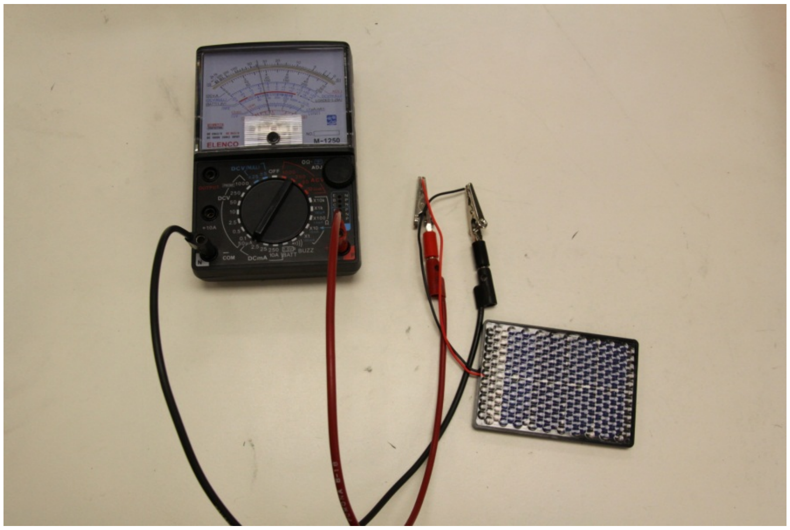


FIGURE 33. SOLAR CELL CONNECTED TO AMM

The success of this experiment depends upon which solar cell is used. Please use the ½ volt output (single cells) in parallel. The higher voltage solar cells are series connected and will not respond properly unless all areas are illuminated.

Below see the set-up for measuring the light output of a LED.

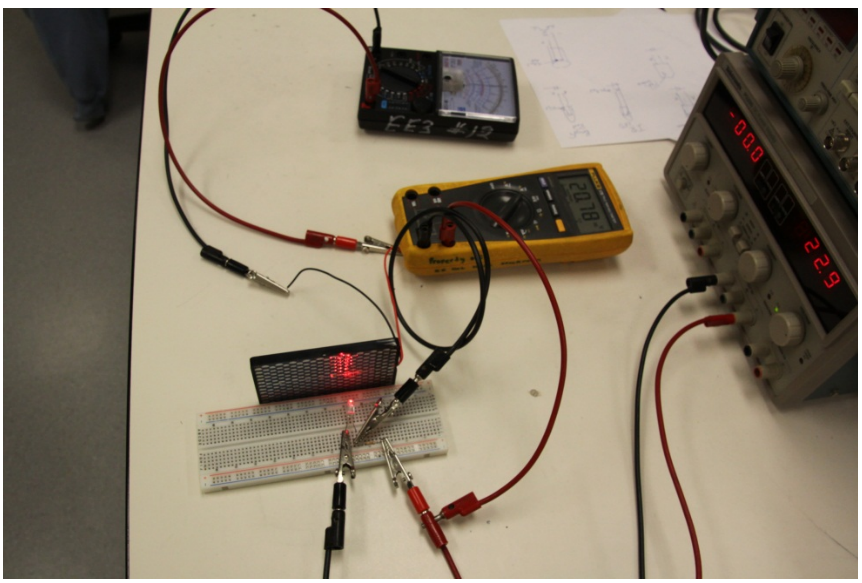


FIGURE 34. SET-UP FOR MEASUREMENT OF LED LIGHT OUTPUT

Masking tape can be used to attach the solar cell to the proto-board.

In the picture below, we see a cardboard box shielding the experiment from room lighting.

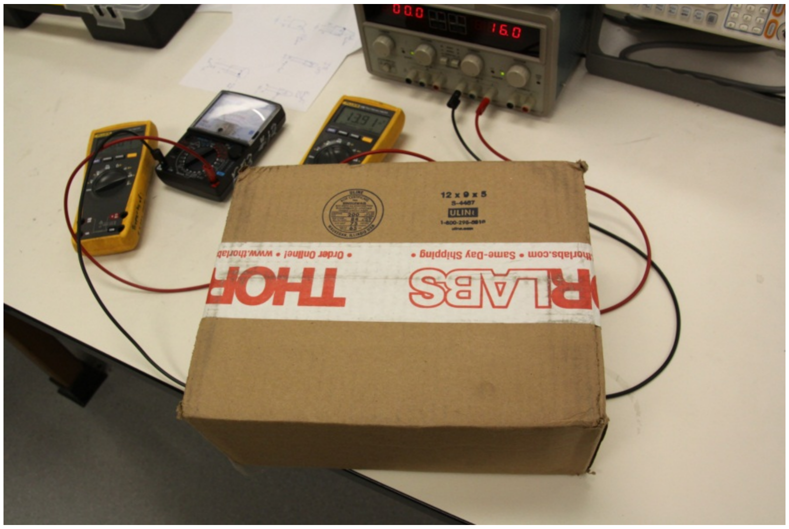


FIGURE 35. CARDBOARD BOX USED AS LIGHT SHIELD

NOTE: a jacket can also serve this purpose.

Measure the current from the solar cell which is linear in light intensity as a function of LED current. Put the AMM in current mode and on the 2.5 mA scale.

WORK SHEET HERE:

Volts (across 1K-ohm resistor) $I_{Solar\ Cell}$ I_{LED}

0.0** ____

1.0 ____

2.0 ____

4.0 ____

8.0 ____

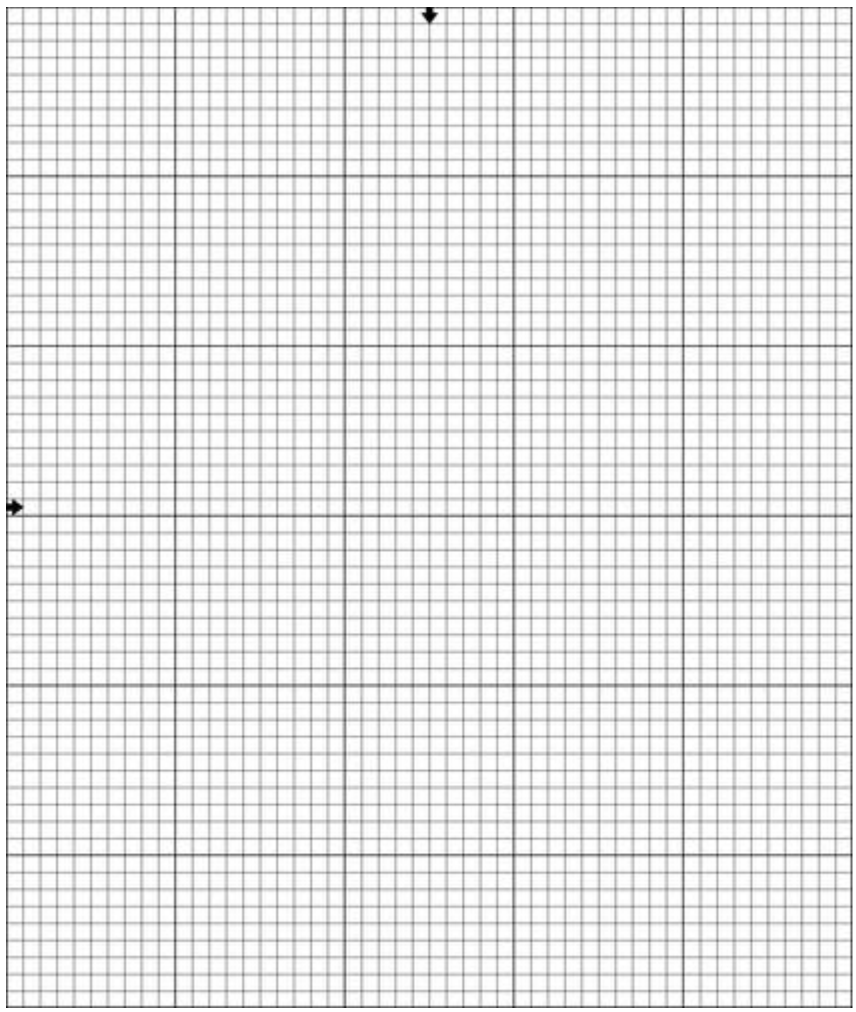
12.0 ____

16.0 ____

20.0 ____

** Any $I_{Solar\ Cell}$ current is due to lab lights and should be subtracted from other measurements.

Plot the solar cell current, i.e. the light output vs. the LED current.



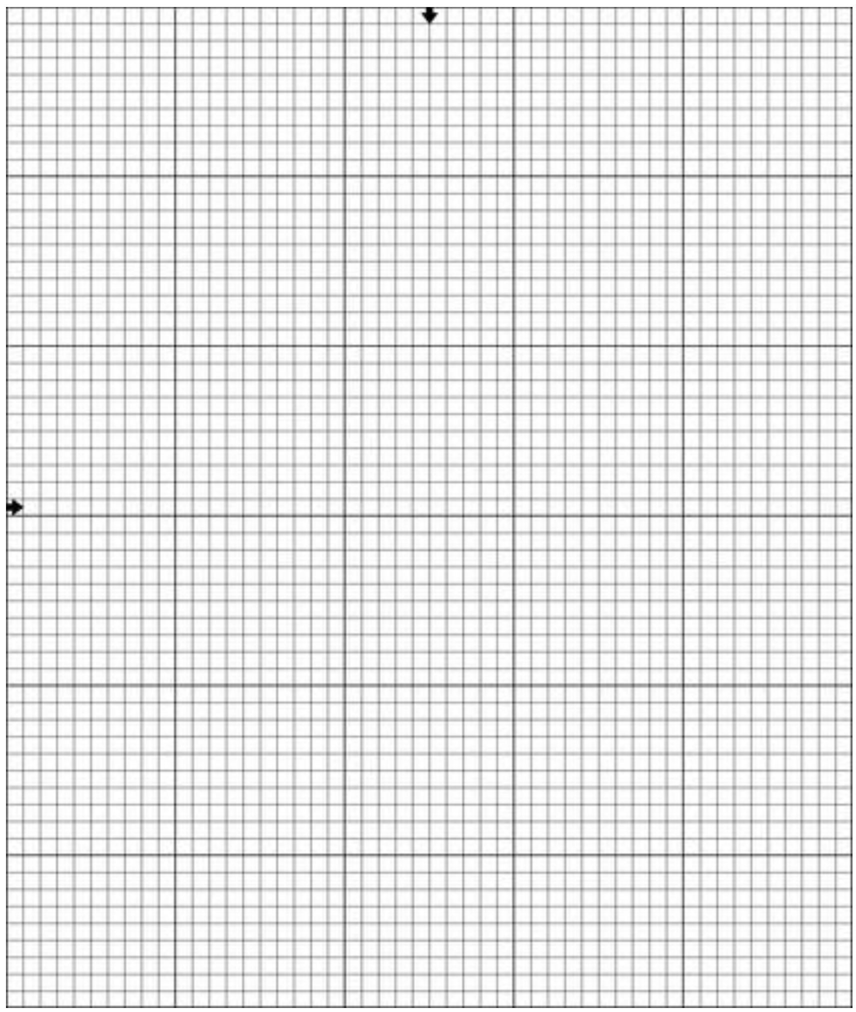
At this point, you have demonstrated that the light output of a LED is a linear function of the current in the device. We shall use this fact to test the behavior of another kind of photo-detector, the photoconductor. The photoconductor resistance will be measured by a multi-meter in the “resistance measuring” mode. Repeat the LED-solar cell experiments replacing the solar cell with the photoconductor. Measure the resistance of the photoconductor as a function of LED current, that is the LED output. The photocell should just “kiss” the LED to ensure proper alignment.

Calculate the current in the LED by measuring the voltage across the k-ohm resistor. By measuring the voltage across the resistor, we are avoiding using a meter in current mode (that might lead to easy damage).

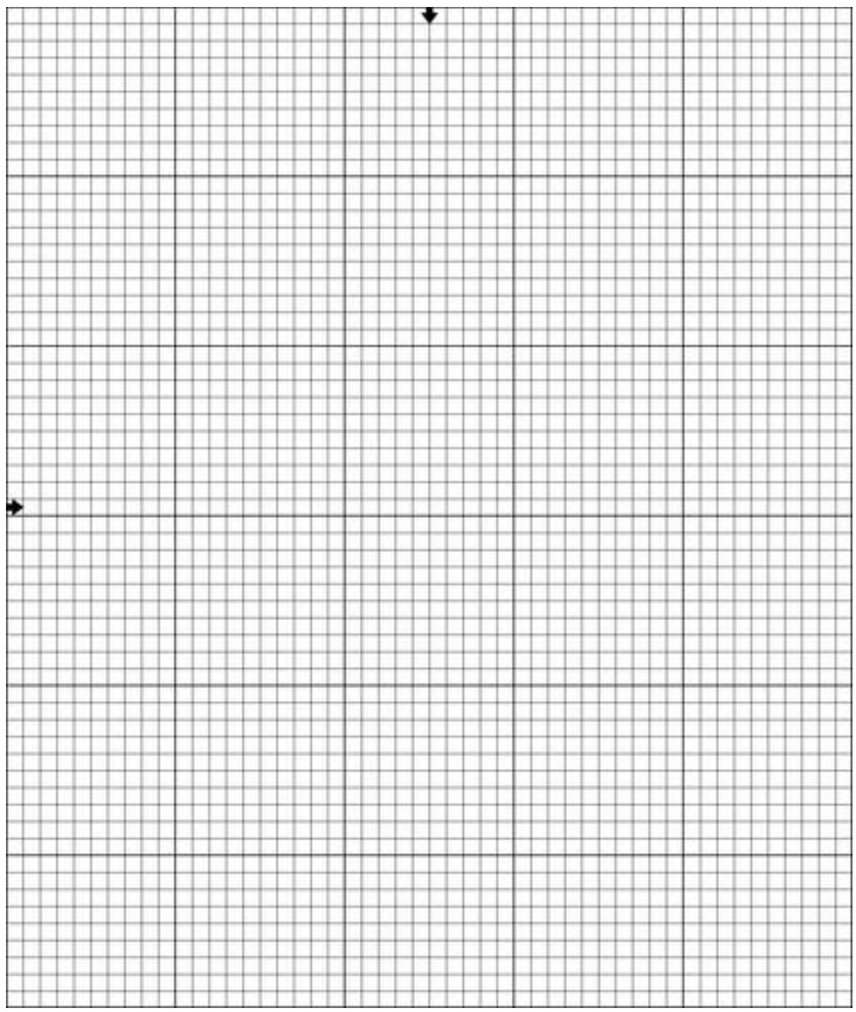
WORK SHEET HERE:

Volts (across 1K-ohm resistor)	$R_{Photoconductor}$	I_{LED}
0.0		
1.0		
2.0		
4.0		
8.0		
12.0		
16.0		
20.0		

Plot the photoconductor resistance vs. I_{LED}.



Plot the reciprocal of the photoconductor resistance vs I_{LED}.



Next week (6), we shall explore the use of a LED light source, a light detector and its circuitry, PN junction, photoconductor, and phototransistor for:

- the measurement of position
- transmission of information (both digital and analog)
- and whatever else you need to explore for your project

Acoustic Devices Projects (Part 1)

For this project, you will be provided with broadband "speakers" and narrow band (ultrasonic) transducers. The laboratory also will have acoustic waveguides (PVC pipe) and couplers, bends, and special slip fittings. Pipes of ¼, ½, and 1 meter in length will be available. Below is the picture of typical devices available for this project.

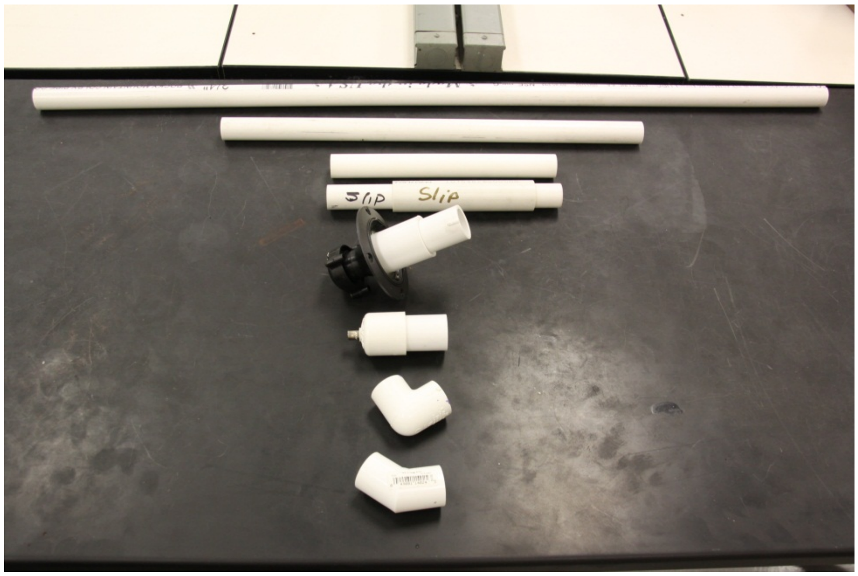


FIGURE 36. ACOUSTIC DEVICES

In the picture [top to bottom], we show: 1 m pipe, ½ m pipe, ¼ m pipe, slip fittings, wideband transducer, narrow band transducer, 90º bend, 45º bend.

Using your NI myDAQ, measure the broadband speakers efficiencies vs. frequency from 3 - 20 kHz. See the figure below:

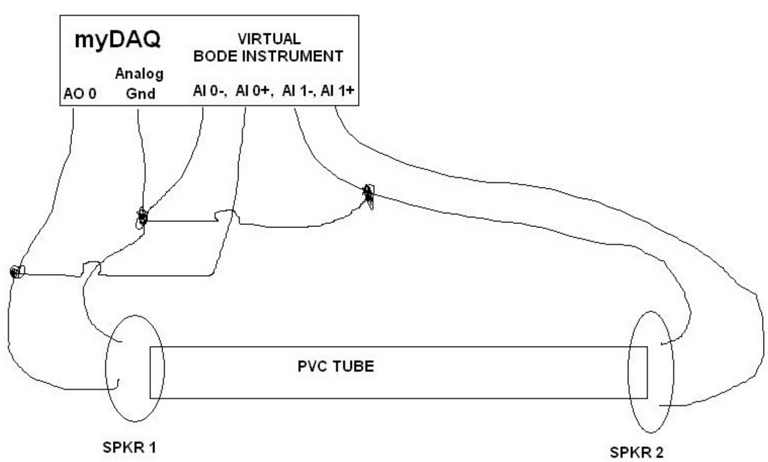


FIGURE 37. VIRTUAL BODE INSTRUMENT

Find the best frequencies for operation.

WORK SHEET HERE:	
Best Frequencies	Efficiency (V_{out})
1st Best f_1: ________	________
2nd Best f_2: ________	________
3rd Best f_3: ________	________

Now measure the narrow band transducer's response, not using the myDAQ, but rather the lab's digital signal generator and Keysight scope. We do this because the ultra-sonic transducer operates above the frequency the myDAQ Bode instrument can handle.

Peak Frequency ________________________

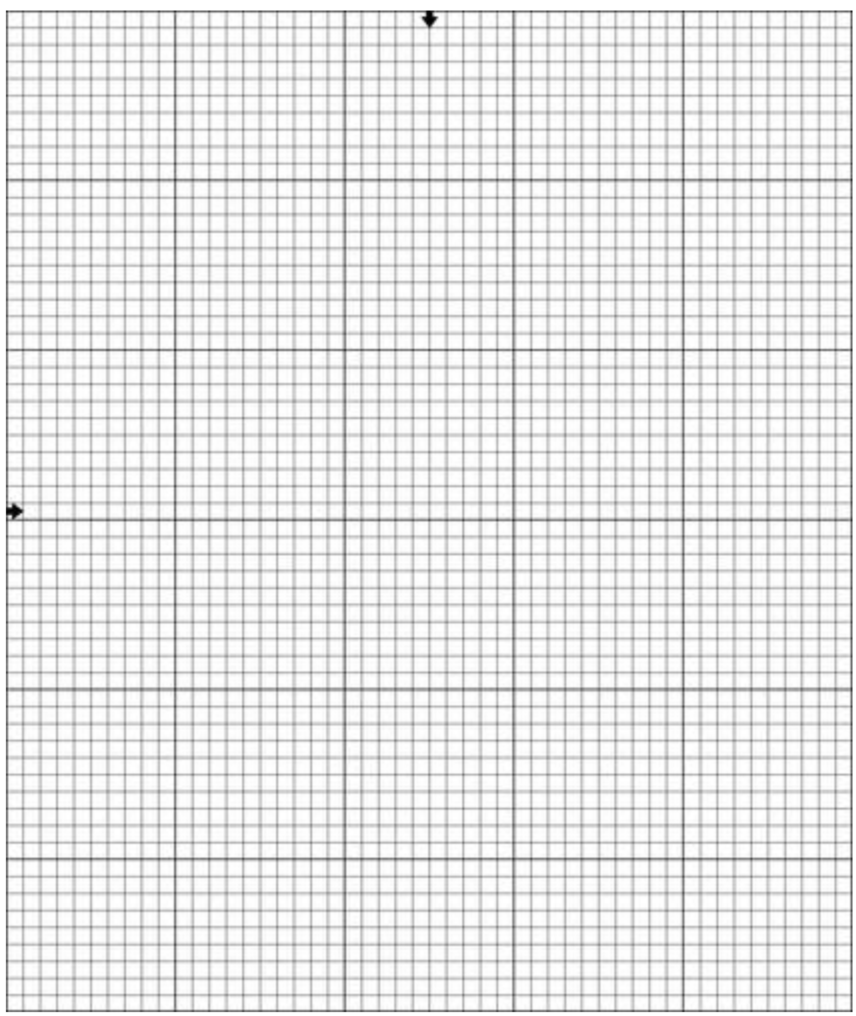
Band Width ________________________

NOTE: the peak response occurs at about 25 KHz.

Using the best frequency for the broadband speakers, measure the signal strength vs. waveguide length.

WORK SHEET HERE:	
Signal Level (Volts)	Pipe Length
______________________________	¼ Meter ________
______________________________	1/2 Meter ________
______________________________	1 Meter _________

Plot the signal vs. distance (length)



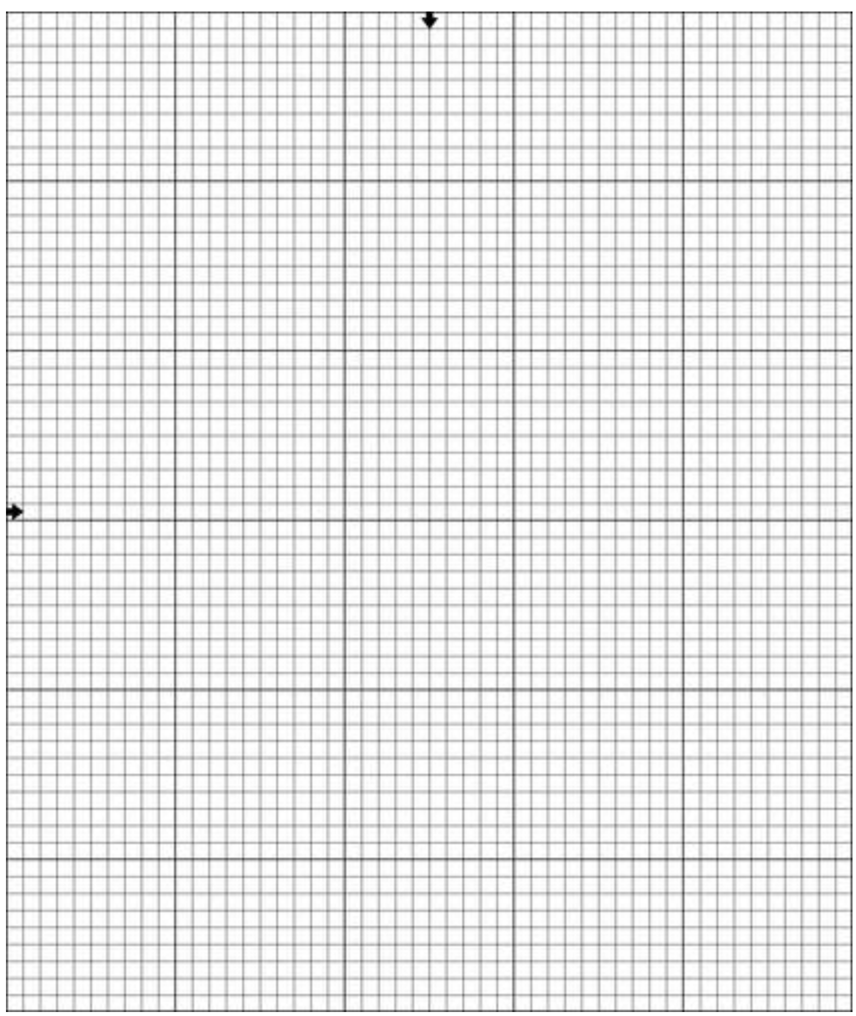
Using the ultrasonic (narrow band) transducer, measure the loss vs. distance (operate at the peak frequency).

Frequency: ___________

WORK SHEET HERE:

Signal Level (Volts)	Pipe Length
________________________________	¼ Meter ________
________________________________	1/2 Meter ________
________________________________	1 Meter ________

Plot the signal vs. distance.



Continuing to use the ultra-transducers, measure the effects of bending the pipe by inserting a 90º bend.

WORK SHEET HERE:	
Through a…	Signal Strength
45º Bend	________________
90º Bend	________________
2 - 45º Bends	________________

Measurement of the Speed of Sound

Connect one transducer with a short pipe (1/4 meter). Put it into one end of the "slip" coupling. Connect the second transducer to the special slip pipe. By sliding the pipe, therefore increasing the length, you will see the phase change. If you measure the distance required to change the phase by 2π, a full wavelength, you will be able to calculate the speed of sound.

Frequency: ___________________

Wavelength: ___________________

Calculate the speed of sound: _________________

The accepted value at sea level is approximately 1100 ft/sec with some dependence on temperature, air pressure, and humidity.

Next week (6), we will measure:

- Open air transmission vs. distance
- Reflection from an object
- Time delay by reflection (sonar ranging)
- Use of a corner cube for reflection
- Resonators
- And ???

Opto-Electronic Projects (Part 2)

In these experiments we will investigate the use of a photo-source (LED) and a photo detector (photoconductor, photodiode, and phototransistor) as a position detector or as a communications link.

As the transmitting half of a position detector system, the LED is excited by the circuit below:

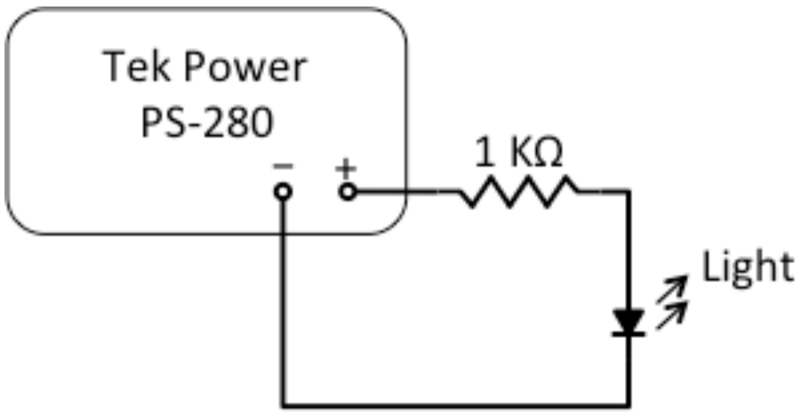


FIGURE 38. LED DRIVER CIRCUIT

For communication, the LED is energized as in the circuit below:

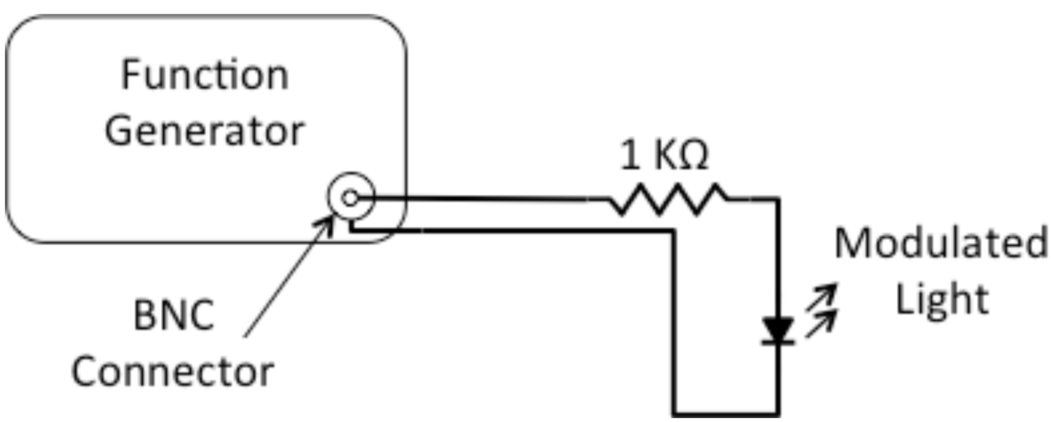


FIGURE 39. LED A/C DRIVER CIRCUIT

The LED output is detected by the circuit below:

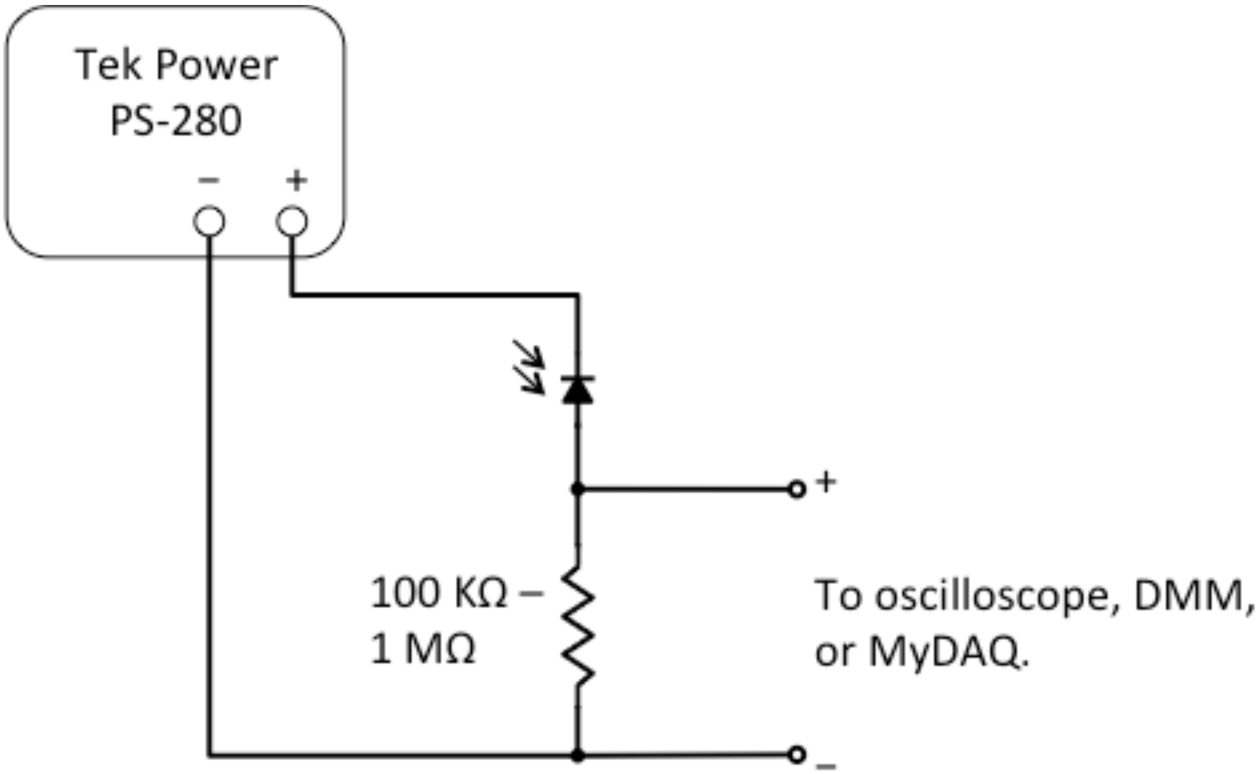


FIGURE 40. PHOTODETECTOR CIRCUIT

The figure below shows a typical experimental setup. Note the polarity of the photoconductor is not important, however, the photodiode should be reverse biased, i.e. cathode to + and the phototransistor collector to + volts.

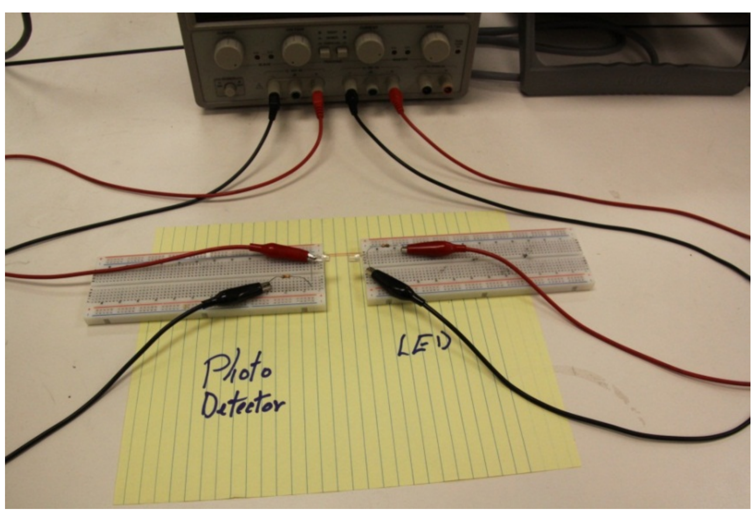


FIGURE 41. LED TRANSMITTER AND PHOTO DIODE RECEIVER

Three different detector devices are available:

1. Photoconductor – the simplest of the devices, but slow in its results;
2. Photodiode – fast and reasonably sensitive;
3. Phototransistor – medium speed but very sensitive.

Experiment

Connect the LED to the power supply and using a 1K ohm resistor, set the voltage to 10 volts. Using the photodiode, connect it as your detector using the following circuit as shown:

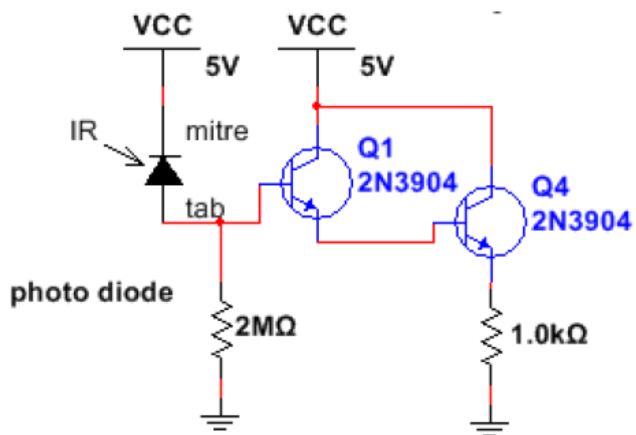


FIGURE 42. OPTICAL POSITION DETECTOR

Note: the LED (not shown in Fig 42) is bent to point towards the photodiode. You can change the sensitivity by changing the resistor values. Measure the voltage across the 1K ohm resistor with a DMM. Place an obstacle between the LED and the photodiode and measure the voltage again. Note the results on the worksheet.

WORK SHEET HERE: Resistor size = ________________
Voltage with NO obstacle: ______________________
Voltage with obstacle: ______________________

Such a change could be used to note the presence of an obstruction. This is, in fact, what is used to stop garage doors from closing when something is in the way or supermarket checkout stand conveyor belts. Replace the photoconductor with a photodiode or phototransistor and repeat your measurements. NOTE: it may be necessary to replace the 10

K ohm resistor with a 1 K ohm resistor due to the increased sensitivity of these photo devices.

WORK SHEET HERE: Resistor size = _______________
Voltage with NO obstacle: _______________________
Voltage with obstacle: _______________________

To demonstrate communications applications, we shall connect the LED to a function generator and our detector circuit using a photodiode connected to the oscilloscope. See the following figure.

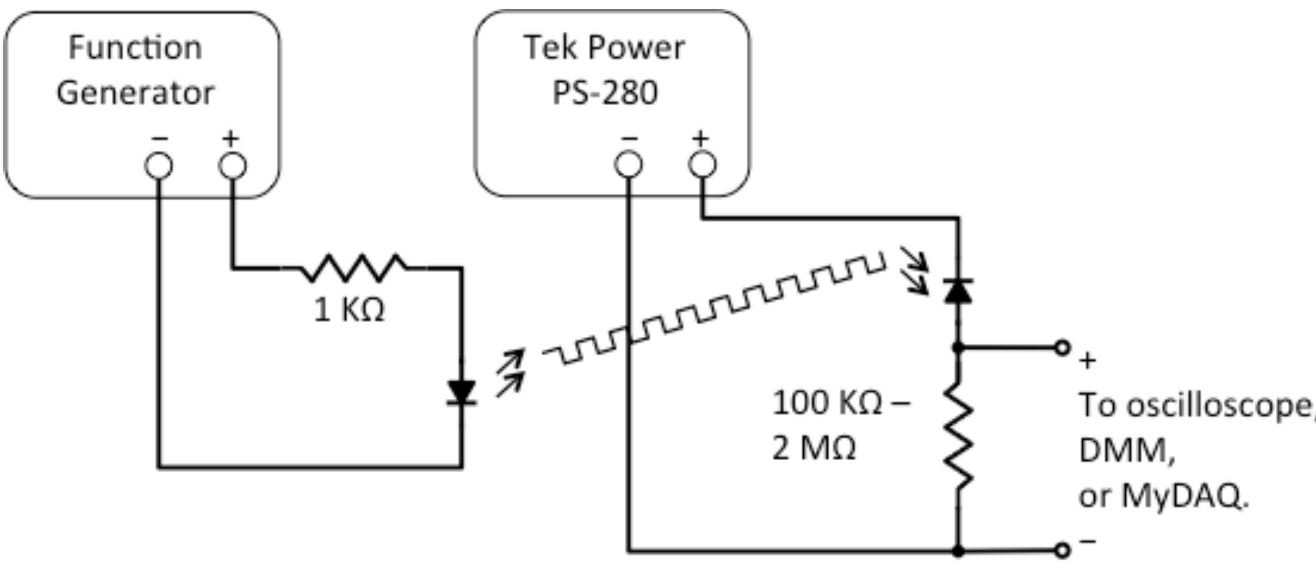
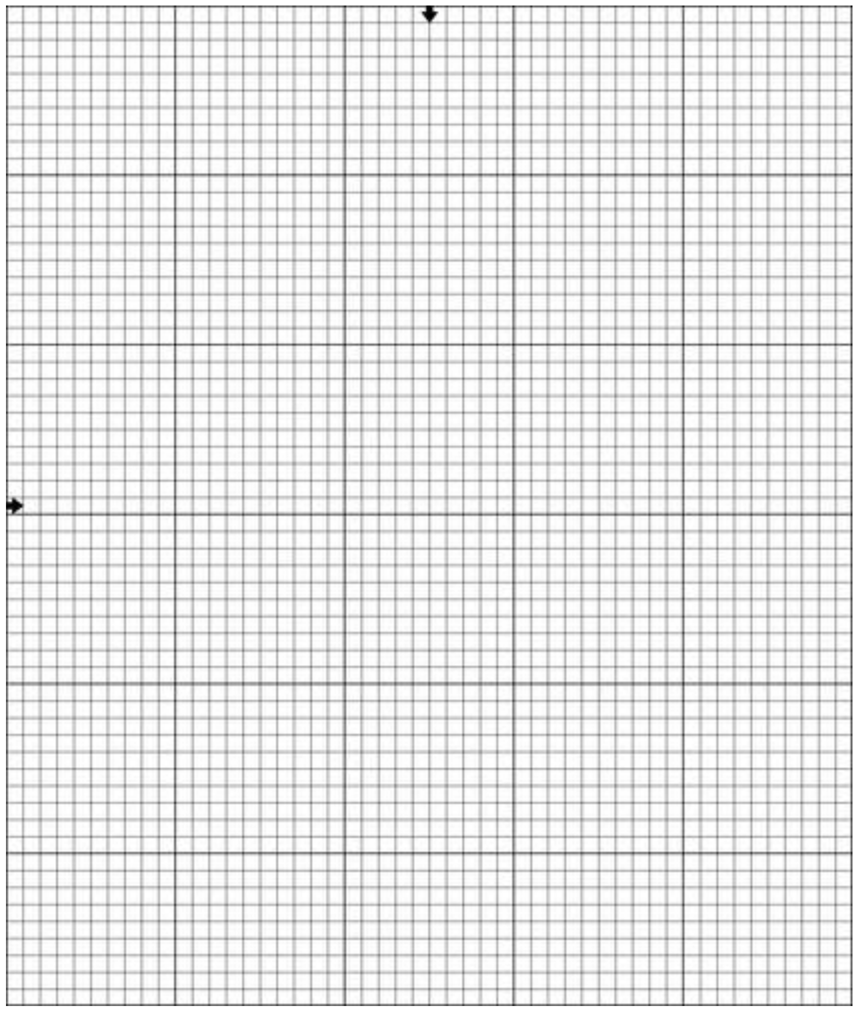


FIGURE 43. OPTICAL DATA LINK CIRCUIT

Connect channel 1 of the scope to the detector circuit. Connect channel 2 to the function generator output. Set the frequency of the function generator to 1 KHz and the amplitude to about 10 volts. Make sure that the scope is set to sync on channel 2. The function generator should be set to square waves. The receiver (detector) should be biased to 10 volts and the load resistor value should be 1K ohms.

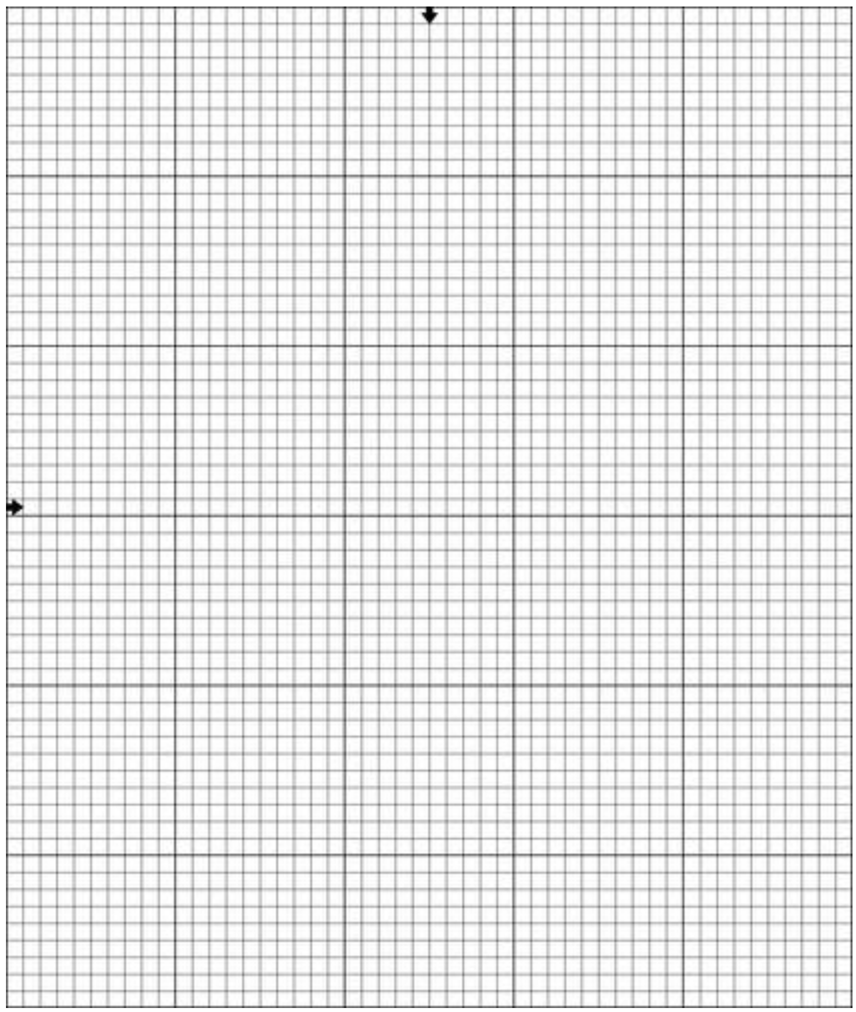
Your detector output, channel 1, should be a square wave. Draw the output, noting the timescale and amplitude.



What happens when you gradually reduce the function generator voltage?

Why does the signal suddenly go away?

Change the function generator output to sine waves. With the function generator set to 10 volts amplitude, draw your output waveform. Be sure to note amplitude and time.



Now use the offset adjustment of the function generator. Move it both positively and negatively. Note your results:

Can you explain what happened?

You will be provided with a NPN Darlington transistor which can be used in conjunction with your photo devices to control large loads. Your photo detectors can control small values of current, i.e. micro-amperes of current to a few milliamperes. Your transistor will amplify these currents by a factor of 1000. Assuming the emitter of the transistor is grounded and a current I_B flows in to the base of the transistor, then if the collector is biased, has a voltage positive with respect to ground, then a collector current 1000 times larger will flow. This will allow your photo device to control a large device such as the motor.

See data sheets in Appendix D “Darlington Transistor”.

Acoustic Devices Projects (Part 2)

We shall measure the free space transmission of the ultrasonic devices. You may conduct experiments as outlined below, or make use of the plastic parabolic reflectors. Connect the scope channel 2 to the sine output of the function generator. Connect the signal out to the narrow band transducer. The second transducer, receiver, should be connected to channel 1. Each transducer is connected to a short piece of pipe as shown below:

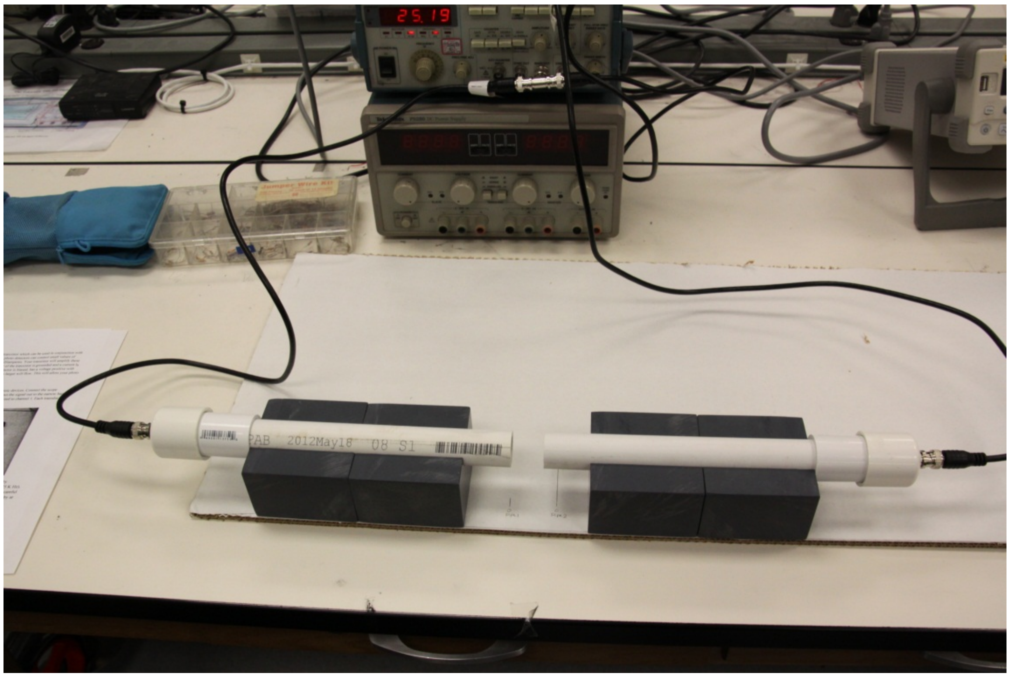


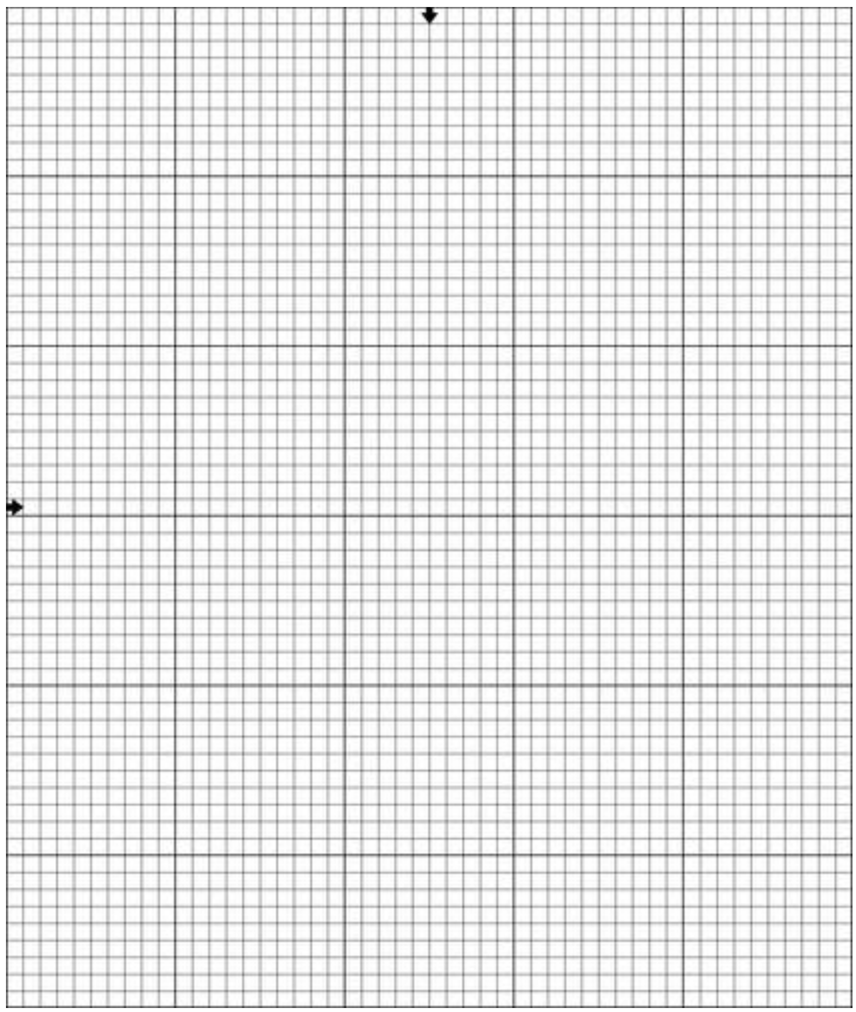
FIGURE 44. TWO HIGH FREQUENCY ACOUSTIC DEVICES

To start, the pipe ends should be together. Measure the peak response of your system by adjusting the frequency device to the peak response of the transducers (approximately 25 K Hz). Measure the detector response as a function of distance between the ends of the pipe [be careful to keep the ends aligned]. Be sure to move the pipe spacing sufficient to reduce the signal by at least a factor of 5. NOTE: Acoustic reflections from the table top may interfere with the accuracy of you measurements. This can be avoided by putting cloth down underneath the experiment, i.e. a jacket or sweater will do a good job.

WORK SHEET HERE:

Distance (inches)	Signal (volts – peak to peak)
0”	
1”	
2”	
3”	
4”	
5”	
6”	
7”	
8”	
9”	
10”	

Plot your results below:



How does the intensity change with distance, i.e. r^n ?

Measure the angular pattern of your transducer by placing the two pipe ends about 5” apart. Starting with the ends aligned, measure the output as a function of lateral displacement. See the figure below.

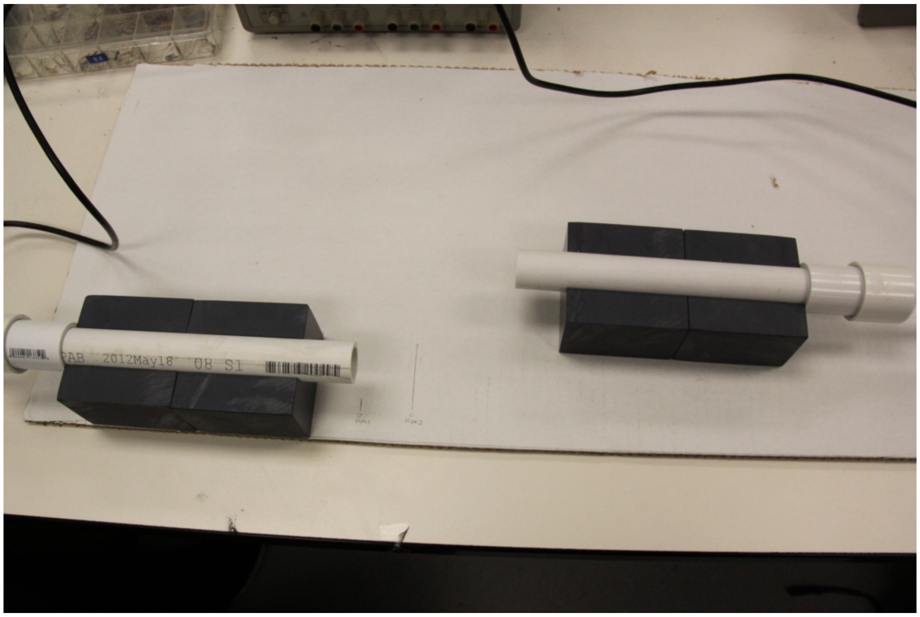
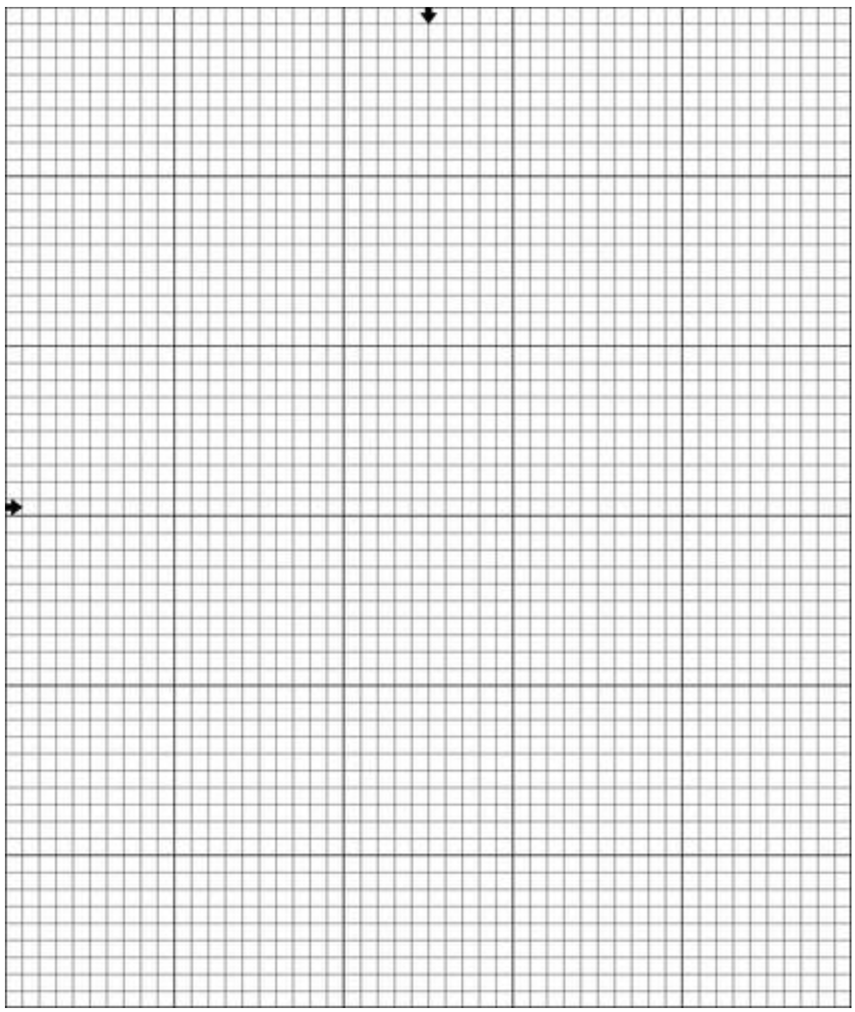


FIGURE 45. TWO ACOUSTIC DEVICES SHOWING LATERAL DISPLACEMENT

WORK SHEET HERE:

Displacement (inches)	Signal (volts – peak to peak)
0”	
1”	
2”	
3”	
4”	

Plot your results:



How does it vary with lateral displacement? Describe the shape of the curve.

Resonators

Place a pair of washers on either side of a spacer, 38 or 76 mm, in a slip tube. Make sure the washers are vertical. This forms an acoustic filter, only allowing sound waves to pass, without great attenuation whose wavelengths are a multiple of the spacer length x 2. Confirm this by using a pair of wide band transducers and the Bode mode of your myDAQ as you did last week. See below:

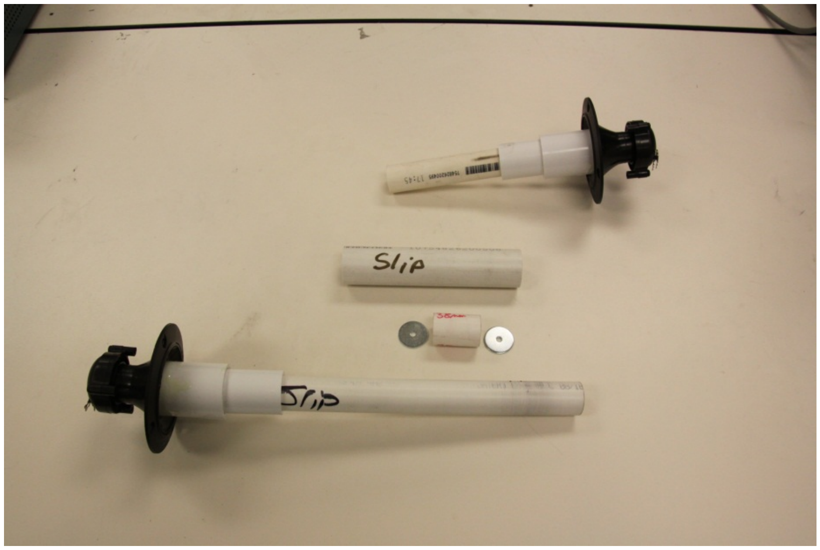


FIGURE 46. ACOUSTIC DEVICES AND PARTS FOR RESONATOR

Lastly, place your narrow band transducers side by side facing the same direction. Connect to the function generator and scope as before.

Stand in front of the devices and note the larger returned signal. Place a hard and flat surface to reflect the sound back. Note the effects of tilting the surface and the change in phase if the surface is moved in and away from the transducer.

Comment on possible uses of these effects:

ANSWER HERE:

Simple Motor-Drive Circuits

The figure below will drive the motor in one direction only. It is activated by light on the photo device (PD).

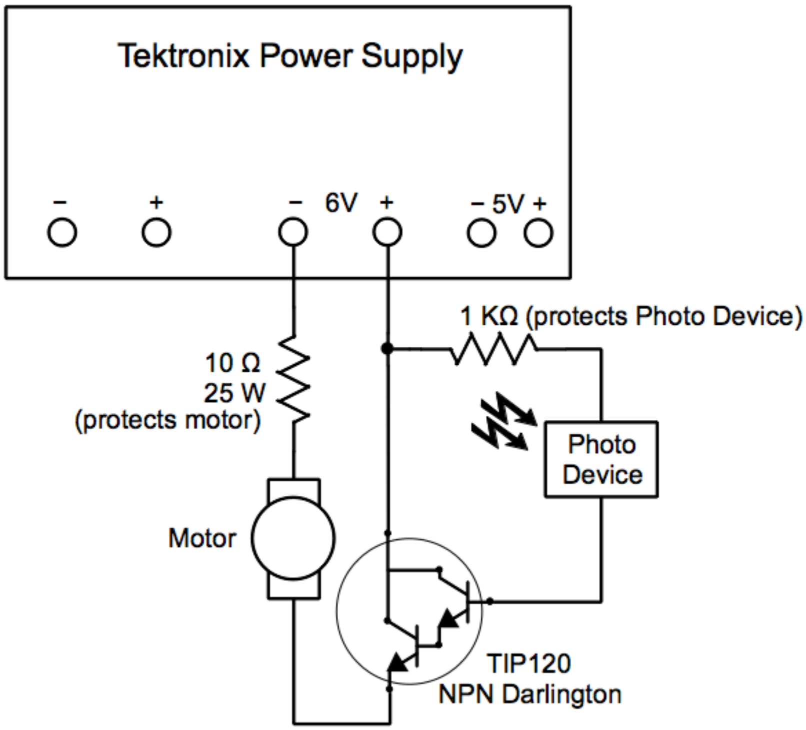


FIGURE 47. SIMPLE UNI-DIRECTIONAL DRIVE CIRCUIT

The photo conductor will work well and is almost unaffected by room lights. The photo transistor and photo diode must be reverse biased. In particular, the photo transistor is very sensitive to room light and must be shielded from the laboratory lights. The side-looking photo diode is encased in black plastic and is essentially blind to visible light and must be activated by infrared.

A simple bi-directional circuit is shown in the next figure. The easiest way to implement this circuit is to use two photo conductors as the photo devices. If you illuminate only one of the photo devices, the motor turns in one direction and will reverse when the other device is illuminated.

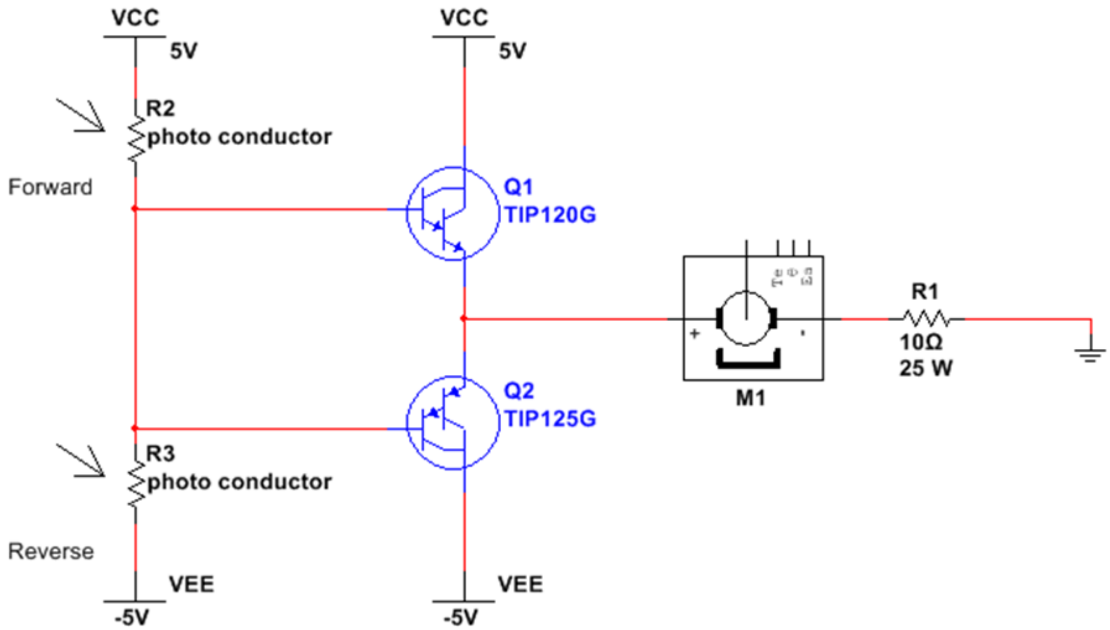


FIGURE 48. BI-DIRECTIONAL MOTOR DRIVE CIRCUIT

Week 10: Project Demonstration: Oral and Written Reports

On the last day of the laboratory, each student (or student group) will be required to deliver a project verbal and written report. The details of the reporting requirements will be given to you by the 5th week by the Teaching Assistant.

APPENDICES

APPENDIX A: Curve Tracer Instructions

The curve tracer can be used to display the current voltage characteristics of both two terminal (diodes) and three terminal devices (transistors both bipolar and field effect types).

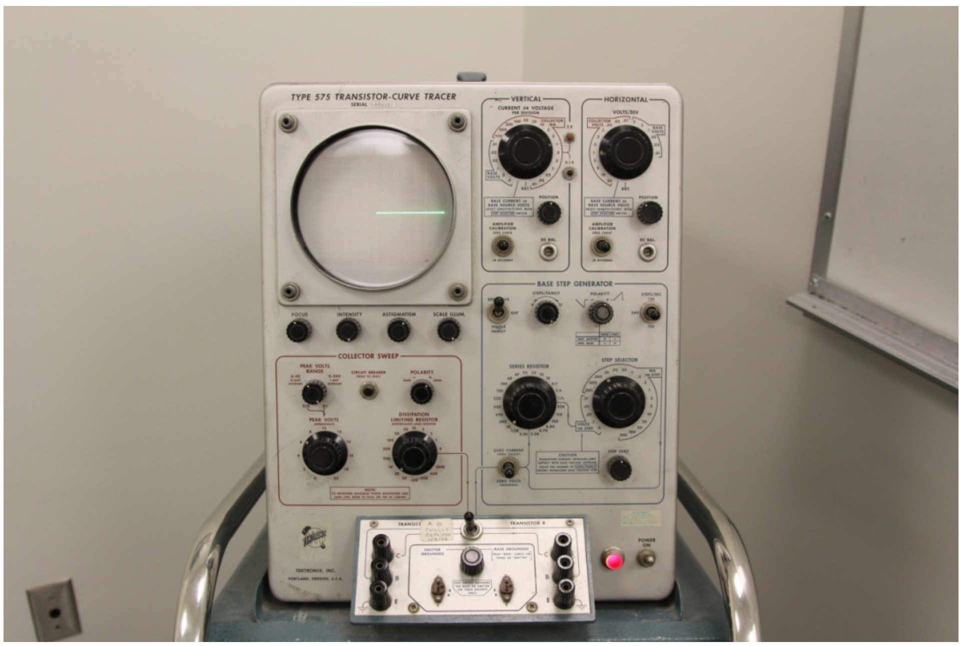


FIGURE A1. CURVE TRACER

Because the curve tracer applies a swept voltage to the device under test, it is capable of destroying the device by excess power dissipation. The operator must avoid this by use of a series power limiting resistor.

FIGURE A2. DISPLAY SHOWING
"DISSIPATION LIMITING RESISTOR" KNOB

In addition, please select the 0 – 20 volt range only. <u>Do Not operate in 0 – 200 V mode!</u> Serious shocks can occur if the 0 – 200 V range is used. DO NOT USE IT

It is good practice to reduce the voltage by setting the nob (Figure A2) to zero when either starting tests or changing polarity. The polarity selector labeled NPN (positive) or PNP (negative) applies either positive or negative voltage on the collector terminal with respect to the emitter terminal.

The resistor value is chosen to limit the power. For example, if 1K ohm is chosen, then no more than 20 milliamperes can flow and the maximum power dissipation possible in the device occurs if half of the voltage 20V/2 is across the device and half across the series limiting resistor. Therefore, 10 mA would flow and the power dissipation 10 mA x 10 V = 100 milliwatts.

Next, we need to set the display current and voltage range.

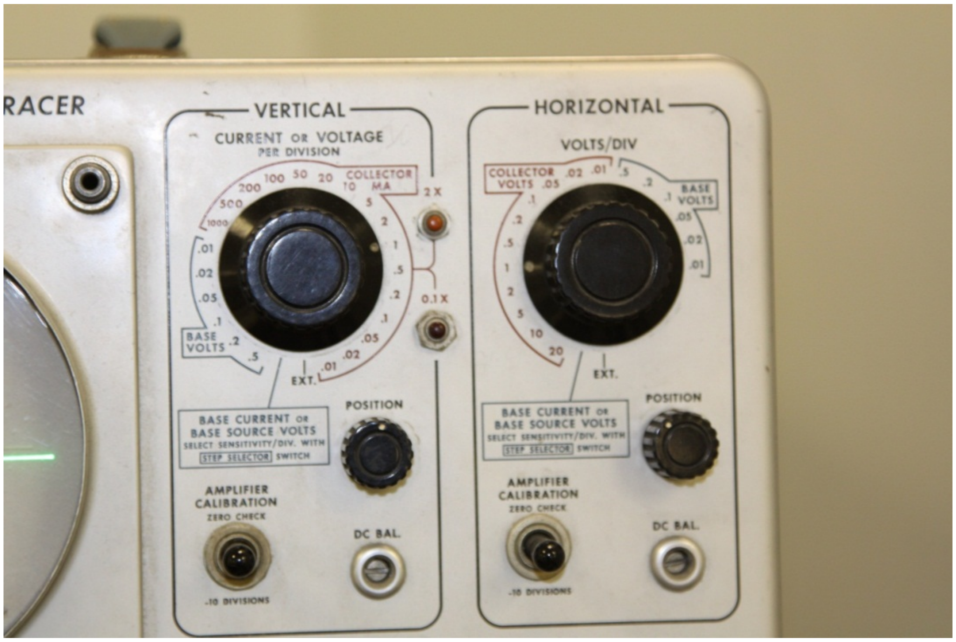


FIGURE A3. VERTICAL AND HORIZONTAL DISPLAY CONTROLS

We will give suggested starting values for each device in the lab experiment. The last step is to connect the device to be tested.

FIGURE A4. DEVICE CONNECTIONS

First, put the selection switch (A/B toggle) to the vertical un-connected position and make sure that "emitter grounded" is selected. We suggest that you connect the anode to the terminal marked “collector” and the cathode to the terminal marked “emitter”. At this time, double check your chosen values. Then move the selector (A/B toggle) to connect your device. Advance the voltage control. If you selected NPN (positive), you should see displayed the forward biased characteristic of your device. If you chose PNP (negative), then you will observe the reverse biased condition. There is nominally no current flowing in the reverse direction. Be careful not to cause reverse breakdown. Unless you increase the series resistor to at least 10 times that of the forward protection value, you will dissipate too much energy in the device.

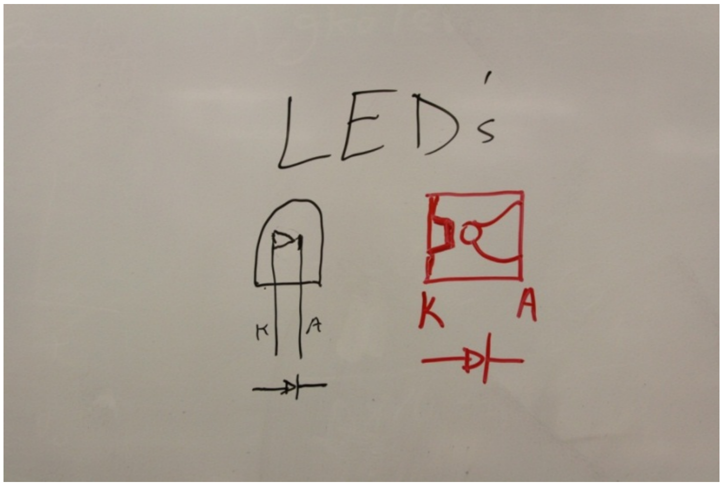


FIGURE A5. SUGGESTED SETTINGS
FOR HIGH BRIGHTNESS LEDS AND HIGH POWERED LEDS
LEFT: HIGH BRIGHTNESS LED RIGHT: HIGH POWERED LED

Curve Tracer settings for:

High brightness LEDs
- Series resistor (5 K ohms)
- Vertical sensitivity (1 milliampere/division)
- Horizontal sensitivity (1 V/division)

High powered square LEDs
- Series resistor (500 ohms)
- Vertical sensitivity (10 milliamperes/division)
- Horizontal sensitivity (1 V/division)

Solar cells (½V 400 milliampere single cell)
- Series resistor (100 ohms)
- Vertical sensitivity (50 milliampere/division)
- Horizontal sensitivity (0.1 V/division)

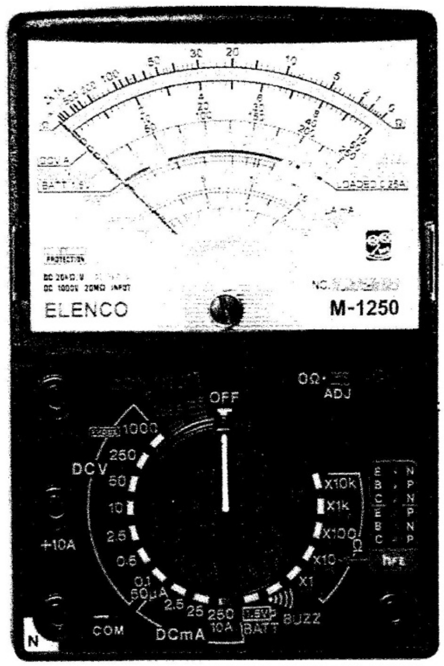
Photodiodes (detectors) i.e. small signal devices

- Series resistor (10 K ohms)
- Vertical sensitivity (0.2 milliamperes/division)
- Horizontal sensitivity (0.1 V/division)

APPENDIX B: Analog Multi-Meters

ANALOG MULTIMETER KIT

MODEL M-1250K



Assembly and Instruction Manual

Elenco® Electronics, Inc.

Buzzer Test

1. Set the range switch to the BUZZ position.
2. The buzzer will sound if there are 20Ω or less across the leads.

DCV (NULL) Test

1. Set the range switch to either the ± 5 or ±25 scale in the DCV (NULL) position.
2. Adjust the 0Ω ADJ pot for a zero center position
3. Plug the red test lead into the positive (+) socket and the black test lead into the –COM socket.
4. Connect voltage to the test leads and read the voltage.

Output Jack Test (allows measurement of AC voltage when superimposed on a DC voltage.)

1. Plug the red lead into the OUTPUT socket and the black lead into –COM.
2. Set the range switch to the appropriate ACV position. Touch the test leads to the power source and observe the reading. Then, multiply by the appropriate scale factor.

Diode Tests

The diode forward current I_f and reverse current I_r are read LI scale. To check a diode in the forward direction proceed as follows:

1) Plug the red test lead into the + socket and the black lead into the –COM socket.
2) Select the approximate forward current desired 150μA, 1.5mA, 15mA or 150mA and set the range switch to this position (blue markings in ohms range).
3) Short the test leads together and adjust the 0ΩADJ pot for a zero reading on the ohms (top) scale.
4) Connect the red test lead to the cathode (striped end) of the diode and the black test lead to the anode of the diode.
5) Read the forward current on the LI scale. The voltage drop across the diode is shown on the LV scale immediately below the LI scale.

THEORY OF OPERATION

Introduction

Your multimeter is of professional quality using 1% precision resistors throughout the design. The accuracy at full scale reading will be within 3% of full scale DC voltage or current (1,000V - 5%, 10A - 5%) and 4% of full scale (for 1,000V - 5%) AC voltage. The accuracy of the ohms measurement is 3% of arc.

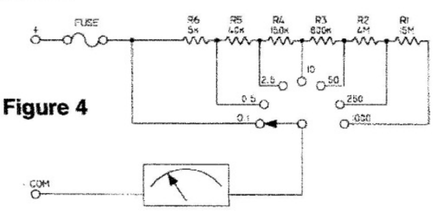
On the DC volts range, the loading impedance of the meter is 20,000 ohms per volt. This means that if the range switch is on the 250V position, the loading to the circuit under test will be 20,000 x 250 = 5MΩ.

The input loading of the meter is a very important factor to be considered when measuring the voltage of a high resistance circuit. Take the example where two 1MΩ resistors are connected in series across a 9V battery. The voltage at the junction of the resistors will be 4.5V. When measured on the 10V scale, the input loading will be about 200kΩ (20,000 ohms/volt times 10V). The voltage at the junction will therefore drop to 1.28V and the meter will read this voltage. If the meter is switched to the 50V position, the loading will be 1MΩ and the meter will read 3V. For reasonably accurate measurement, the circuit under test should have an impedance of less than 100kΩ or you should use the higher ranges. The loading on the 250V and 1,000V ranges will be 5MΩ and 20MΩ respectively, but it will be hard to read 4.5V on these ranges.

DC Voltage Measurement

Figure 4 shows a simplified diagram of the DC voltage measuring circuit. Here resistors are switched in series with the meter to provide the desired ranges.

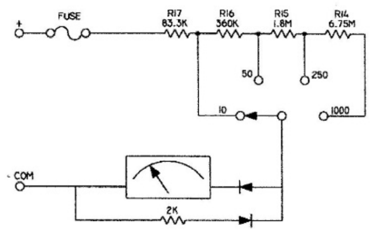
Figure 4



AC Voltage Measurement

Figure 5 shows a simplified diagram of the AC voltage measuring circuit. Two diodes are added to the series resistors to rectify the AC voltage. The input impedance on the AC voltage ranges is 9kΩ per volt. On the 250VAC range, the input impedance is therefore 2MΩ.

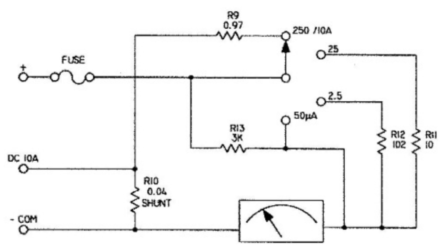
Figure 5



DC Current Measurement

Figure 6 shows a simplified diagram of the DC current measuring circuit. Here the resistors are placed across the meter to shunt the current. On the 50µA range, the current is fed directly to the meter and the voltage drop across the meter at full scale deflection is .1 volt. On all of the other ranges, the full scale voltage drop across the meter is .25 volts. A .5 amp fuse is added to the circuit for protection against overload.

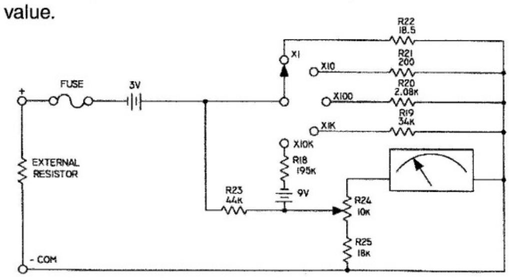
Figure 6



Resistance Measurement

Figure 7 shows a simplified diagram of the resistance measuring circuit. Here a known 1% resistor, in parallel with the meter and the zero adjust resistors, is compared to the external resistor in a series circuit. The current is supplied by the 3V battery on the X1, X10 and X1k ranges. On the X10k range, a 9V battery is placed in series with the 3V battery to supply more current to the series circuit. To calibrate the ohms circuit, the external resistor is made zero ohms by shorting the test leads together. This places the full battery voltage across the internal resistors. The current in the meter is adjusted to full scale deflection, or zero reading on the dial. When an external resistor is made equal to the internal resistance, the meter will deflect to half scale and the dial marking will show its value.

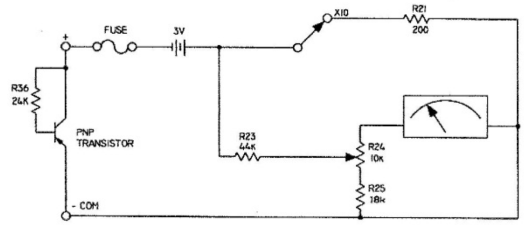
Figure 7



hFE Measurement

Figure 8 shows a simplified diagram of the hFE measuring circuit for PNP transistor. Here the range switch is in the X10 ohms position and the transistor circuit takes the place of the external resistor in the ohms measurement. The higher the hFE of the transistor, the more current flows in the external circuit and the lower the effective resistance. The meter reads this resistance and the hFE of the transistor may be read on the hFE scale.

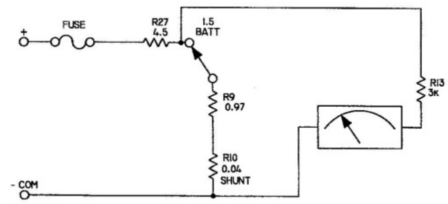
Figure 8



Battery Test

Figure 9 shows a simplified diagram of the battery measuring circuit. The battery voltage is measured under a 0.25A load.

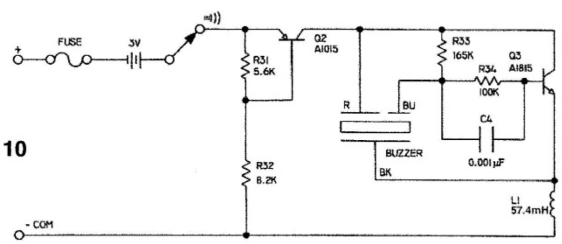
Figure 9



Buzzer Test

Figure 10 shows a simplified diagram of the audio continuity circuit. When a 20Ω load or less is place across the terminals, transistor Q3 conducts and allows Q3 to oscillate.

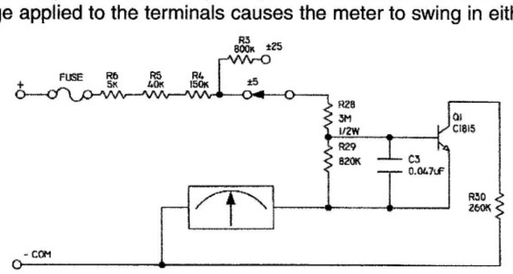
Figure 10



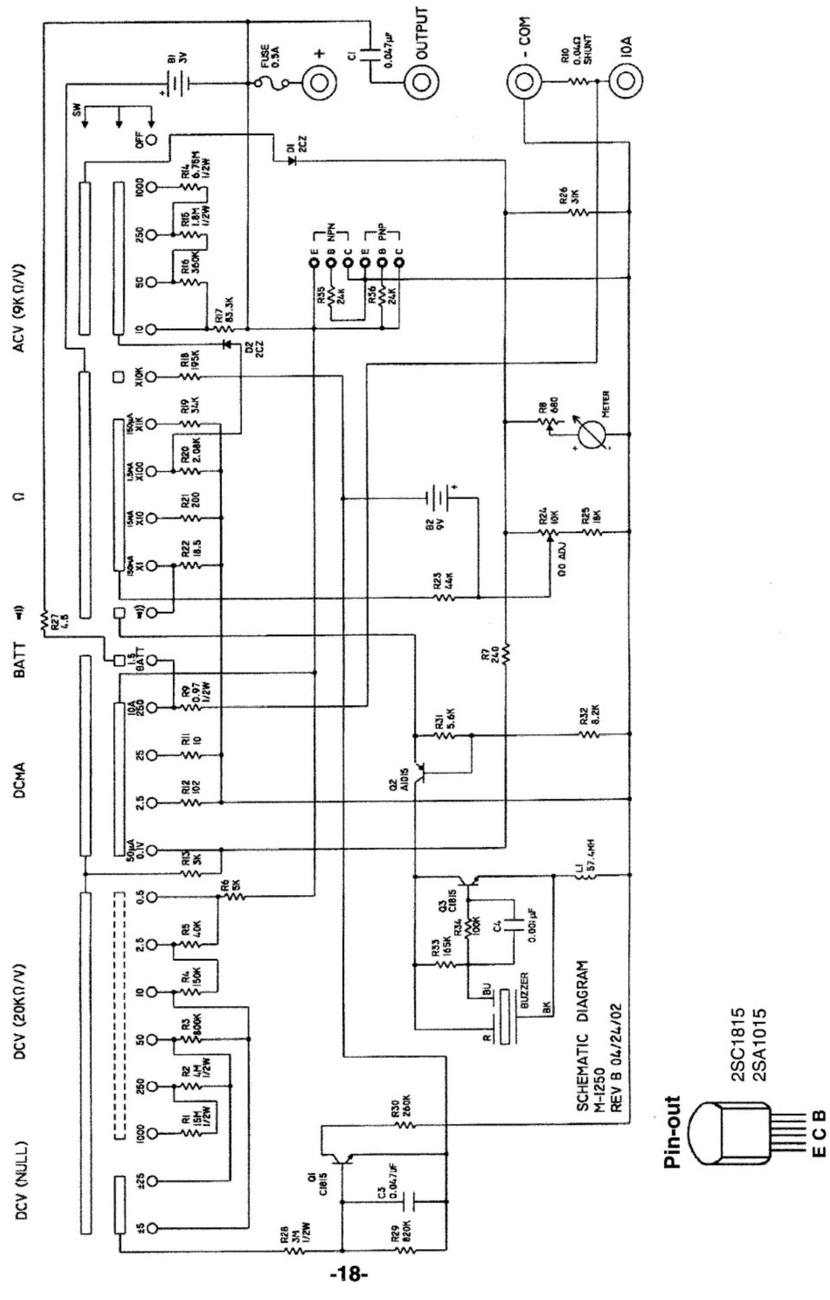
DC NULL Test

Figure 11 shows a simplified diagram of the DCV (NULL) circuit. The meter is set to 0 on the DCV (NULL) scale. Positive or negative voltage applied to the terminals causes the meter to swing in either direction.

Figure 11



SCHEMATIC DIAGRAM M-1250K



DSR-85

ELENCO® DIAL SCALE READING EXERCISE

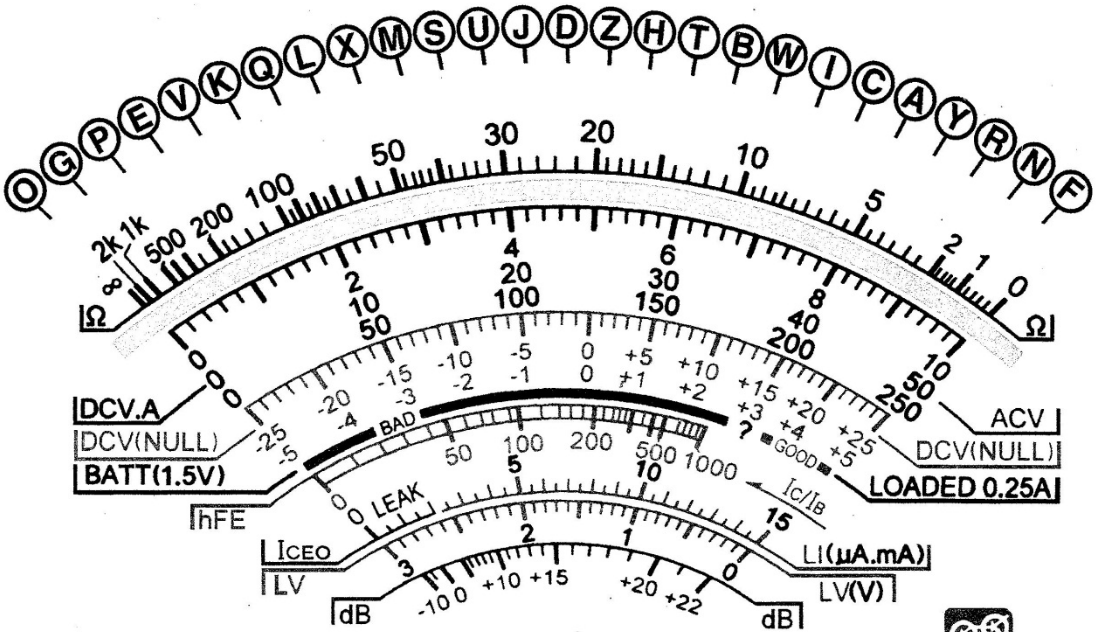


Figure A

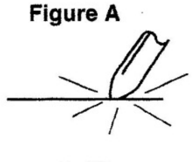


Figure B

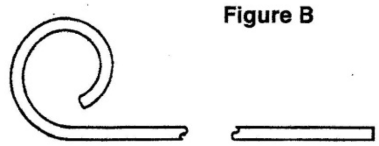
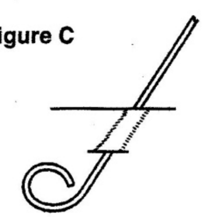


Figure C



Assembly Procedure

- ☐ Cut the paper along the two dotted lines under the scale with a knife or a razor blade as shown in Figure A.
- ☐ Make a loop at one end of the wire by wrapping it around the end of your small finger as shown in Figure B.
- ☐ Insert the wire through the two slots as shown in Figure C.

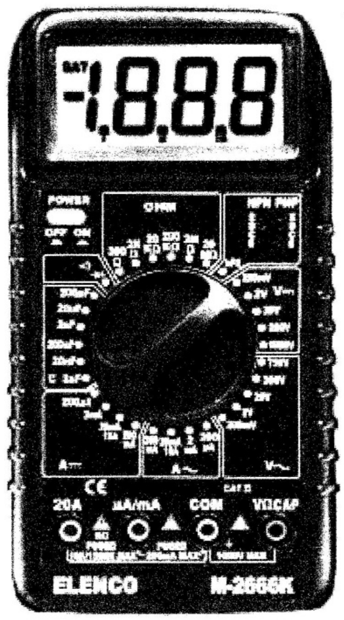
APPENDIX C: Digital Multi-Meters

DIGITAL MULTIMETER KIT

MODEL M-2666K

WIDE RANGE DIGITAL MULTIMETER WITH CAPACITANCE AND TRANSISTOR TESTING FEATURES

7 56619 00300 9



Assembly and Instruction Manual

Elenco™ Electronics, Inc.

INTRODUCTION

Assembly of your M-2666 Digital Multimeter Kit will prove to be an exciting project and give much satisfaction and personal achievement. If you have experience in soldering and wiring technique, you should have no problems. For the beginner, care must be given to identifying the proper components and in good soldering habits. Above all, take your time and follow the easy step-by-step instructions. Remember, "An ounce of prevention is worth a pound of cure".

The meter kit has been divided into a number of sections to make the assembly easy and avoid major problems with the meter operation.

Section A - Meter display circuit assembly.

Section B - DC voltage and current circuit assembly.

Section C - AC voltage and current circuit assembly.

Section D - Resistance & buzzer circuit assembly.

Section E - Capacitance and transistor testing circuit assembly.

Section F - Final assembly.

THEORY OF OPERATION

A block diagram of the M-2666K is shown in Figure 1. Operation centers around a custom LSI chip. This IC contains a dual slope A/D converter, display, latches, decoder and the display driver. A block diagram of the IC functions is shown in Figure 6. The input voltage, current or ohm signals are conditioned by the function and selector switches to produce and output DC voltage between 0 and +199mV. If the input signal is 100VDC, it is reduced to 100mV DC by selecting a 1000:1 divider. Should the input be 100VAC, then after the divider it is processed by the AC converter to produce 100mVDC. If current is to be read, it is converted to a DC voltage via internal shunt resistors. For resistance measurements, an internal voltage source supplies the necessary 0-199mV voltage to be fed to the IC input.

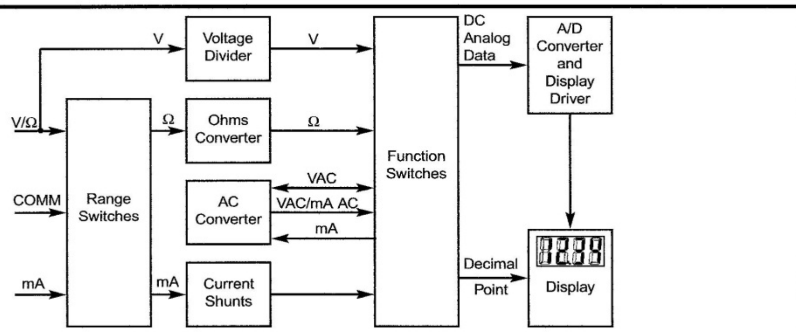


Figure 1 Simplified Block Diagram

The input of the 7106 IC is fed to an A/D (analog to digital) converter. Here the DC voltage amplitude is changed into a digital format. The resulting signals are processed in the decoders to light the appropriate LCD segment.

Timing for the overall operation of the A/D converter is derived from an external oscillator whose frequency is selected to be 40kHz. In the IC, this frequency is divided by four before it clocks the decade counters. It is further divided to form the three convert-cycle phases. The final readout is clocked at about three readings per second.

Digitized measurements data is presented to the display as four decoded digits (seven segments) plus polarity. Decimal point position on the display is determined by the selector switch setting.

VOLTAGE MEASUREMENT

Figure 3 shows a simplified diagram of the voltage measurement function.

The input divider resistors add up 10MΩ with each step being a division of 10. The divider output should be within –0.199 to +0.199V or the overload indicator will function. If the AC function is selected, the divider output is AC coupled to a full wave rectifier and the DC output is calibrated to equal the rms level of the AC input.

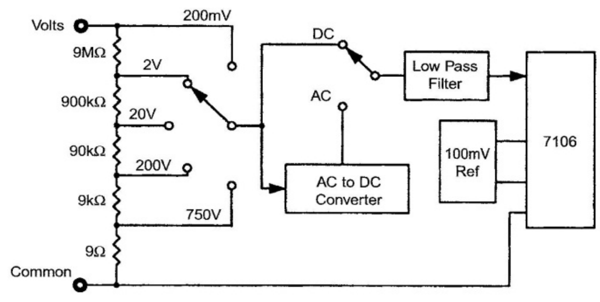


Figure 3 Simplified Voltage Measurement Diagram

CURRENT MEASUREMENT

Figure 4 shows a simplified diagram of the current measurement positions.

Internal shunt resistors convert the current to between –0.199 to +0.199V which is then processed in the 7106 IC to light the appropriate LCD segments. If the current is AC in nature, the AC converter changes it to the equivalent DC value.

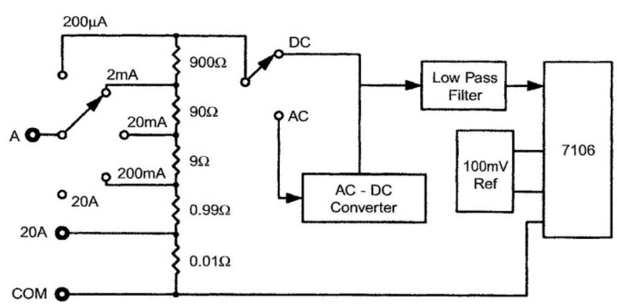


Figure 4 Simplified Current Measurement Diagram

A/D CONVERTER

A simplified circuit diagram of the analog portion of the A/D converter is shown in Figure 2. Each of the switches shown represent analog gates which are operated by the digital section of the A/D converter. Basic timing for switch operation is keyed by an external oscillator. The conversion process is continuously repeated. A complete cycle is shown in Figure 2.

Any given measurement cycle performed by the A/D converter can be divided into three consecutive time periods: autozero (AZ), integrate (INTEG) and read. Both autozero and integrate are fixed time periods. A counter determines the length of both time periods by providing an overflow at the end of every 1,000 clock pulses. The read period is a variable time, which is proportional to the unknown input voltage. The value of the voltage is determined by counting the number of clock pulses that occur during the read period.

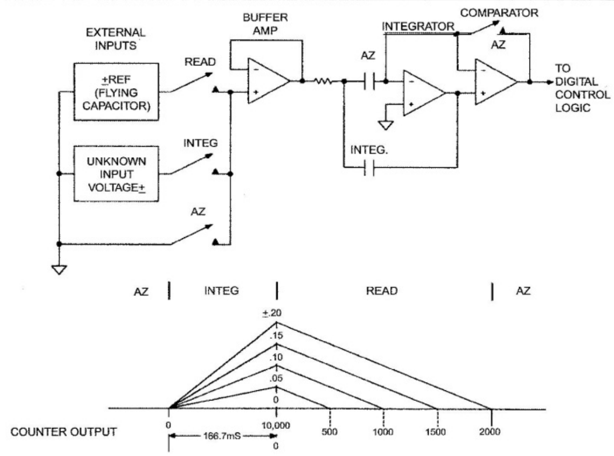


Figure 2 Dual Slope A/D Converter

During autozero, a ground reference is applied as an input to the A/D converter. Under ideal conditions the output of the comparator would also go to zero. However, input-offset-voltage errors accumulate in the amplifier loop, and appear at the comparator output as an error voltage. This error is impressed across the AZ capacitor where it is stored for the remainder of the measurement cycle. The stored level is used to provide offset voltage correction during the integrate and read periods.

The integrate period begins at the end of the autozero period. As the period begins, the AZ switch opens and the INTEG switch closes. This applies the unknown input voltage to the input of the A/D converter. The voltage is buffered and passed on to the input of the A/D converter. The voltage is buffered and passed on to the integrator to determine the charge rate (slope) on the INTEG capacitor. At the end of the fixed integrate period, the capacitor is charged to a level proportional to the unknown input voltage. This voltage is translated to a digital indication by discharging the capacitor at a fixed rate during the read period, and counting the number of clock pulses that occur before it returns to the original autozero level.

As the read period begins, the INTEG switch opens and the read switch closes. This applies a known reference voltage to the input of the A/D converter. The polarity of this voltage is automatically selected to be opposite that of unknown input voltage, thus causing the INTEG capacitor to discharge as fixed rate (slope). When the charge is equal to the initial starting point (autozero level), the read period is ended. Since the discharge slope is fixed during the read period, the time required is proportional to the unknown input voltage.

The autozero period and thus a new measurement cycle begins at the end of the read period. At the same time, the counter is released for operation by transferring its contents (previous measurement value) to a series of latches. This stored stat is then decoded and buffered before being used for driving the LCD display.

RESISTANCE MEASUREMENTS

Figure 5 shows a simplified diagram of the resistance measurement function.

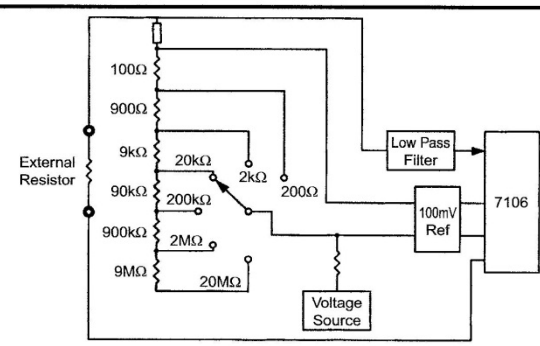


Figure 5 Simplified Resistance Measurement Diagram

A simple series circuit is formed by the voltage source, a reference resistor from the voltage divider (selected by range switches), and the external unknown resistor. The ratio of the two resistors is equal to the ratio of their respective voltage drops. Therefore, since the value of one resistor is known, the value of the second can be determined by using the voltage drop across the known resistor as a reference. This determination is made directly by the A/D converter.

Overall operation of the A/D converter during a resistance measurement is basically as described earlier in this section, with one exception. The reference voltage present during a voltage measurement is replaced by the voltage drop across the reference resistor. This allows the voltage across the unknown resistor to be read during the read period. As before, the length of the read period is a direct indication of the value of the unknown.

h_{FE} MEASUREMENT

Figure 6 shows a simplified diagram of the h_{FE} measurement function. Internal circuits in the 7106 IC maintain the COMMON line at 2.8 volts below V+. When a PNP transistor is plugged into the transistor socket, base to emitter current flows through resistor R49. The voltage drop in resistor R49 due to the collector current is fed to the 7106 and indicates the h_{FE} of the transistor. For an NPN transistor, the emitter current through R50 indicates the h_{FE} of the transistor.

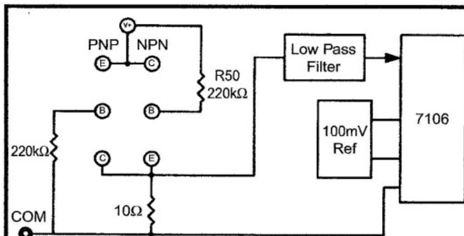


Figure 6

CAPACITANCE MEASUREMENT

The capacitor circuit consists of four op-amps. IC3 D& A form an oscillator, which is applied to the test-capacitor through the test leads. The capacitor couples the oscillator to pin 6 of IC3B. The amount of voltage developed at pin 6 is indicative of the capacitors ESR value. IC3B and C amplify the signal which is seen at pin 8. The AC signal is then converted to a DC voltage and displayed on the meter.

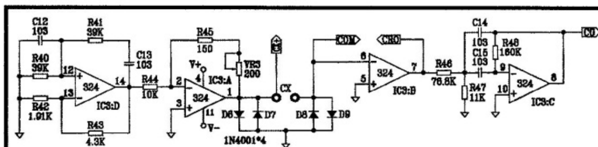


Figure 7

APPENDIX D: Darlington Transistor

TIP120, TIP121, TIP122
TIP125, TIP126, TIP127

Complementary power Darlington transistors

Features

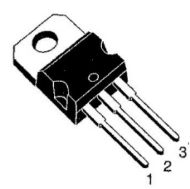
- Low collector-emitter saturation voltage
- Complementary NPN - PNP transistors

Applications

- General purpose linear and switching

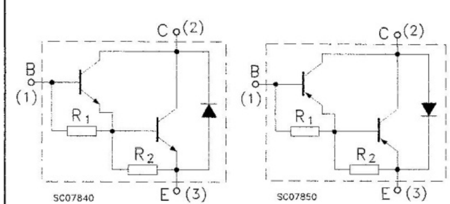
Description

The devices are manufactured in planar technology with "base island" layout and monolithic Darlington configuration. The resulting transistors show exceptional high gain performance coupled with very low saturation voltage.



TO-220

Figure 1. Internal schematic diagrams



NPN: R_1= 7 KΩ
R_2= 70 Ω

PNP: R_1= 16 KΩ
R_2= 60 Ω

Table 1. Device summary

Order codes	Marking	Package	Packaging
TIP120	TIP120	TO-220	Tube
TIP121	TIP121		
TIP122	TIP122		
TIP125	TIP125		
TIP126	TIP126		
TIP127	TIP127		

1 Electrical ratings

Table 2. Absolute maximum rating(1)

Symbol	Parameter		Value			Unit
		NPN	TIP120	TIP121	TIP122	
		PNP	TIP125	TIP126	TIP127	
V_{CBO}	Collector-base voltage ($I_E = 0$)		60	80	100	V
V_{CEO}	Collector-emitter voltage ($I_B = 0$)		60	80	100	V
V_{EBO}	Emitter-base voltage ($I_C = 0$)		5			V
I_C	Collector current		5			A
I_{CM}	Collector peak current		8			A
I_B	Base current		0.12			A
P_{TOT}	Total dissipation at $T_c \leq 25$ °C $T_{amb} \leq 25$ °C		65 2			W
T_{stg}	Storage temperature		-65 to 150			°C
T_J	Max. operating junction temperature		150			°C

1. For PNP types voltage and current values are negative.

Table 3. Thermal data

Symbol	Parameter	Value	Unit
$R_{thj\text{-}case}$	Thermal resistance junction-case max.	1.92	°C/W
$R_{thj\text{-}amb}$	Thermal resistance junction-ambient max.	62.5	°C/W

2 Electrical characteristics

(T_{case} = 25 °C; unless otherwise specified)

Table 4. Electrical characteristics[1]

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
I_{CEO}	Collector cut-off current (I_B = 0)	for TIP120/125 V_{CE} = 30 V for TIP121/126 V_{CE} = 40 V for TIP122/127 V_{CE} = 50 V			0.5 0.5 0.5	mA mA mA
I_{CBO}	Collector cut-off current (I_B = 0)	for TIP120/125 V_{CE} = 60 V for TIP121/126 V_{CE} = 80 V for TIP122/127 V_{CE} = 100 V			0.2 0.2 0.2	mA mA mA
I_{EBO}	Emitter cut-off current (I_C = 0)	V_{EB} = 5 V			2	mA
$V_{CEO(sus)}$[2]	Collector-emitter sustaining voltage (I_B = 0)	I_C = 30 mA for TIP120/125 for TIP121/126 for TIP122/127	 60 80 100			 V V V
$V_{CE(sat)}$[2]	Collector-emitter saturation voltage	I_C = 3 A I_B = 12 mA I_C = 5 A I_B = 20 mA			2 4	V V
$V_{BE(on)}$[2]	Base-emitter on voltage	I_C = 3 A V_{CE} = 3 V			2.5	V
h_{FE}[2]	DC current gain	I_C = 0.5 A V_{CE} = 3 V I_C = 3 A V_{CE} = 3 V	1000 1000			

1. For PNP types voltage and current values are negative.
2. Pulsed duration = 300 µs, duty cycle ≤2%

2.1 Electrical characteristics (curves)

Figure 2. Safe operating area

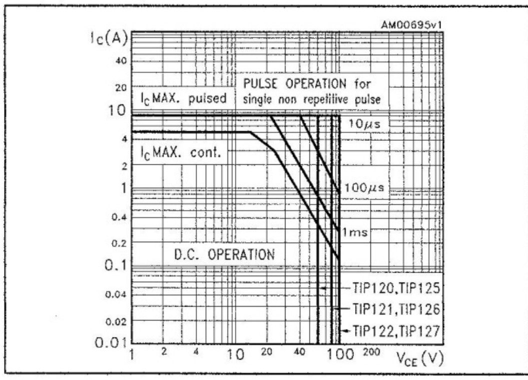


Figure 3. Derating curve

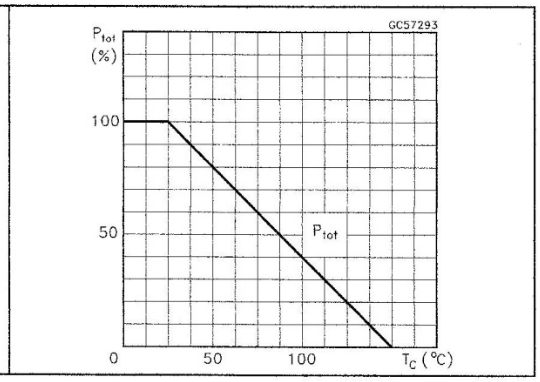


Figure 4. DC current gain for NPN type

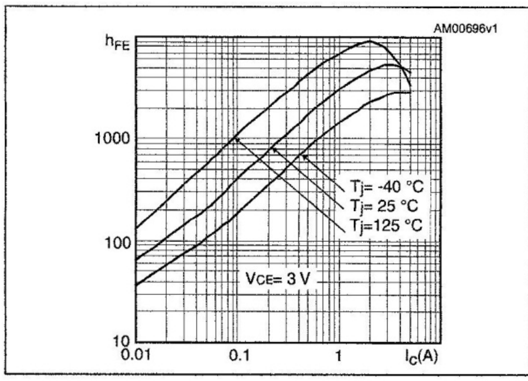


Figure 5. DC current gain for PNP type

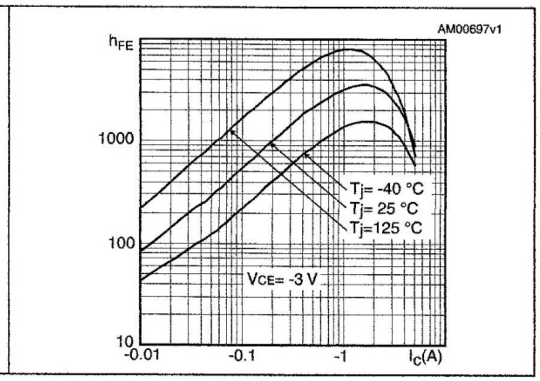


Figure 6. Collector-emitter saturation voltage for NPN type

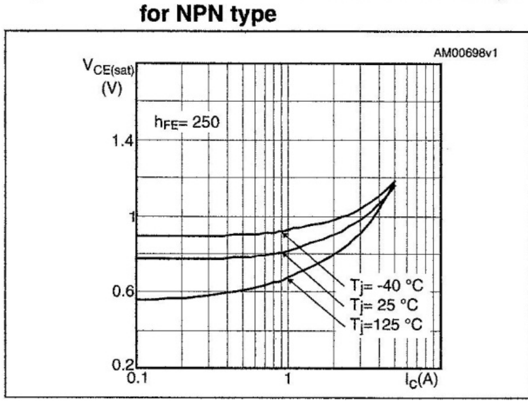


Figure 7. Collector-emitter saturation voltage for PNP type