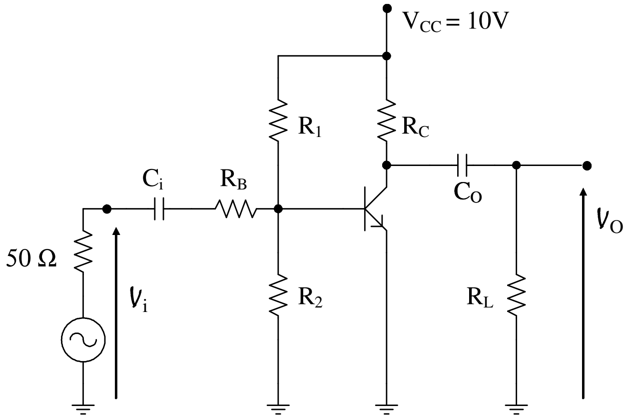

Electronics I Laboratory
EECS 170LA

2011 Edition

Written by:

Chin C. Lee, P. Burke

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Foreword

This manual was prepared for Electronics I laboratory. It consists of eight experiments. They were designed not only to help you understand semiconductor devices and simple semiconductor device circuits but also to let you learn how to use the basic electronic instruments and computer interface. You will have ample opportunities to build and solder your own circuits, use your circuits to observe and study device characteristics, present your results, and comment on any discrepancy. This is the first time your circuits have an active component such as a bipolar junction transistor or an MOS transistor. You will experience using these devices in your circuits before you learn their operational principle.

All the experiments had been performed and verified to ensure their intended objectives. The person who actually carried out each experiment is Juan Velasquez, an EE senior. Juan also sketched almost all the circuit diagrams in this manual. His effort and dedication to this project is greatly appreciated. I also like to thank Professor Allen Stubberud, then the Department Chair, for providing financial support for Juan in the summer of 1997.

This manual has been revised and updated every year. I hope that you enjoy doing the experiments and gain lots of experimental skills and hand-on experience.

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September 18, 2011

Summary

EECS 170LA Electronics I Laboratory

Objective: To enhance the understanding of semiconductor properties, semiconductor device physics and operation principles, transistor equivalent circuits, and transistor amplifiers.

Required for EE and C_pE Majors, one unit (design unit), effective fall 1998.

Laboratory Location: EH1141, EH1130

Experiments and Objectives

1. Introduction and Equipment operations (1 Week)

Introduction of ECE113LA Laboratory contents, procedures, and regulations, and learning how to use all the equipment properly.

2. Soldering Technology and RC Circuits (1 Week)

To study various solders, to actually solder components on a printed circuit (PC) board to build RC circuits, and to measure the function of the circuits built.

3. Characterization of Semiconductors (1 Week)

To illustrate the basic semiconductor characteristics using a hot probe to determine n- or p-type, and a four-point probe to measure the resistivity.

4. Characterization of P-N Junction and Schottky Diodes (1 Week)

To study the forward and reverse bias characteristics of various types of diodes including ordinary p-n junction diodes, Zener diodes, light-emitting diodes (LED), photodiodes, and laser diodes, and their temperature dependence.

5. Transient Response of Diodes (1 Week)

To study the transient response of diodes, to measure the minority carrier storage time of p-n junction diodes, and to verify experimentally that Schottky diodes do not involve minority carriers in the current conduction process.

6. Characterization of Bipolar Junction Transistors and MOSFETs (1 Week)

To measure and investigate the static input, output and transfer characteristics of BJTs and MOSFETs.

7 Bipolar Junction and MOS Transistors As Switches (1 Week)

To design a transistor inverter and investigate the switching characteristics of BJTs and MOSFETs.

8 Bipolar Junction Transistor Amplifier (2 Weeks)

To design, build and measure an analog amplifier using a BJT or an MOSFET transistor.

EECS 170LA Lab Report Guidelines and Grading Policy

Each student will submit their own lab report. It will be due at the beginning of the following lab section.

The grading of your laboratory report will focus on how well you achieve the class goals as documented by your writing. Your report should be brief but complete. Do not write sentences just to fill up space. Every word should have its importance, otherwise do not put it in the report. Your report will be judged not by its length but by its contents and quality.

- The **format** to be followed in writing your report is:

1. A **cover page** with the title of the experiment; your name, section number and student ID number; partner's name; and date of the experiment.
2. A concise statement of the **Objective (s)** (1 paragraph) of the experiment in your own words. What do you expect to learn from the experiment? What are you going to measure/build/design?
3. A **Procedure** section (1 or more paragraphs) which explain how you measured/built/designed, show the circuit schematics if necessary, includes a brief theoretical analysis if needed.
4. A **Results and Analysis** section (1 or more paragraphs): This section will be the central part of your report. Be sure to include nominal values for Source (Vin), electrical components and instrument settings if relevant, and includes electrical measurements in tabular form to make them clear. **Present your result as figures if needed, these figures will be the central result in your report.** Compare the measured results with calculated ones. Explain any discrepancy.

   For all the data measurement and data analysis, **all axes must be labeled; No units, no credit; Any figure should be labeled (e.g. Fig. 1, Fig. 2, etc.); Any figure should be referenced in the main text in the order in which it appears**.

   It is fine to cut/paste figures, schematics from data sheets, lab manuals, or any other source. If you do this, you must cite the reference (e.g. data sheets, lab manual, etc.)
5. A **Discussion** section (1 paragraph): Tell us what you think about the experiment, how well did it work?

- Grades

The grading policy to be followed in your each lab report is:

1. Attendance is mandatory. A report for a particular experiment will be accepted only if the experiment is actually performed.
2. You are going to perform an experiment in a group of two students. But each student submits individual report. Report is due to the lab TA one week after the experiment is performed. No late report will be accepted.
3. Your score for each lab report will based on the weightings as:
   Objectives (10%), Procedures (30%), Results and Analysis (50%), Discussion (10%)

EECS 170LA

Experiment 1 Introduction and Equipment Operations (1 Week)

1. OBJECTIVE: Introduction of EECS 170LA Laboratory contents, procedures, and regulations, and learning how to use all the equipment properly.

2. LABORATORY RULES

    1. Do not bring newspapers or magazines to the laboratory.
    2. No food and drink except bottle water.
    3. No walkman and other audio gadgets.
    4. Turn off your cellular phones.
    5. Must wear shoes for your own protection.

3: LABORATORY PROCEDURES

    1. Lab. TA will normally lecture for 20 minutes before each experiment.
    2. Experiment time: 1 to 3 hours, must be finished in 2.5 hours.
    3. Each group should check the equipment inventory on the station before experiment, and report any missing equipment to the TA.
    4. Do not use any equipment without reading the manual, and without understanding the equipment functions.
    5. TA will check the equipment of your station before you leave.
    6. Each group needs to turn in a Lab Report in a week after the experiment.
    7. **You are required to read the description of next experiment in advance so that you come to the laboratory prepared.**

4. SAFETY AND HAZARD GUIDELINES

Safety is always a major concern in the laboratory. Safety is more important than the experiments themselves. You should never compromise safety for the experiments. In this laboratory, you should be extremely careful in using the soldering iron and the hot plate. ***Never touch the soldering iron and the hot plate with your hands or any parts of your body***. You may get burned if you touch them.

5. GUIDELINES OF EQUIPMENT OPERATION

Students need to read the operation manuals to understand how to use the equipment to prevent damage to the equipment. Please take good care of them and do not abuse them. The equipment listed in the next section will be used very often in your experiments. You are required to read the operation manuals and to make sure that you know how to use the equipment properly. You also need to read the specifications of each equipment. The proper usage of the equipment will not only save your time but also extend the life of the equipment. If you are not sure about the key functions of the equipment, please read the manuals. Do not just try blindly. ***The operation of equipment and the understanding of equipment specifications is important engineering training that will eventually help you do a better job as an electrical and computer engineer.***

6. EQUIPMENT LIST

Each station has its own equipment. You shall be responsible for the proper usage of all the equipment. The TA will verify the equipment list before you leave the laboratory.

Description	Qty.	Manuals
1. HP54602B Oscilloscope 150MHz	1	HP 54600 series oscilloscope user and service guide
2. HP10071A Oscilloscope Probes	2	
3. HP8116A Pulse/function generator (or Arbitrary waveform generator)	1	Operating and service manual
4. HP5314A Frequency Counter	1	Operating and service manual
5. HP E3620A DC Power supply 2-output	1	Operating and service manual
6. HP E3630A DC Power supply 3-output	1	Operating and service manual
7. HP E2373A Digital multimeters	2	Operating manual
8. HP E2306A Test leads kit	2 kits	
9. Coaxial cables, BNC male to male	2	
10. Coaxial cables, BNC male to alligator clip	2	
11. Soldering Iron Station with 1 lb. solder	1 set	
12. Tweezers, pliers, wire cutter	1 set	
13. Breadboard	1	
14. Storage box	1	

7. EQUIPMENT OPERATIONS

1. Display several kinds of waveforms generated by the pulse/function generator on the oscilloscope, e.g. sinusoidal waveform, square waveform, sawtooth, and pulses. You will be asked to describe the key parameters of the signals displayed on the oscilloscope, such as amplitude, period, frequency, duty factor, delay time, rising time, falling time, and pulse width.
2. Use the digital multimeters to measure the voltage of the outputs of the two DC power supplies and verify the readings with that shown on the power supply meter. Pay attention to the specifications of ***input impedance*** in voltage mode and that in current mode. The ***input impedance*** affects the accuracy of your measurements but it is often ignored even by the experienced electrical engineers.
3. Use the frequency counter to measure the frequency of a signal from the pulse/function generator and compare your result with that indicated on the generator.

8. QUALIFICATION QUIZ OF EQUIPMENT USAGE

You will be asked to display any kind of signal waveforms specified by the TA on the oscilloscope. In addition, we still ask you about the key functions of all the equipment. If you do not pass the quiz, you are required to repeat this experiment before you can move on to the next experiment. The TA will give specify a waveform, voltage, and frequency. You will generate the waveform with your function generator, and then display that on your oscilloscope. You are not allowed to use the “auto setup” button!

9. MEASURING THE INPUT IMPEDANCE OF A DVM

"Impedance" can have a real and imaginary part. At dc, the impedance is only real. So when we say "input impedance" and "input resistance" at dc, we mean the same thing.

An ideal voltmeter has infinite input impedance. However, real voltmeters do have a finite input impedance. I want you to measure the input impedance of a voltmeter using the circuit shown in Fig.1.1 below. For R, use a value of 1 kΩ and 1 MΩ.

The important point here is that the DVM measures the voltage across its input terminals. Therefore, the measured voltage will not be the same as the battery voltage. Work out a formula to relate the two. Then determine Z_{DVM}. Next, compare your measurement to the manufacture's specs. (They are in the manual of the DVM.)

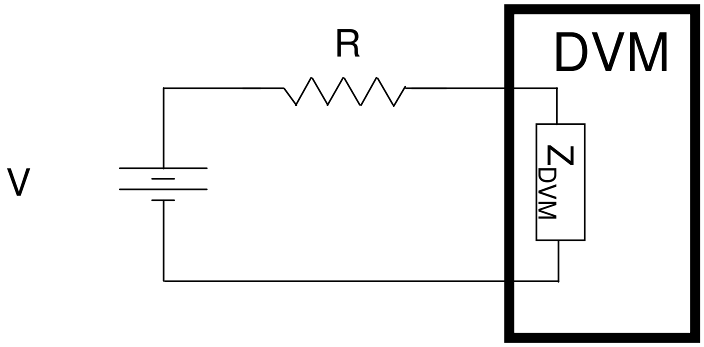

Figure 1.1: Circuit to measure the DVM input impedance.

10. MEASURING THE INPUT IMPEDANCE OF AN OSCILLOSCOPE

"Impedance" can have a real and imaginary part. An oscilloscope measures ac waveforms. Therefore, we care about both the real impedance (resistance) and imaginary impedance. On an oscilloscope, typically the imaginary impedance is specified as a capacitance that is in parallel with the resistance. Usually, these values (input resistance, input capacitance) are actually printed on the front of the oscilloscope itself.

In these experiments, we will operate at 1 kHz. At this frequency, what is the imaginary part of the input impedance, assuming the specs of scope are correct? Now, I want you to measure the input impedance as shown in Fig. 1.2 below, using both 1 MΩ and 1 kΩ resistors.

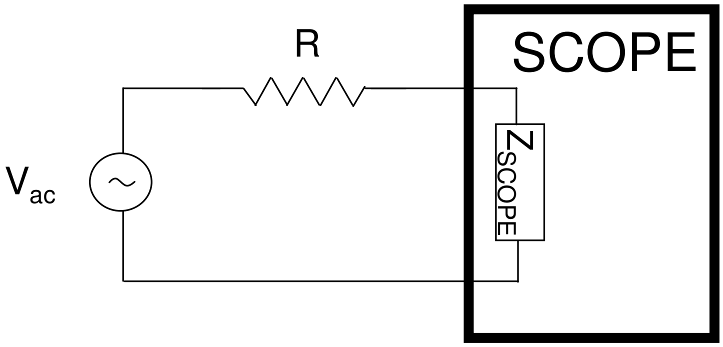

Figure 1.2: Circuit to measure the input impedance of an oscilloscope.

The important point here is that the scope measures the voltage across its input terminals. Therefore, the measured voltage will not be the same as the battery voltage. Work out a formula to relate the two. Then determine Z_{SCOPE}.

Now, repeat that experiment at 1 MHz. At this frequency, what is the magnitude of the imaginary part of the input impedance? Are you worried about cable capacitance? The capacitance is about 20 pF/foot, as shown in Fig. 1.3 below.

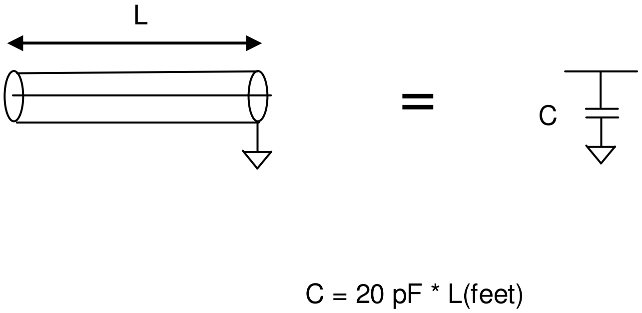

Figure 1.3: Capacitance of typical coaxial cable.

Now, there is one more thing you have to worry about: Your function generator in the lab is not a perfect voltage source. It is a voltage source in series with a resistance, which is called the "source resistance" or "source impedance". This is explained in Fig. 1.4 below. Keep this in mind for all the experiments you do in the lab.

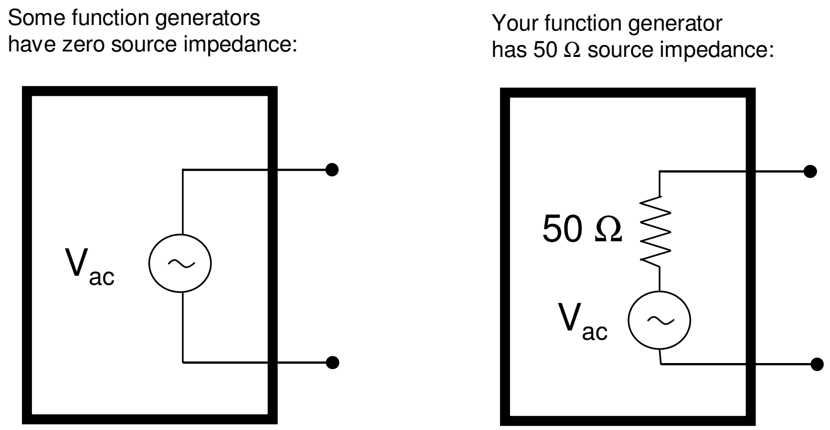

Figure 1.4: Your function generator might have a non-zero source resistance, as shown above.

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Experiment 2 Soldering Technology and RC Circuits (1 Week)

1. OBJECTIVE: To study various solders, to actually solder components on a printed circuit (PC) board to build RC circuits, and to measure the characteristics of the circuits built.

2. BACKGROUND INFORMATION ON SOLDERS

Due to great usage of soldering technology in electric and electronic products, it is essential to know solders and soldering techniques. Basically, solders are made in various physical forms. Different form facilitates specific method of solder application. Available forms are described below.

Solder bar: Rectangular-shape length weighing up to 1 kg used to replenish solder bath in wave-soldering.
Solder ingot: Similar to bars, but weighing 0.9 to 4.5 Kg.
Solder wire: Continuous length of diameter from 0.25 to 6.5 mm, wrapped onto a spool of net weight from 0.45 to 23 Kg. Wire is used in hand soldering or for automatic feeding in machine soldering operations. Some wires have rosin flux core.
Solder preforms: Thin solder sheets of specific shapes, common or unusual, to conform to the desired joint geometry.
Solder cream (paste); A mixture of small solder spheres with flux into paste mainly for automatic or easy dispensing. It is used in hybrid circuits, pick-and-place assembly, and surface mount assembly technology.

The most commonly used solder compositions are covered by the federal specification QQ-S-571. Most solders are simple binary compositions of tin and lead. For electronic applications, the near-eutectic compositions are of paramount importance. The Pb-Sn system consists of three equilibrium phases: (L) the liquid phase, (Pb) the solid solution of Sn in Pb, and (β-Sn) the solid solution of Pb in β-Sn. The pure β-Sn has body-centered tetragonal structure and is usually called white tin. Upon cooling below 13°C, the β-Sn transforms to α-Sn that has diamond structure, and is called gray tin. Gray tin is significantly lighter than white tin. Thus, the phase transformation at 13°C involves also volume change.

The eutectic reaction occurs at 183°C with a composition of 63 wt.% Sn and 37 wt.% Pb (some phase diagram uses 61.9 wt.% Sn, but 63 wt.% is more widely accepted). This particular composition is called the eutectic composition and the melting point 183°C is the eutectic temperature. The point defined by this specific composition and temperature is the eutectic point. The horizontal line at 183°C is the solidus line below which the alloy solidifies. The extension from one end of the horizontal line to the melting point of Pb and that from the other end to the melting point of Sn are also solidus line. The lines connecting the eutectic point to the 327°C melting point of Pb and to the 232°C melting of Sn are liquidus lines above which the alloy becomes liquid. Between the liquidus and solidus lines, the alloy is a mixture of solid and liquid phases. The difference between the liquidus and solidus lines is the melting range. At eutectic composition, the melting range is zero.

The Pb-Sn alloys form joints with metals such as copper because Sn and Cu interact to produce Cu_6Sn_5 intermetallic compound at the interface. However, Sn in the Pb-Sn alloys oxidizes easily to produce SnO and SnO_2 that have very high melting temperature [1], [2]. The oxides thus form a solid barrier that prevents the liquid solder from having contact with the copper. As a result, a joint cannot be produced. In common soldering operations, flux is almost always used to remove the tin oxide layer in order to achieve bonding. Besides Pb-Sn alloys, there are other solders available for various applications. Some of them are shown in the attached sheet. Due to environmental concern on Pb, lead-containing solders have been considered for phasing out and will eventually be banned. In fact, lead-containing solders have been prohibited in applications that have long-term contacts with water and food, such as plumbing. Lead-free solders have thus become more and more important.

3. PROCEDURES

Before you come to the laboratory to do this experiment, you must review the theory on R-C circuits, in particular, transfer functions and impulse responses.

For the electric circuits shown in Figure 2.1, solder the components on a printed circuit board using a soldering iron. Set the pulse/function generator to sine wave mode. Measure the amplitude of the output voltage at several different frequency values. Record the data in your lab book as a table. Next, in your lab book, plot the transfer function (output voltage/input voltage) as a function of frequency on a log-log scale. Make sure you have data well below and well above the 3dB frequency. **This figure will be the central result of your lab report.**

Measure the impulse response of the circuits by sending a pulse signal with pulsewidth much shorter than the RC time constant. Compare the measured response with the theoretical response and explain any disagreement in your report.

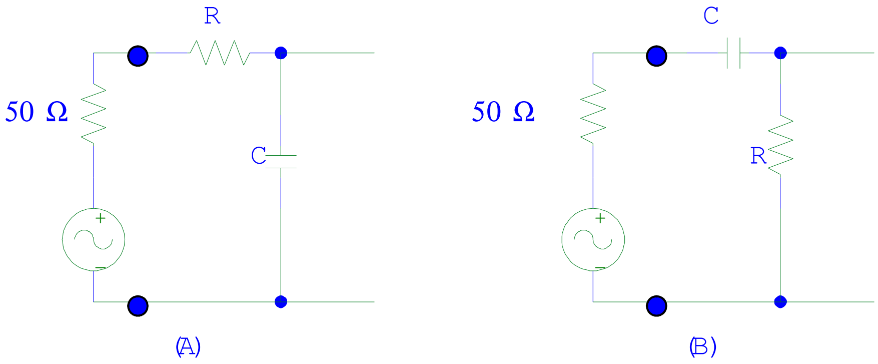

Figure 2.1 Lowpass and highpass RC filters. The 50-ohm resistor represents the source impedance of the function generator.

References

1. Goran Matijasevic and Chin C. Lee, "Void-Free Au-Sn Eutectic Bonding of GaAs Dice and its Characterization Using Scanning Acoustic Microscopy," J. Electronic Materials, Special Issue for Packaging Technology, 18, a joint publication of Minerals, Metals, and Materials Society and the IEEE, pp. 327-337, March 1989.
2. Goran Matijasevic, Chen Y. Wang and Chin C. Lee, "Void-Free Bonding of Large Silicon Dice Using Gold-Tin Alloys," IEEE Trans. Components, Hybrids, and Manufacturing Tech., 13, pp. 1128-1136, December 1990.

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Experiment 3 Characterization of Semiconductors (1 Week)

1. OBJECTIVE: To illustrate basic semiconductor characteristics using a hot probe to determine n- or p-type, and a four-point probe to measure the resistivity.

2. PRINCIPLES

Hot probe technique

This method allows easy determination of the type, i.e., p- or n-type, of a semiconductor sample using a soldering iron, a probe, and a precision voltmeter as shown in Fig.3.1:

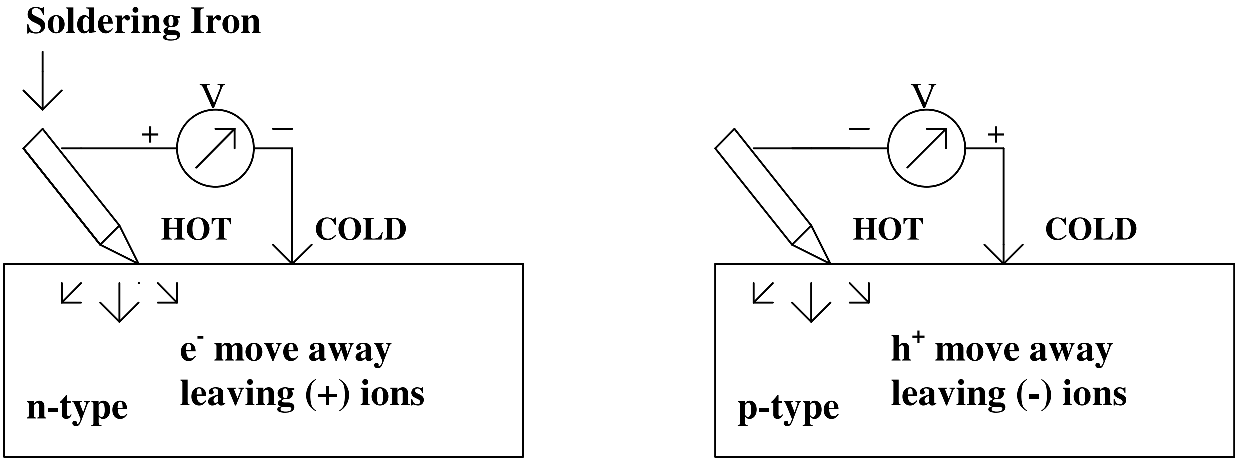


Figure 3.1 Schematic diagram of hot-point probe measurement technique

In the measurement, the soldering iron is placed on one location of the semiconductor wafer to produce a temperature gradient between the soldering iron and the cold probe. Due to the thermoelectric (Seebeck) effect, the carriers (electrons or holes) move from the hot soldering iron towards the cold probe, leaving ions (ionized dopants) of opposite charge near the hot tip.

For an n-type semiconductor, electrons carrying negative charge move away from the hot soldering iron, leaving positive ions (ionized donors) behind. This results in a positive voltage at the soldering iron. This may also be explained as follows. Since no net current flows between the iron and the cold probe, an electric field must be produced to counteract the field induced by the movement of the electrons.

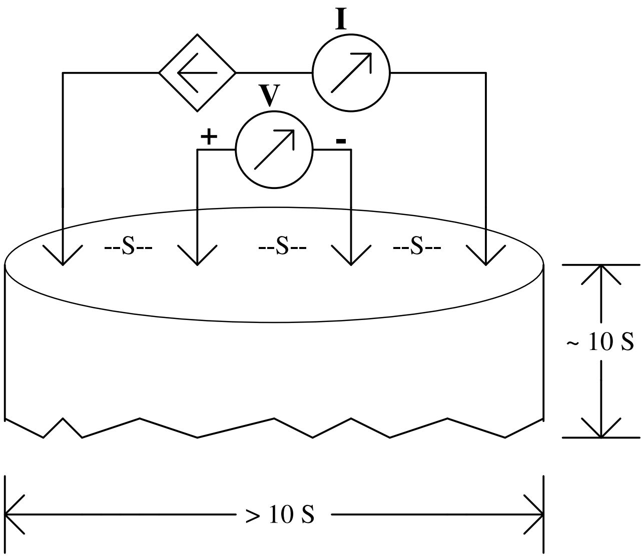
For a p-type specimen, holes carrying positive charge move away from the hot soldering iron, leaving negative ions (ionized acceptors) behind. This results in a negative voltage at the soldering iron. In addition to the determination of semiconductor type, this experiment on a p-type specimen shows that holes do exist and that they carry positive charge.

Four-point probe method

This is probably the most commonly used method to measure the resistivity of a semiconductor wafer or a conducting film on a substrate. Another parameter associated with the resistivity is the the ***sheet resistance*** defined as,

$R_s = \rho/t$ Ω/square (1)

where ρ is the resistivity and t is the thickness. R_s represents the resistance per "square" of wafer or conducting film strip.
Fig. 3.2 exhibits the four-point measurement technique. Current is injected from a current source into the wafer through two outer probes. The amount of current I is measured using a digital multimeter in current mode. The voltage induced between the two inner probes, V, is then measured using another multimeter in voltage mode. The voltmeter must have a very high input impedance, such as 10 MΩ, to avoid affecting the current. Notice that the probes have equal spacing of s.



$\rho = (V/I)2\pi S$

Figure 3.2 Configuration of four-point probe technique for resistivity measurement

If the probes rest on a homogeneous and semi-infinite medium, it can be shown that the resistivity is given by,

$\rho = 2\pi(V/I)s$ (1)

In reality, the semiconductor is not infinitely thick. In fact, most semiconductor wafers are quite thin comparing to the probe spacing and their lateral extents are not infinity. If the wafer thickness is much smaller than the lateral dimensions, the sheet resistance is given by,

$$R_S = F\,V/I \qquad \Omega/\text{square} \qquad (2)$$

where F is a correction factor. Curves for F as a function of d/S are shown in Fig.3.3, where d is the lateral dimension and S is the probe spacing. In the limit when d >> S, the correction factor becomes $\pi/\ln 2=4.54$. Once the sheet resistance is measured, the resistivity is simply,

$$\rho = R_S t \qquad \Omega\text{-cm} \qquad (3)$$

where t is the wafer thickness.
Figure 3.4 displays the measured resistivity for silicon (at 300K) as a function of the impurity concentration. At this temperature, all donor or acceptor impurities that have shallow energy levels are ionized. Under these conditions, the carrier concentration is equal to the dopant concentration. From these curves we can obtain the impurity concentration of a semiconductor if the resistivity is known, or vice versa.

3. PROCEDURES

1. Use the hot probe method to determine the semiconductor type of the Si substrates provided. Measure the voltage developed between the hot and cold probes. Present your result in the report.

2. Use the four-point probe to measure the resistivity and to determine impurity concentration of the substrates provided. Repeat the measurement for substrates at higher temperature (about 60° C). Present your results in the report.

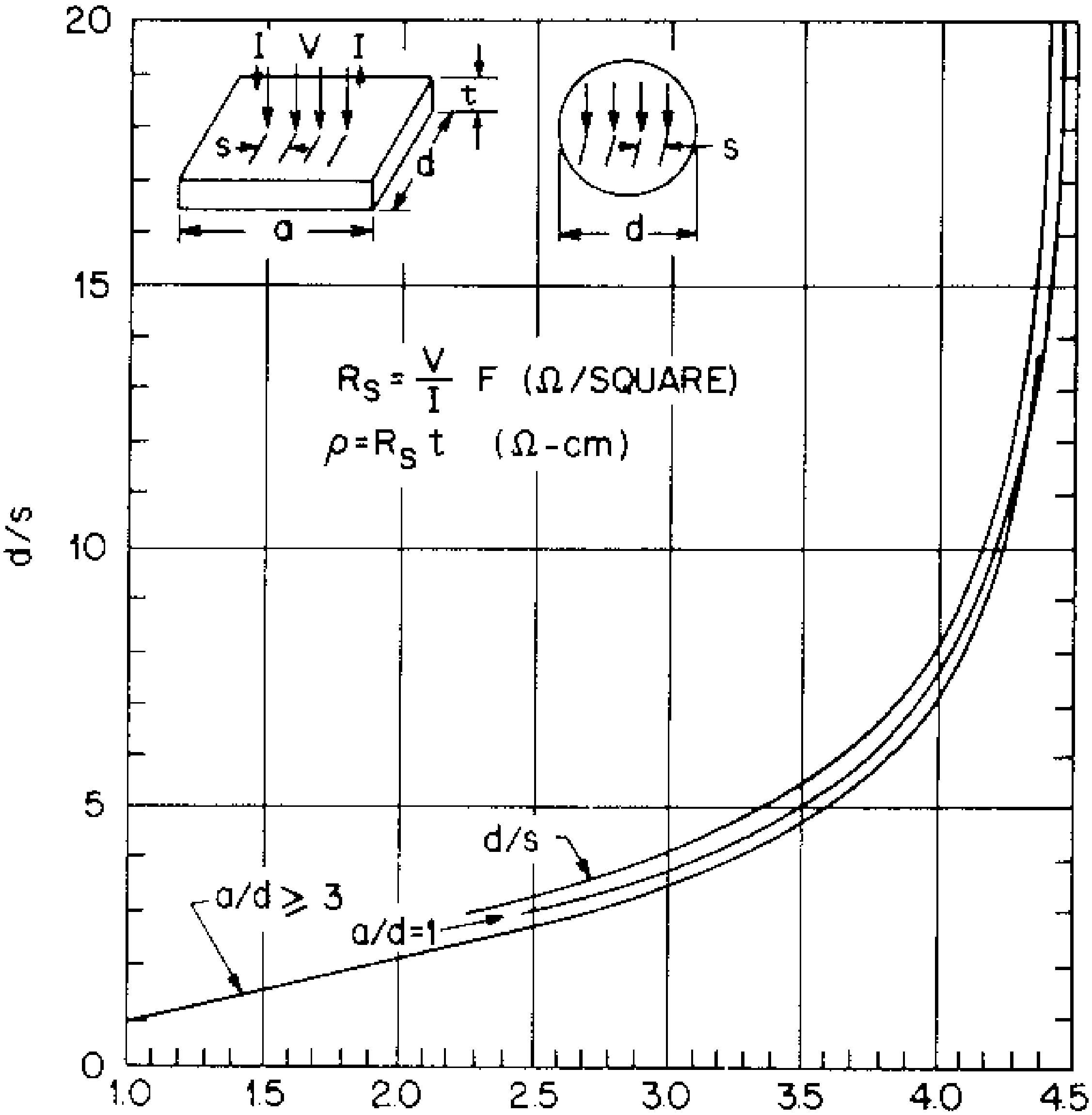


Figure 3.3 Correction factor for the resistivity measurement using a four-point probe [1]

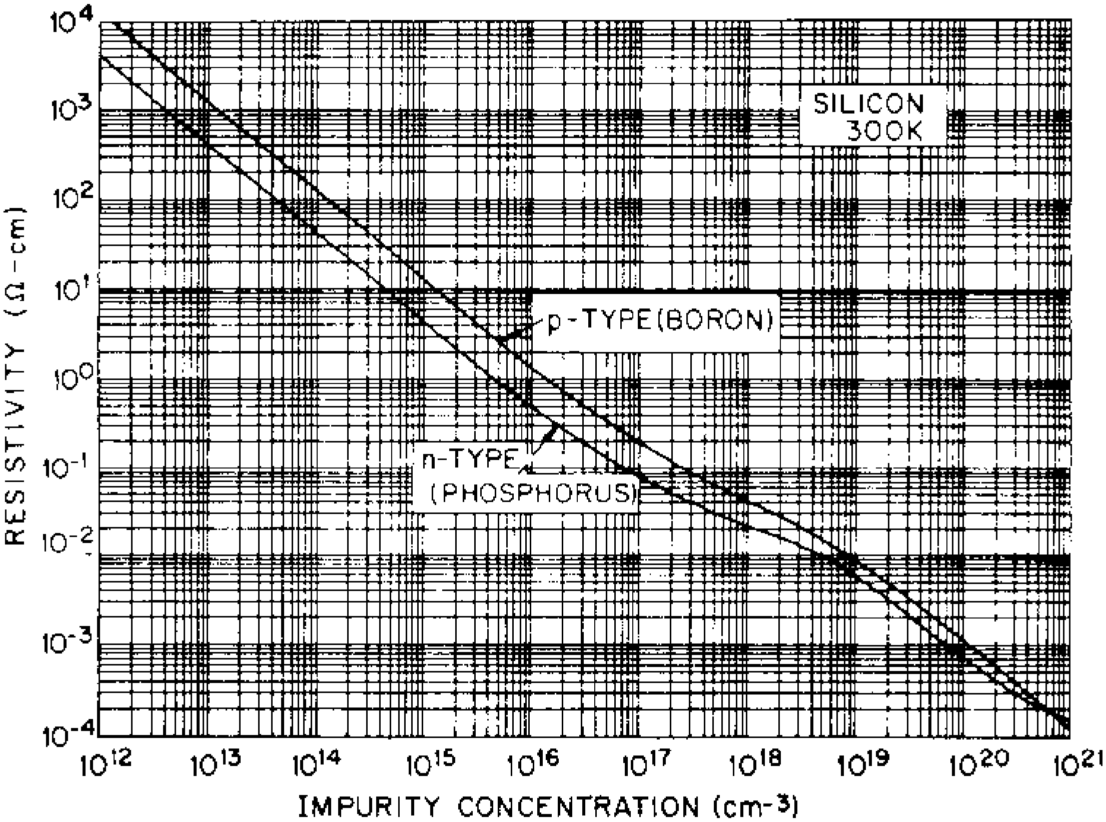


Figure 3.4. Resistivity versus impurity concentration for Si and GaAs [1].

Reference

[1] S.M. Sze, *Physics of Semiconductor Devices,* 2nd ed., John Wiley & Sons, New York, 1981

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Experiment 4 Characterization of P-N Junction and Schottky Diodes (1 Week)

1. OBJECTIVE: To study the forward and reverse bias characteristics of various types of diodes including ordinary p-n junction diodes, Zener diodes, light-emitting diodes (LED), photodiodes, and laser diodes, and their temperature dependence using the X-Y operation mode of an oscilloscope followed by confirmation with a curve tracer.

2. PRINCIPLE

In general, the I-V characteristics of diodes and transistors are measured by an instrument called Curve Tracer. In this experiment, however, you are asked to design and build a simple circuit to display the I-V characteristics of diodes on the oscilloscope in X-Y operation mode. The signals required for driving your circuit are taken form the function/pulse generator. The results that you obtain are than confirmed by a curve tracer.

The I-V relationship of an ideal diode is given by the ideal diode equation,

$$I = qA\left(\frac{D_p}{L_p}P_{no} + \frac{D_n}{L_n}N_{po}\right)\left(e^{qV/nkT} - 1\right)$$

$$I = I_o\left(e^{qV/nkT} - 1\right)$$

where I is the diode current, V is the bias voltage, I_o is the reverse saturation current, and n is the ideality factor having a value between 1 and 2. For a diode under forward bias condition, the ideal diode equation describes the experimental results very well so far as the diode is not driven heavily into high level injection situation. On the other hand, this equation does not correctly predict the behavior of the diode under reverse bias condition. In deriving the ideal diode equation at reverse bias, we use depletion approximation assuming that no carriers exist in the depletion region. However, in reality, the depletion region of the diode at reverse bias has electron-hole pairs (EHP's) that are constantly generated because of thermal energy. Once these electron-hole pairs are generated, the electrons and the holes are separated due to the electric field in the depletion region. As a result, a current component due to this thermal generation of EHP's is produced. Accordingly, under reverse bias condition, we need to add this current component to the ideal reverse saturation current. Thus, the actual reverse saturation current should be corrected as,

$$I_{SAT} = I_o + I_{th}$$

where I_{th} is the component due to thermal generation. In fact, for most diodes, I_{th} is much greater than I_o. Since I_{th} is very sensitive to temperature, I_{SAT} is also very sensitive to temperature. Experimental data show that I_{SAT} usually increases by a factor of 2 as the temperature increases by every 10°C. The ideal diode equation predicts that the reverse saturation current is independent of the reverse voltage. However, due to the domination of I_{th}, the actual reverse saturation current increases slowly with the reverse voltage. At higher reverse voltage, the depletion region becomes wider, resulting in larger I_{th}.

When the reverse bias voltage is increased further, the diode eventually reaches breakdown. The breakdown is caused by either Zener (tunneling) or avalanche (impact ionization) effect. For Zener breakdown, the breakdown voltage decreases with temperature. For avalanche breakdown, it increases with temperature. Therefore, from the temperature coefficient of the breakdown voltage, we can determine whether the diode is a true Zener diode or an avalanche diode.

3. PROCEDURES

1. Build the simple circuit shown in Fig. 4.1 to measure the I-V curve. There are two DVMs. The upper DVM measures the voltage drop across R. This is proportional to the current flow through the diode. There, this is a measure of the diode current. Note: The DVM is "floating", meaning neither of the DVM inputs are grounded. This is OK.
The lower DVM directly measures the voltage drop across the diode.
Vary the source voltage and record the diode current and voltage at several different points. Your end result should be plotted by hand in lab before you leave. If you want to know what it should look like, you can look at the cover of your text book for the lecture class (Pierret). **This figure will be the central result of your report.**

2. Measure the I-V characteristics of the diodes provided, and the breakdown voltage (if less than 16V) at room temperature and at a higher temperature in the range of 50 to 80°C. Present your results and discuss how the measured parameters vary with temperature.

Note: a. In normal operation, a photodiode is reverse biased while a laser diode is forward biased. Laser diodes are very delicate device for which the light output power is very sensitive to driving current, and thus can be easily burned if the driving current exceeds the maximum rating. Accordingly, in using laser diodes, please watch out carefully in not exceeding the maximum current stated in the data sheet. **Do not get your eyes too close to the laser diode while it is lasing. Keep your eyes away from it by 3 feet or more.**

b. Data sheets of some representative diodes are attached near the end of this manual.

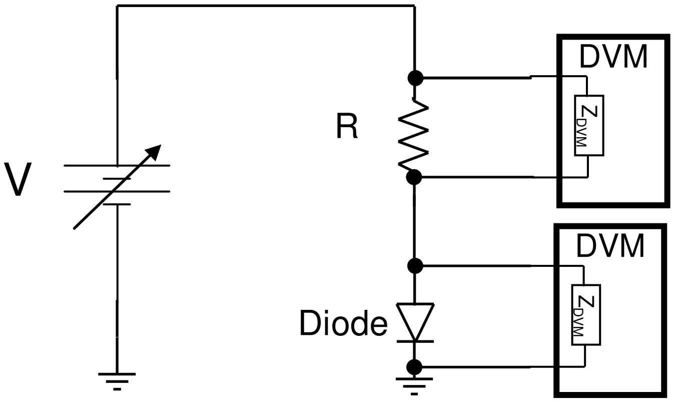

Figure 4.1: Schematic to measure the diode I-V curve.

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Experiment 5 Transient Responses of Diodes (1 Week)

1. OBJECTIVE: To study the transient response of diodes, to measure the minority carrier storage time of p-n junction diodes, and to verify experimentally that Schottky diodes do not involve minority carriers in the current conduction process.

2. PRINCIPLE

There is a time delay in re-establishing reverse-bias steady-state condition when a p-n junction diode is switched from forward to reverse bias. Fig.5.1a depicts the general current-time (i-t) transient response exhibited by the diode while Fig.5.1b shows the corresponding diode voltage. Under forward bias, excess minority carriers pile up in the quasi-neutral regions of the diode adjacent to the depletion region as portrayed in Fig. 5.2. The finite time required for the removal of these “stored” minority carriers leads to the externally observed delay and the reverse recovery transient effect.

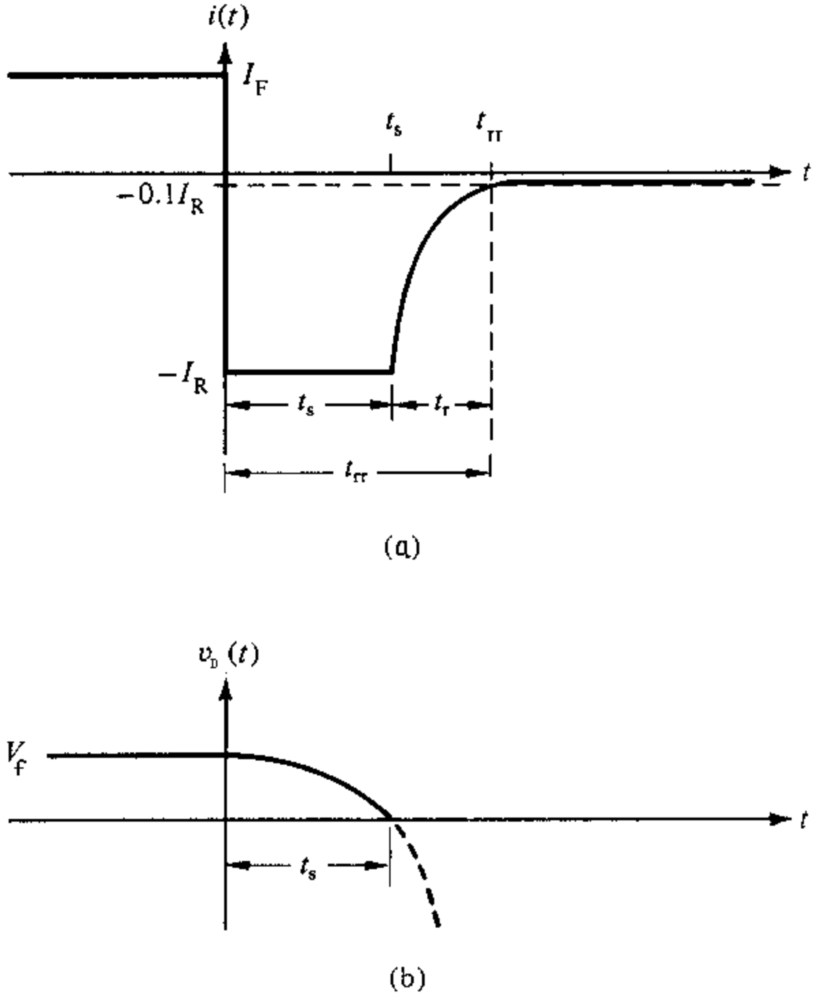


Figure 5.1 Transient response of a P-N junction diode

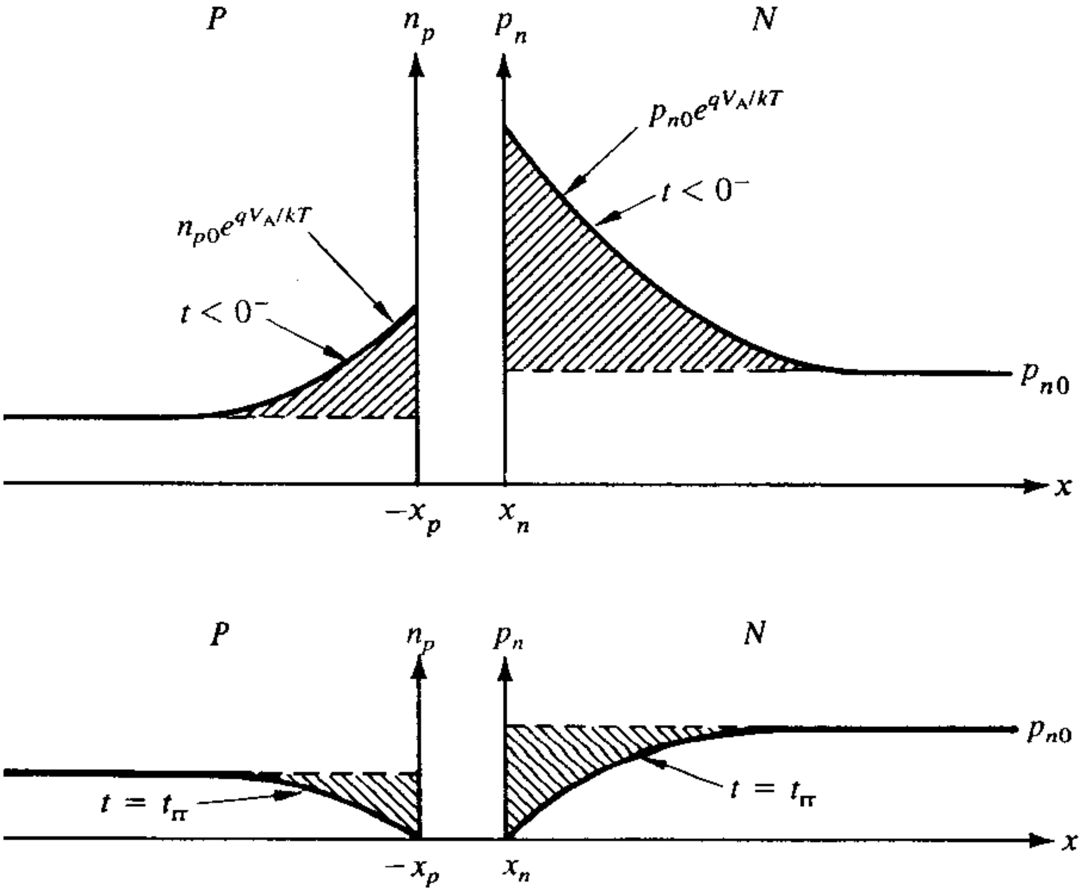


Figure 5.2 Storage of minority carriers

The switching response displayed in Fig. 5.1 contains two distinct time segments. In the first segment, the current is approximately constant at a large reverse value of $i = -I_R$ for a duration of t_s. During the second segment of the response, the magnitude of the current monotonically decreases to its steady-state value. Of practical note, the second portion of the transient response is significantly affected by the stray capacitance in the measurement circuit. For this reason, the storage time t_s rather than the reverse recovery time t_{rr} is often employed to characterize the switching response of p-n junction diodes.

The storage time actually observed in a given measurement depends on two experimental parameters and one material parameter. The forward bias current I_F, as defined in Fig.5.1, determines the amount of excess minority carriers stored in the diode prior to switching; the larger the I_F, the more the excess carriers, and the longer the storage time t_s. I_R controls the extraction rate of the carriers across the junction; the larger the I_R, the shorter the t_s. Finally, the minority carrier lifetime, τ_n on the p-side and τ_p on the n-side, specifies the rate at which the excess minority carriers disappear by recombination with the majority carriers on the respective side of the junction. Given the commonly seen p^+-n or n^+-p diodes, however, the activity of the carriers on the lightly doped side dominate the response, and only the lifetime of the minority carriers on the lightly doped side affects t_s. Performing a detailed analysis and assuming a p^+-n diode, one finds t_s to be given by the relation,

$$erf\left(\sqrt{\frac{t_s}{\tau_p}}\right) = \frac{1}{1 + I_R / I_F}$$

where $$erf(\xi) = \frac{2}{\sqrt{\pi}} \int_o^{\zeta} e^{-x^2} dx$$

is the error function. The variation of t_s/τ_p versus I_R/I_F as deduced from the above equation is plotted in Fig. 5.3.

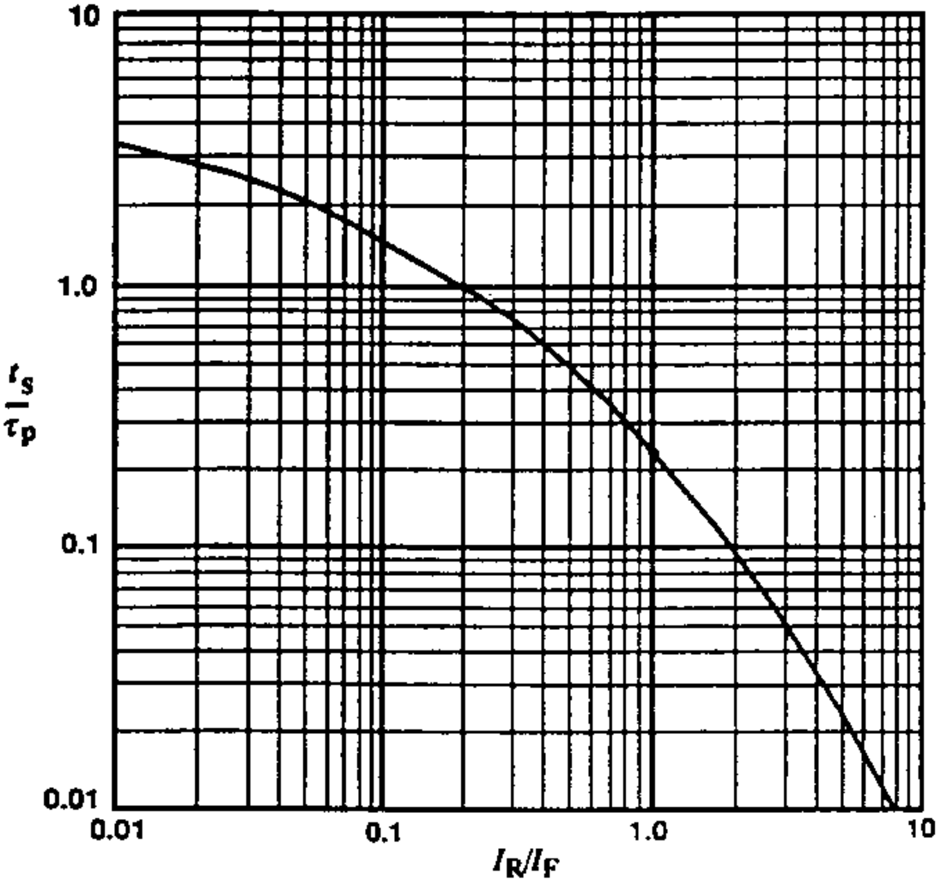


Fig. 5.3 t_s/τ_p versus I_R/I_F plotted in log scale.

3. Procedures

1. For the rectifier p-n junction diode provided, build a transient response measurement circuit sketched in Fig. 5.4. Rapid switching of the voltage applied across the test diode is facilitated by the pulse, or square voltage waveform obtained from the function/pulse generator. Drive the circuit that you build with proper signal. Observe the transient response and the reverse recovery transient effect. Capture the input wafevorm and output waveform in the same screen using the computer. Measure I_F and I_R and compare your measured values with calculated values. For calculation, use $I_F = (V_P - V_{on})/R_L$ and $I_R = (V_N+V_{on})/R_L$, where V_P is the voltage in positive cycle of the waveform applying to the diode and the resistor, V_N is the voltage amplititude in the negative cycle, and V_{on} is the turn-on voltage of the diode. A technique to change I_F and I_R is to adjust the DC offset of the square voltage waveform. Measure the storage time t_s and deduce the minority carrier lifetime τ_p on the lightly doped side of the junction. Show that the circuit does not have rectifying function any more when the period of the voltage waveform becomes smaller than $2t_s$. Present your results in the report.

2. For the switching p-n junction diode provided, repeat the same things.

3. For the Schottky diode provided, repeat the same things.

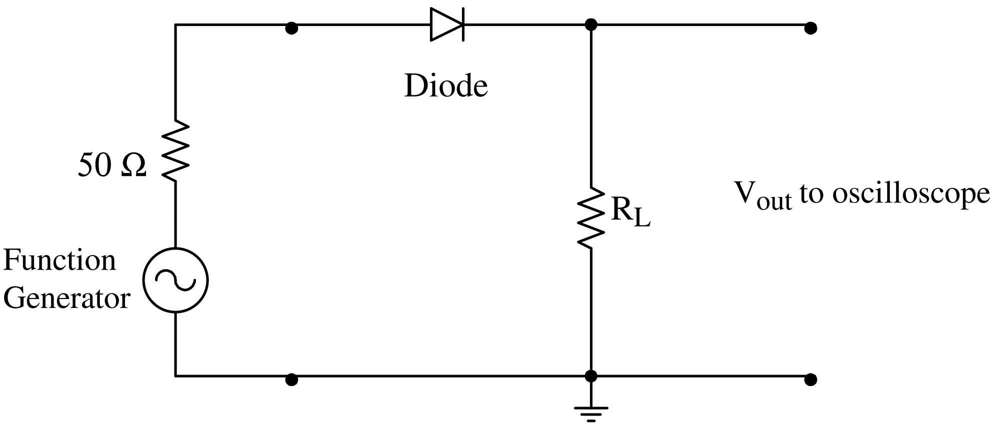


Fig. 5.4 Simple circuit for the study of transient responses.

EECS 170LA

Experiment 6 Characterization of Bipolar Junction Transistors (1 Week)

1. OBJECTIVE: To measure and investigate the static input, static output and static transfer characteristics of BJTs and MOSFETs.

2. BACKGROUND INFORMATION

The particular BJT characteristics are related to the circuit configuration and biasing mode. The circuit configuration, shown in Fig.6.1, identifies the lead that is common to the input and output of the circuit. The biasing mode indicates the polarity of bias voltages applied to the emitter-base and collector-base junctions, as given in Table 1. In analog applications such as amplification, common-emitter configuration in forward-active mode is most common. In digital applications such as switching, the most important circuit is common-emitter configuration with the BJT switching between cut-off and saturation modes. Examples of the common-emitter input and output characteristics are displayed in Fig.6.2 for PNP transistors and in Fig. 6.3 for NPN transistors.

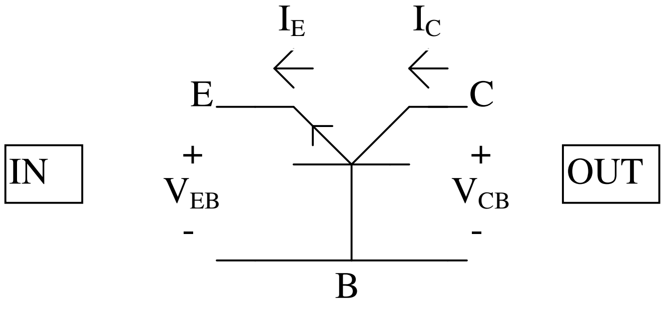
In some applications such as TTL (transistor-transistor logic), one BJT of the logic gate operates in reverse (or inverted) active mode in which the roles of emitter and collector are interchanged. In reverse active mode, carrier injection from the collector into the base is less efficient than that from the emitter into the base in the forward active mode. Thus, the current gain is significantly reduced under reverse-active mode operation. Under forward-active operation, the d.c. current gain, $\beta_{dc}=I_c/I_b$, ideally is a device constant. Based on first-order considerations, I_c and I_b should exhibit the same exponential dependence on V_{be}/kT. In real devices, however, the relations of I_c and I_b versus V_{be}/kT deviate from ideal as noted in Fig.6.4. Since β_{dc} is just the ratio of I_c to I_b, it is obvious from Fig. 6.4 that β_{dc} decreases at both low and high current levels. The dependence of β_{dc} on I_c , a characteristic normally supplied by BJT manufacturers, is sketched in Fig. 6.5.

In this experiment, an NPN BJT will be measured to obtain characteristics similar to those depicted in Fig. 6.2. For MOSFETs, “source”, “gate”, and “collector” are equivalent to emitter, base, and collector, respectively, of BJTs.

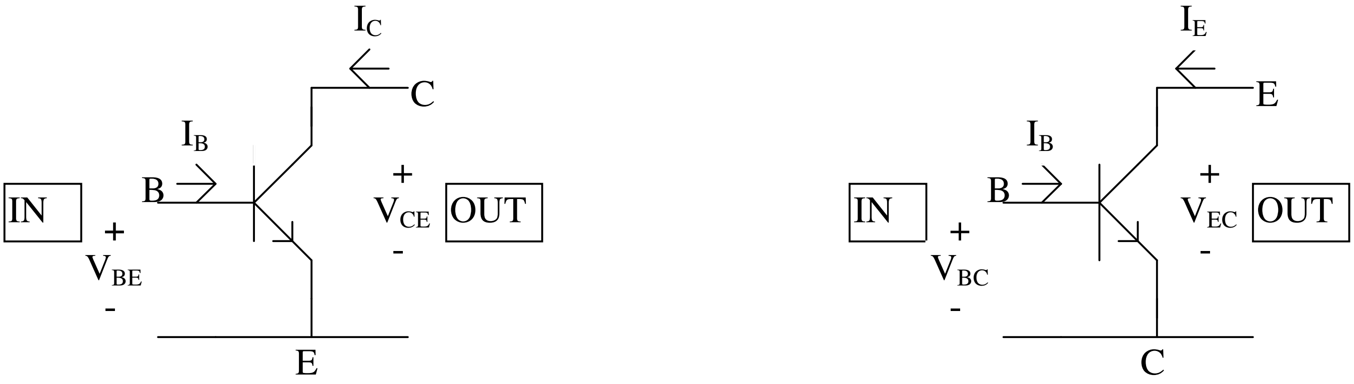
3. PROCEDURE

Measure the I_C vs. V_{CE} characteristics for at least 3 different values of I_B. If you are wondering what the result should look like, I suggest you look at the cover of your textbook for lecture (i.e. Pierret.) Or, you could look at figure 6.2d. From these plots, determine the value of β for your transistor. Plot I_C vs. V_{CE} manually before leaving the lab. **This figure will be the central result of your lab report!** You should also measure the I_B vs V_{BE} curve. **This figure will also appear in your written report.**

For your measurement circuit, I suggest you use the circuit shown in Fig. 6.3 below. Depending on your transistor, this may not be the best measurement circuit. If you can think of a better measurement circuit, then by all means do. Be sure to document what circuit you used in your manual. Also, not that the scope can be used as a dc voltmeter (albeit an expensive one) if you don’t have enough hand held dc voltmeter. Also, handheld DVMs can be used to measure current, i.e. as ammeters. Next, do the same thing for a MOSFET!



(a) Common base



(b) Common emitter

(c) Common collector

Figure 6.1 Circuit configuration: (a) common base; (b) common emitter; (c) common collector.

Table 1 Transistor operation modes

Biasing Mode	Biasing Polarity **E-B** Junction	Biasing Polarity **C-B** Junction
Forward Active	Forward	Reverse
Inverted Active	Reverse	Forward
Saturation	Forward	Forward
Cutoff	Reverse	Reverse

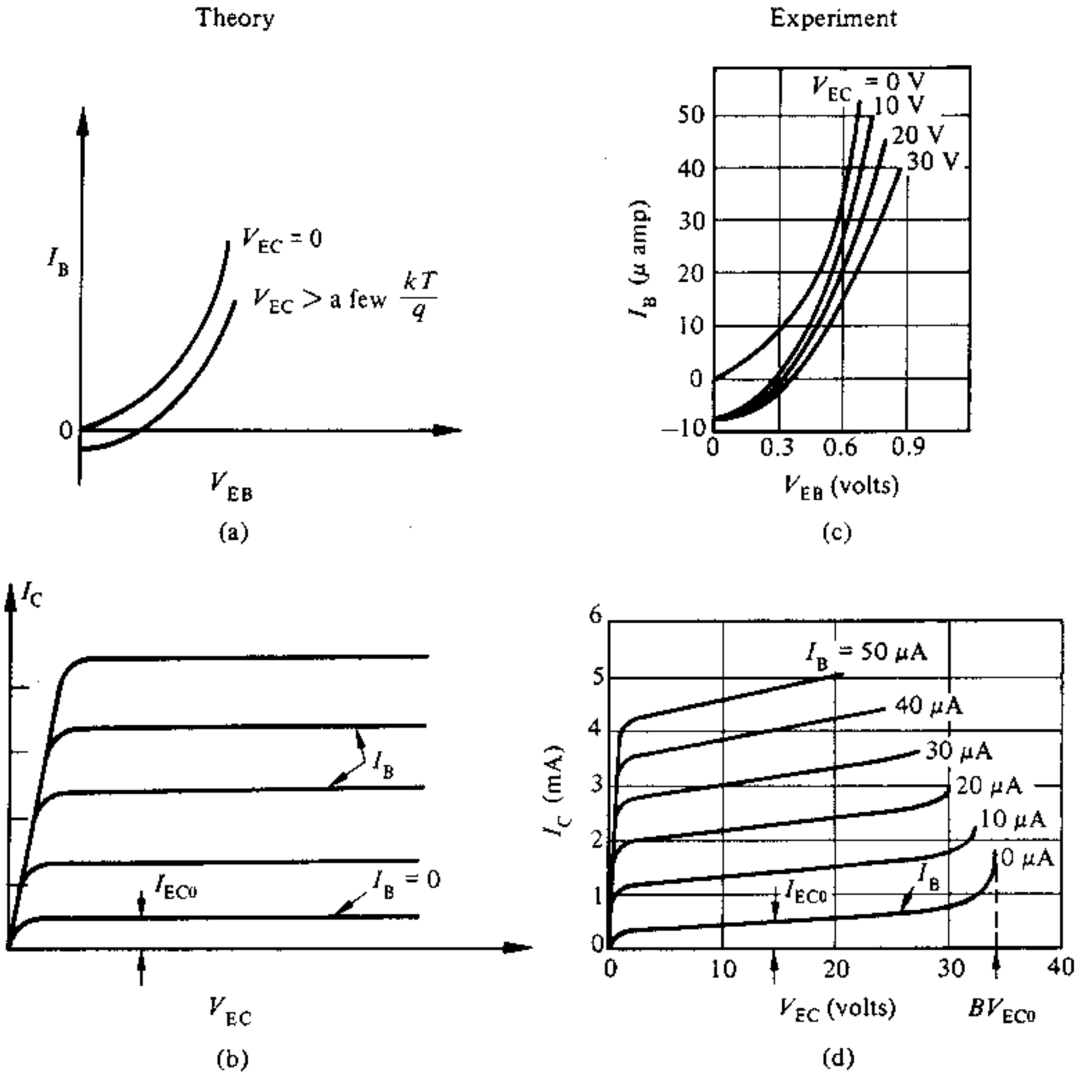


Figure 6.2 Theoretical and measured characteristics of a PNP transistor in common-emitter configuration, (a) and (c): input characteristics, (b) and (d) output characteristics.

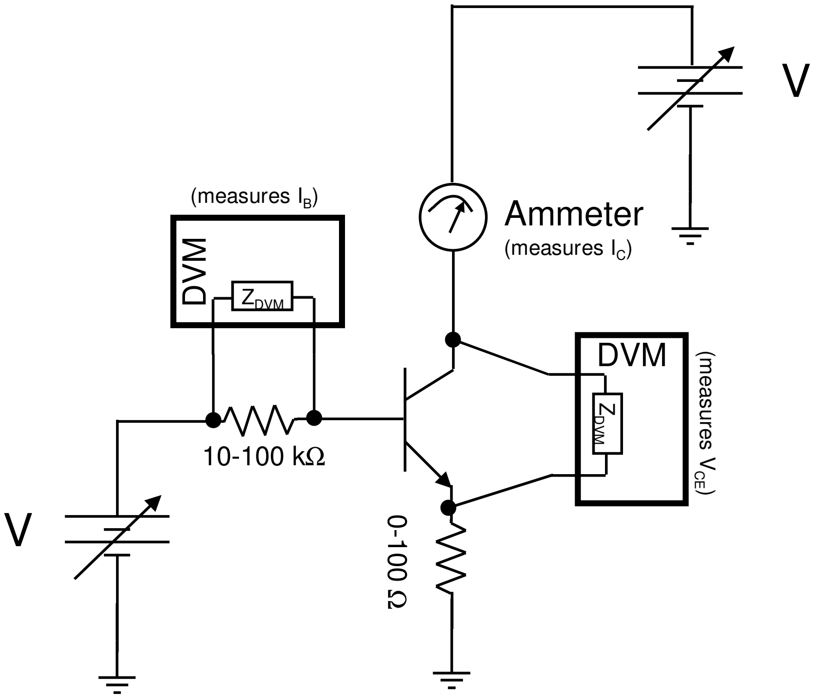


Figure 6.3: Suggested circuit to measure BJT IV curves.

EECS 170LA

Experiment 7 Bipolar Junction and MOS Transistors As Switches (1 Week)

1. OBJECTIVE: To design a transistor inverter and investigate the switching characteristics of BJTs and MOSFETs.

2. PRINCIPLE

In digital and switching applications, and some power applications, a transistor is used as an electric switch to control the current that passes through it, similar to a faucet that controls the amount of water that flows through it. The faucet is controlled by your hand, but the transistor is controlled by an electrical signal, i.e., the input signal. Thus, it is valuable to study the switching characteristics of a transistor circuit: how fast can the switch turn the current on and off? What input signal strength is needed? What much current can the switch handle? What is the leakage current when the switch is turned off? How much voltage is needed to push the current through the switch?

3. PROCEDURE

1. Build the inverter circuit shown in Fig. 7.1 on the PCB. Choose proper value for R_L and R_B. Drive the transistor with a voltage pulse and observe the output voltage signal. The transistor must be driven into saturation or near saturation when the input signal is high.
2. Select an input pulse width much larger than the response time of the transistor so that you can observe both the turn-on and turn-off transients.
3. Display both the input and output signals on the oscilloscope, compare them and comment on the time delay (with respect to the input signal) incurred at the output signal during turn-on and turn-off transitions.
4. Repeat the same things using an MOS transistor as the switching device.

In your report, you should sketch the input and output waveform for both BJT and MOSFET transistors. You should also indicate what the rise and fall times are. Would these transistors be fast enough for a 3 GHz circuit?

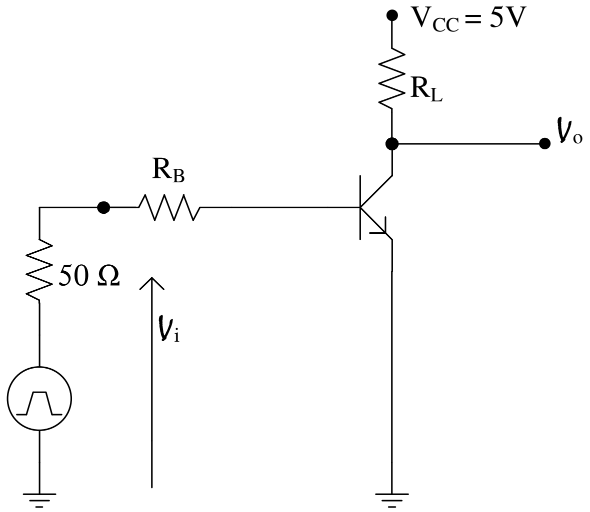


Figure 7.1 A transistor inverter circuit

Notepad

EECS 170LA

Experiment 8 Bipolar Junction Transistor Amplifier (1 Week)

1. OBJECTIVE: To design and build and measure an analog amplifier using a BJT or an MOSFET.

2. PRINCIPLE

Besides digital and switching applications, an equally important transistor application is analog amplification where a small electrical signal is made larger for further processing or for driving an output device. An excellent example of analog amplification is the rf amplifier in your TV receiver that amplifies the rf signal picked up by the antenna. Another example is the audio amplifier in your CD player that drives the loud speaker. In analog application, high linearity between the output and input signals is extremely important in maintaining low distortion.

3. PROCEDURES

1. Build the amplifier circuit shown in Fig. 8.1 on the PCB. C_i is a blocking capacitor that blocks DC current from getting back to the input signal source. C_o is also a blocking capacitor that blocks DC current from the transistor collector to the output load. R_1 and R_2 are bias resistors that set the transistor base terminal at proper bias (operation) current and bias voltage. R_C is the resistor connecting collector to the DC power supply, V_{CC}. It is clear that the maximum collector current is given by V_{CC}/R_C. R_L represents external load that the amplifier drives. The input and output circuits are both an RC highpass filter. They together determine the lower -3dB cutoff frequency of your amplifier. Thus, you need to choose the resistor and capacitor values properly. The upper -3dB cutoff frequency is determined by the transistor.
2. Without connecting the input source to the amplifier, measure the bias voltage at the collector. This bias voltage should be about $V_{cc}/2$ to achieve low distortion. Connect the input signal source to the amplifier and apply a small 10kHz sinusoidal voltage. Display both the input voltage and output voltage signals on the oscilloscope. Increase the input voltage until the output voltage waveform starts to incur distortion. Capture the waveforms using computer. Find out the peak-peak output voltage and determine the voltage gain. Compare the measured gain with calculated one. Comment on any discrepancy between measured and calculated values.
3. Set the pulse/function generator to CW mode and manually adjust the frequency to find out the lower -3dB cutoff and upper -3dB cutoff frequencies. Compare them with calculated ones. Measure the gain at several different frequencies, and make a table in your lab book. Make sure you have several frequencies above cutoff, below cutoff, and in the middle (flat) region of the spectrum. Plot these manually before leaving the lab. **This figure will be the central result of your report.**

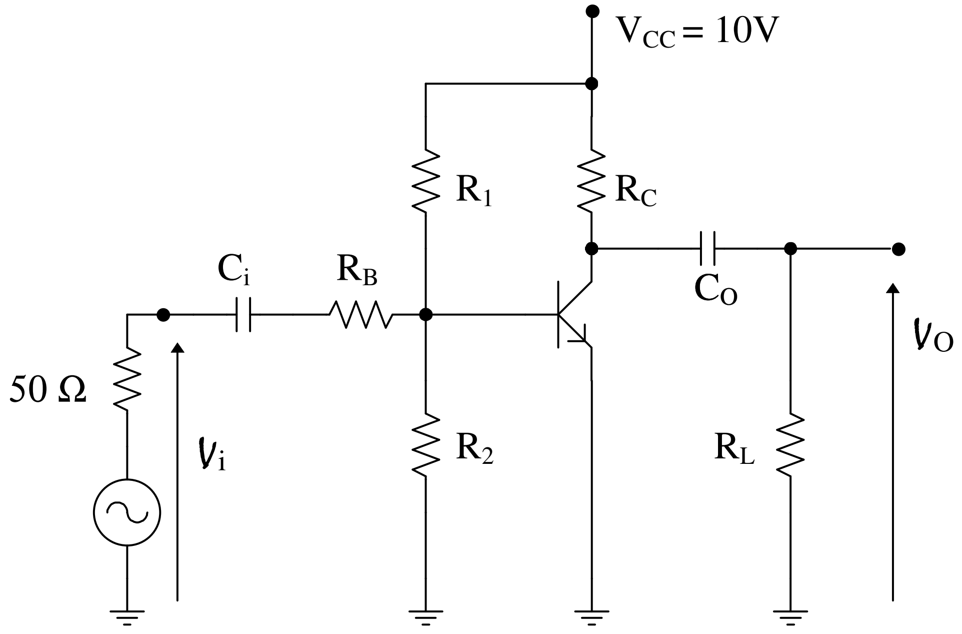


Figure 8.1 A simple transistor amplifier circuit.

List of Active Components

Part No.	Description	Quantity	Data Sheet
	PN Junction Switching Diode	A reel	No
1N4005	PN Rectifying Diode, similar to NTE116	80	Yes
5024A	NTE Zener Diode 15V	15	Yes
5007A	NTE Zener Diode 3.9V	23	Yes
1N4734A	Motorola Zener Diode 5.6V	300	Yes
MBD101	Motorola Schottky Diode	100	Yes
3010	NTE Green LED	50	Yes
3007	NTE Red LED	50	Yes
TOLD9520	Toshiba Laser Diode	100	Yes
2N2219A	NPN Junction Transistor	100	Yes
2N2905A	PNP Transistor	100	Yes
2N3904	NPN Small Signal Transistor	100	Yes
2N306	PNP Small Signal Transistor	100	Yes
TIP120	NPN Power Transistor	6	No
TIP125	PNP Power Transistor	14	No
2N7000	N-channel enhancement mode D-MOS	100	Yes

List of Passive Components

NEWARK CATALOG #	DESCRIPTION	QUANTITY
50F8301	10 Ω resistor	100
50F8303	100 Ω resistor	100
50F8304	332 Ω resistor	100
50F8305	604 Ω resistor	100
50F8302	1.0K Ω resistor	100
50F8307	2K Ω resistors	100
50F8309	4.99 KΩ resistor	100
50F8300	10 KΩ resistor	100
50F8313	20 KΩ resistor	100
50F8314	86.6 KΩ resistor	100
50F8315	100 KΩ resistor	100
50F8316	200 KΩ resistor	100
50F8317	1 MΩ resistor	100
87F5104	1µF capacitor	100
87F5118	10µF capacitor	100
98F860	0.047µF capacitor	100
98F3561	0.1 µF capacitor	100
95F4975	0.47 µF capacitor	100
95F4968	0.015 µF capacitor	100

All resistors are 1% and 1/4 watt.