EEE334 Lab#3

PN Junction Diodes and Applications

It is strongly recommended to perform lab experiments when an EEE334 Lab TA is on duty, since only she/he can verify the correctness of your lab data. *Other Lab TAs may stamp and sign your lab data sheets but CANNOT GUARANTEE the correctness of your data, and you will then bear full responsibility and penalty for collecting incorrect data.*

The objective of this lab is to familiarize the student with basic properties of junction diodes as well as to provide an overview of some important diode applications.

Sections 3.1-3.3 of the lab involve the study of properties of the PN junction diodes and this **requires knowledge of EXCEL**. These experiments involve a study of the Current-Voltage characteristics of PN junction Zener diodes using a curve tracer (LEADER LTC–905) in conjunction with an oscilloscope (Tektronix DPO-4032) and EXCEL to determine **Turn On** and **Break down** Voltages. Also included are the study of the DC and small signal (AC) analysis of a diode.

Sections 3.4-3.10 of the lab involve an overview of some important diode applications. These experiments will enable a student to acquire additional experience in analyzing and evaluating diode circuits and also to observe typical examples of semiconductor diodes in use. The applications include wave shaping, such as rectifier, clamper, and limiter (clipper) circuits. A Zener diode voltage regulator and voltage multiplier circuit are illustrated, as well. For these sections, keep in mind that you will need to use lab observations and information about these circuits in your book to describe their function in the Discussion section of the lab report.

This lab contains detailed instructions for equipment set up and LTSpice, and this will not be the case for the remaining labs.

3.1 Current-Voltage characteristics of PN junction diodes

A curve tracer is an instrument used in analyzing the current-voltage characteristics of a diode or transistor. This is achieved by varying the voltage or current applied to the device, while observing the other component. The LTC-905 curve tracer is used in this lab, and it is connected to the DPO-4032 oscilloscope in order to observe and study the I-V curve of different diodes. The connections, component placement, settings for the curve tracer and oscilloscope are described below.

Oscilloscope to Curve tracer Connections:

1. Connect the red (positive) input of **Channel 1** of the oscilloscope (corresponding to the X or Horizontal axis) to the red HORIZONTAL output of the curve tracer.
2. Connect the black (negative) input of **Channel 1** of the oscilloscope to the black HORIZONTAL output of the curve tracer.
3. Repeat the same connections for **Channel 2** (corresponding to the Y or VERTICAL axis) of the oscilloscope and the VERTICAL outputs of the curve tracer as shown in Fig. 3.1.

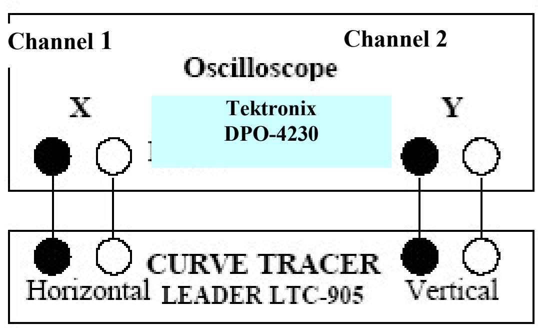

Fig. 3.1 Connection of curve tracer to Oscilloscope and the diode

The following NOTES pertain to the Curve Tracer:

Note 1: The upper SELECTOR switch can be toggled between Transistor, TRANS for a BJT, or FET according to the component that is being analyzed

Note 2: The lower SELECTOR switch can be toggled between port A and port B according to the port into which the component has been inserted

Note 3: Rotating the corresponding knob can vary the base current/gate voltage. The collector current/drain sweep voltage can be similarly varied. This is used to generate the characteristic curves of the component as the voltage and/or current is varied.

Diode Forward Bias Analysis:

Document in your data sheet and report the definition of **Turn on voltage**.

Oscilloscope and Curve Tracer Settings for Forward Bias

Oscilloscope (Tektronix DPO 4032):

1. Preparing the oscilloscope for this experiment:
    a. Turn Oscilloscope **ON**.
    b. If there are measurements appearing at the bottom of the screen, remove them all by doing the following:
        i. Press **Measurement**.
        ii. Press the soft key on the bottom of the screen corresponding to **Remove Measurement**.
        iii. Press the soft key on the right side of the screen corresponding to **Remove All Measurements**.
2. Setting the oscilloscope to display the XY mode:
    a. Press the **ACQUIRE** soft key located in the **Horizontal** knob and key controls.
    b. To set the XY mode **ON**:

i. Press the soft key corresponding to the **XY Display** appearing at the bottom of the oscilloscope screen.

ii. Press the soft key corresponding to the **Triggered XY** appearing at the right hand side of the screen.

iii. Ensure an XY graph appears covering the half leftmost part of the oscilloscope screen.

iv. **LOOK FOR** a yellow small **OR** big fuzzy **SPOT** somewhere on the XY screen, most likely at the origin.

3. Set Channel 1 to 100 mV/Div, by turning the **Scale** knob for Channel 1.
4. Set Channel 2 to 100 mV/Div, by turning the **Scale** knob for Channel 2.
5. Invert Channel 2. To perform this:
    a. Press the soft key button for Channel 2.
    b. Press the soft key corresponding to **Invert** on the bottom of the screen and set it to **ON**.
6. Set the **Coupling** for Channels 1 and 2 to **Ground**:
    a. Press Channel 1 soft key.
    b. Press the corresponding soft key for **Coupling** at the bottom of the screen until the chassis **Ground** symbol is selected.
    c. Repeat steps 6a and 6b for Channel 2. **When the yellow SPOT becomes finer and smaller, it may be difficult to see.**
7. Adjust the finer **SPOT**, **which indicates the origin**, to the **lower left-hand corner** of the oscilloscope screen by using the **Position**

knobs. This enables you to use the entire screen to see the Forward Bias I-V curve.

8. After setting the new origin, set Channels 1 and 2 to DC mode by doing the following:
    a. Channel 2 menu should already appear at the bottom of the screen, otherwise press the soft key for Channel 2.
    b. Press the corresponding soft key for **Coupling** until **DC** is selected.
    c. Press Channel 1 soft key.
    d. Press the corresponding soft key for **Coupling** until **DC** is selected. **NOTICE** the finer yellow **SPOT**, now located at the left-hand corner becomes, fuzzier again.
9. Set the Time/div to **4.0 ms** by adjusting the **Scale** knob of the **Horizontal** knob and key controls.

Curve Tracer Settings:

1. **COLLECTOR/DRAIN SWEEP VOLTAGE** is set to 10V
2. **POLARITY** is set to DIODE FORWARD (NPN side)
3. **SELECTORS**: Upper: TRANS. Lower: A
4. **BASE CURRENT / GATE VOLTAGE**: Any setting (NA)
5. **CURRENT LIMIT**: SIGNAL
6. **H LENGTH**: Rotate fully clockwise

Experimental Procedure:

1. Obtain the Zener diodes 1N5234, 1N5237, and 1N5239. The positive and negative terminals of each diode are as shown in Fig. 3.2 below.

2. Connect the 1N5234 Zener diode between the C (+) and E (–) terminals on the A side of the curve tracer. You may use wires for the Jack area OR if the diode leads are thin, the leads can be inserted into the small holes of the Transistor plug indicated as C (+) and E (–).

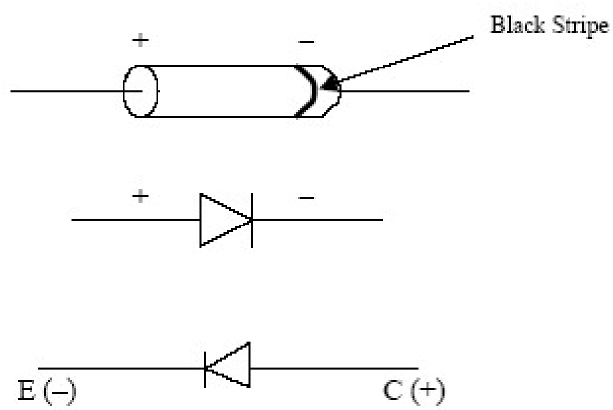

Fig. 3.2 Diode Configurations

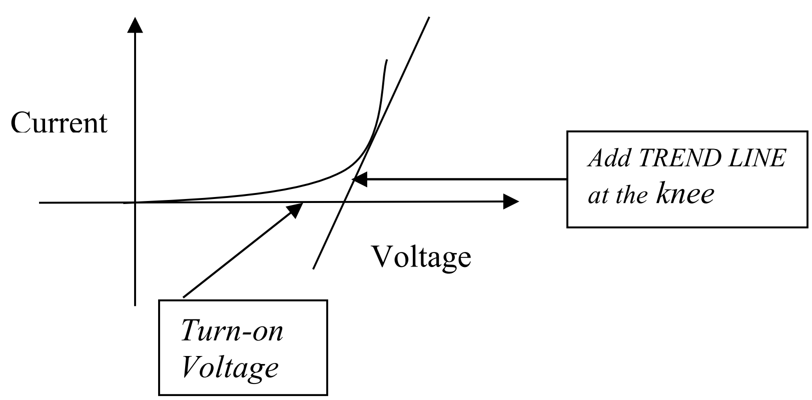

Fig. 3.3 Diode I-V curve (Forward Bias)

3. Set the Power Switch on the Curve Tracer to the **ON** position.
4. Ensure a curve resembling Fig. 3.3 above appears on the oscilloscope screen.
    a. **IMPORTANT, this is an I-V curve, so you must know that the Voltage is on the X axis and the Current on the Y axis.**
    b. The curve may be very fuzzy and faint.
5. To improve the definition and intensity of the curve do the following
    a. Press the **Intensity** button

        On the upper right hand corner, **a** Waveform Intensity and **b** Graticule Intensity percentages readout should appear.

    b. Turn Knob **a** until the Waveform Intensity readout shows **100%**
    c. Press **Acquire**
        i. On the bottom of the screen, press the soft key for **Mode**.
        ii. On the right hand side of the screen, press the soft key for **Hi Res**.
        iii. **Ensure that the curve trace is well defined and brighter.**
6. **Save the Waveform in .CSV format by doing the following:**
    a. Press **Menu** on the bottom of the screen.
    b. Press the **Save Waveform** soft key also on the bottom of the screen.

c. Press the **Waveform Source** soft key on the right side of the screen.

   Turn Knob **a** to select All Displayed Waveforms.

d. Press **To File** soft key again on the right side of the screen.

   i. Turn Knob **a** to scroll down to your Memory media.
   ii. Press the **Select** button

       You may also select a desired folder to save to by scrolling and selecting in the same manner just mentioned.

   iii. **Select the .CSV Spread Sheet File Format** by pressing the corresponding soft key on the right side of the screen. **IMPORTANT, if the data is not in .CSV format you will not be able to do the required analysis in Excel.**

e. Press **OK Save All**, an hour glass appears indicating saving data.

7. Ensure the data has been saved.
8. DO NOT CHANGE THE OSCILLOSCOPE'S SETTINGS AFTER THIS POINT UNTIL THE NEXT SECTION.
9. Set the Curve Tracer Power Switch to the **OFF** position.
10. Use **Excel**, preferably on your laptop or, in the lab computer to open the data file obtained from the oscilloscope.
    a. It contains approximately 10015 rows of data points for TIME, CH1 and CH2!
    b. CH1 is the Voltage data and CH2 is the current data

i. **IMPORTANT**, the Current data collected directly from the oscilloscope is in V/cm:

ii. **Before plotting, use the Conversion Table 3.1 to convert the Current to its correct units/div, mA/cm or A/cm.**

11. Plot the data of CH1 (Voltage, X axis) and the **converted** data of CH2 (Current, Y axis).
    a. Use an XY scatter type graph.
    b. Label the graph **Diode Characterization-Forward Bias**.
    c. Label the axis appropriately including the units i.e. Current in A or mA, Voltage in V, etc.
12. Determine the value of the **Turn on Voltage**, which is the X axis intersection of the tangent line at the **knee** of the curve as shown in Fig. 3.3

    IMPORTANT, you need to add a linear TREND LINE at the knee **of your plot to find the** Turn on voltage **value accurately**

<u>**Note:**</u> The forward bias I-V curve, the understanding and value with proper units and sign of the **Turn on Voltage are THE OBJECTIVES OF THIS SECTION**

Diode Reverse Bias Analysis:

Document in the datasheet and in the report results the definition of **Breakdown Voltage**

Oscilloscope and Curve Tracer Settings for Reverse Bias

Oscilloscope:

From the Forward bias settings just do the following changes:

a. Use the **Position** knobs to set the finer yellow **SPOT**, representing the origin, to the upper **Right hand corner** of the screen. This will allow the use of the entire screen to see the reverse bias curve.
b. Set Channel 1 to 1 V/cm using the scale knob for Channel 1.
c. Set Channel 2 to 1 V/cm using the scale knob for Channel 2.

Curve Tracer Settings:

From the Forward bias settings just do the following changes:

1. COLLECTOR SWEEP is set to 20V.
2. **POLARITY is set to DIODE BACKWARD (PNP side).**

Experimental Procedure:

1. With the 1N5234 diode still between the C and E terminals on the A side of the curve tracer, set the Power Switch on the Curve Tracer to the **ON** position.
2. Ensure a curve resembling Fig. 3.4 appears on the oscilloscope screen.
3. Save the curve in .**CSV Spread Sheet File Format** following the instructions for saving given in the Forward Bias section.
4. Ensure the data has been saved.

5. Set the Curve Tracer Power Switch to the **OFF** position.
6. On your laptop or lab computer, use **Excel** to open the data file obtained from the oscilloscope.
    a. It contains approximately 10015 rows of data points for TIME, CH1 and CH2!
    b. CH1 is the Voltage data and CH2 is the current data
        i. **IMPORTANT**, the Current data collected directly from the oscilloscope is in mV/cm or V/cm:
        ii. **Before plotting, use the Conversion Table 3.1 to convert the Current to its correct units/div, A/cm or mA/cm.**
7. Plot the data of CH1 (Voltage, X axis) and the **converted** data of CH2 (Current, Y axis).
    a. Use an XY scatter type graph.
    b. Label the graph **Diode Characterization-Reverse Bias**.
    c. Label the axis appropriately including the units i.e. Current in A or mA, Voltage in V, etc.
8. Determine the value of the **Breakdown Voltag**e, which is the point at the X axis as shown **in Fig. 3.4 below, in our case there is no gradual knee but a sharp bend instead.**

<u>**Note**:</u> The reverse bias, the understanding and the value with proper units and sign of the **Breakdown Voltage are THE OBJECTIVES OF THIS SECTION**

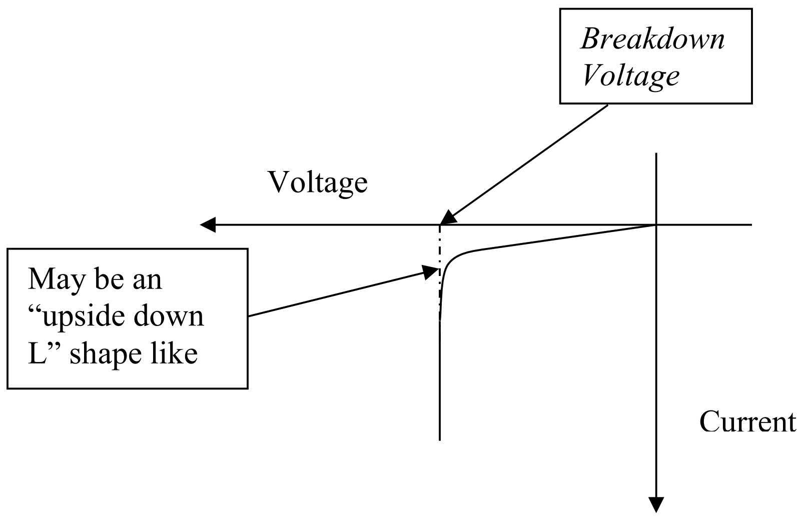

Fig. 3.4 Diode I-V curve (Reverse Bias)

9. Repeat the above procedure for the remaining diodes, this means DO THE FWD BIAS AND REVERSE BIAS FOR ALL 3 DIODES, but see the next steps first.
   a. To go back to Forward Bias settings just do the following:
      i. On the Oscilloscope:
         1. Adjust the finer yellow SPOT back to the lower **Left hand corner** of the screen.
         2. Set Channel 1 and Channel 2 back to 100 mV/cm.

      ii. On the Curve Tracer:
         1. Set the POLARITY back to **NPN**.
         2. COLLECTOR SWEEP back to 10.
         3. **Replace the diode.**

4. Switch POWER to **ON**.

10. Go back up to the instruction mentioning to ensure to see the Forward bias curve on the screen. **Repeat the procedure until all three Zener diodes are characterized.**

Table 3.1 Conversion Table for Converting VOLTS to AMPS

Vertical Y sensitivity on scope	Conversion using LTC-905 curve tracer
50 mV/cm	0.5 mA/cm
0.1 V/cm	1 mA/cm
0.2 V/cm	2 mA/cm
0.5 V/cm	5 mA/cm
1 V/cm	10 mA/cm
2 V/cm	20 mA/cm
3 V/cm	30 mA/cm

3.2 DC analysis of a diode

1. **Record the usually assumed** V_d for a diode, then **calculate** Vout, and i_d, the current passing through the diode, in the circuit shown in Fig. 3.5.
2. Construct the circuit:
    a) RLC meter and use R=1kΩ.
    b) Use the 1N4005 (or 1N4003, perform the same in this lab) diode and adjust V_T to 5V.
3. Measure V_{out} across R using the digital multimeter.
4. Measure i_d, the current passing in the diode.
5. Measure V_d, the voltage drop across diode.

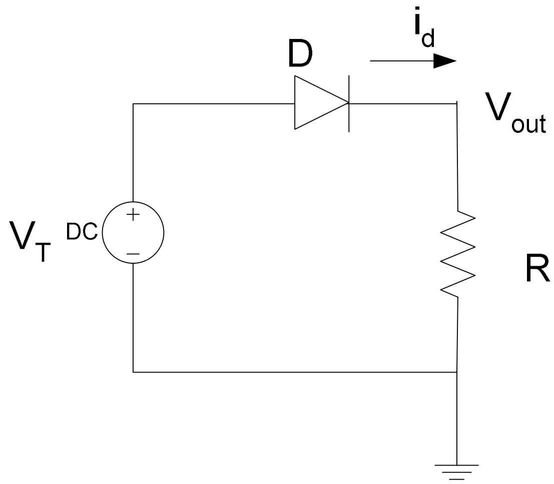

Fig. 3.5

6. Simulate the circuit in LTSpice.
   a. Show the DC op pnt results. Show Vout and id.
7. Obtain the Current – Voltage characteristic of the diode by doing a DC Sweep of the LTSpice circuit:
   a. Go to Run >> DC Sweep, select DC Sweep and enter the following settings:
      i. Sweep Variable Type: Voltage Source
      ii. Name: V1 (DC source name)
      iii. Sweep Type: Linear Sweep
      iv. Start Value: 0
      v. End Value: 5
      vi. Increment: 0.1
      vii. Click O.K. after set up, and then Close.
   b. Plot the voltage across the diode and resistor, plot the current through the diode.
8. Once the trace is visible, measure the relevant parameters, such as the Voltage and Current at 5V in this case.

9. Save a copy of the trace with relevant parameters to be pasted directly onto your lab report LTSpice results.
10. Use % Error to compare the calculated with the measured and the LTSpice results.

3.3 Small signal (AC) analysis of a diode

1. **Calculate** Vout assuming Vd = 0.7V, these are the DC voltage drops across the resistor and the diode respectively in Fig 3.6.
2. According to the Vd **assumption** from above, calculate I_d, the DC current through the diode.
3. Construct the circuit.
   a. Use R=1kΩ. Measure its value using the RLC meter.
   b. Use 1N4005 (or 1N4003, perform the same in this lab) diode.
   c. Adjust V_T to 5V DC.
   d. Set The Function Generator, Vs, to High Z.
   e. Set V_S, to 1 Vpp sinewave at 1 kHz.
4. Use the oscilloscope to obtain:
   a. The waveform of Vs and Vout, the AC voltages of the source and the drop across the resistor respectively.
      i. Pay close attention to waveform offsets, if there is any, record it**. What does an offset represent?**
      ii. Place the relevant parameters, such as Vpp and Vrms, of both waveforms on the screenshot.
      iii. Save a bmp format copy of the screenshot including the relevant parameters.
      iv. Calculate the Vrms for Vs and Vout from the Vpp obtained from the oscilloscope.
      v. Are the calculated Vrms' values equal to the oscilloscope values? Explain why or why not.
   b. Using the MATH function, obtain i_d, the current waveform passing through the diode

Hint: In order to get i_d, obtain the V_{out} waveform first, then divide by the actual value of the resistor.

i. Place the relevant parameters, such as Ipp and i(rms), of the waveform on the screenshot.

ii. Save a bmp format copy of the screenshot including the relevant parameters.

c. To obtain the waveform of V_d, the AC voltage drop across diode

i. Set the oscilloscope to 200mV/div and the Channel to DC Coupling

Note: At this resolution the waveform for V_d looks like noise, why?

ii. Pay close attention to the waveform offset

i. Measure the offset using the **Mean** in the oscilloscope.

ii. What does this offset represent?

iii. Save a bmp screen shot of V_d and **relevant parameter** at this resolution.

iv. Set the oscilloscope to 5mV/div and the Channel to AC Coupling in order to observe V_d

v. Place the relevant parameters, such as Vpp and Vrms, of the waveform on the screenshot.

vi. Save a bmp format screenshot including the relevant parameters of your results at this resolution.

5. Use the DMM to:

a. Measure and record the DC and AC values of V_{out}.

b. Use the above measurements to determine the DC and rms values of i_d.

c. Measure and record the DC and rms values of V_d.

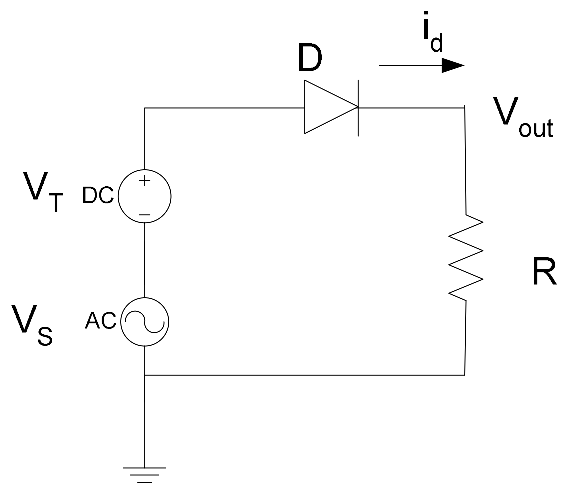

Fig. 3.6

6. Simulate the circuit in LTSpice:
   a. Use VDC = 5V.
   b. Signal since wave settings:
      a. VOFF=0, VAMPL=0.5, FREQ=1k
   c. For LTSpice results, obtain a Transient Analysis with relevant parameters for v_d, Vout and i_d.
7. Use % Error to compare calculated, lab results and LTSpice results.

3.4 Half-Wave Rectifier

1. Construct the circuit as shown in Fig. 3.7. Adjust V_S to 15 Vpp sine wave at 1 kHz.

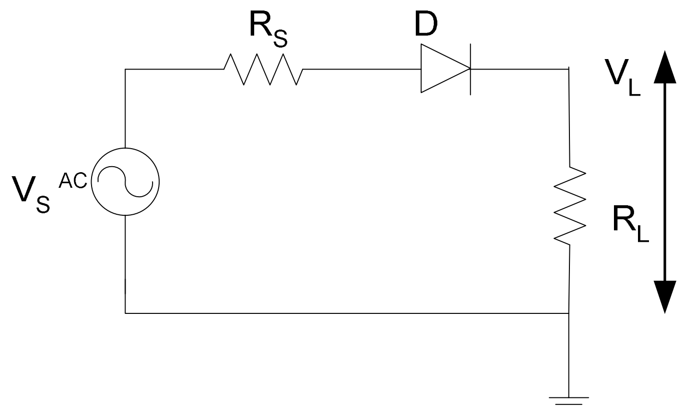

Fig. 3.7 Half-wave rectifier

2. Use $R_S = R_L = 1k\Omega$. Measure their values using the RLC meter. Use the 1N4005 (or 1N4003, perform the same in this lab) diode.
3. Using the oscilloscope (Tektronix–DPO4032), obtain the input waveform of V_S and the output waveform, V_L and relevant parameters.
4. Simulate the circuit in LTSpice and compare with the oscilloscope results.

3.5 Full-Wave Rectifier

1. Connect the diode bridge rectifier (DB101) and the transformer as shown in Fig. 3.8. Use the transformer with the wooden base.

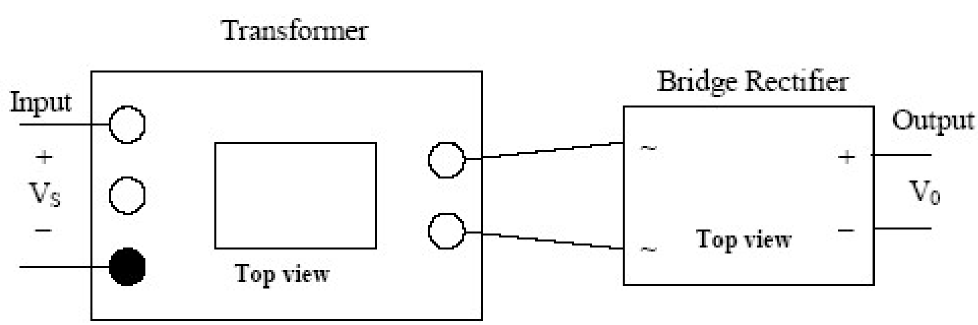

Fig. 3.8 Diode full-wave rectifier

2. Adjust V_S to 15 Vpp Sine Wave with a frequency of 50 Hz and observe the output waveform.
3. Obtain a screenshot of ONLY the output waveform with relevant parameters.
   Note: The input to the bridge rectifier must be connected as shown in Fig. 3.8.

3.6 Peak Detector (Rectifier)

1. Construct the circuit as shown in Fig. 3.9. Adjust V_S to 15 Vpp sine wave at 1 kHz.
2. Use C_L = 100nF and R_L =100kΩ. Measure their values using the RLC meter. Use the 1N4005 (or 1N4003, perform the same in this lab) diode.
3. Using the oscilloscope (Tektronix–DPO4032), obtain the input waveform of V_S and the output waveform, V_L and relevant parameters.
4. Simulate the circuit using LTSpice. Obtain the waveform of V_S and V_L
   Note: Use signal sine wave for the AC source in the LTSpice schematic. VOFF=0, VAMPL=7.5, FREQ=1k.
5. Are your measured and simulated results matched? Compare the results.

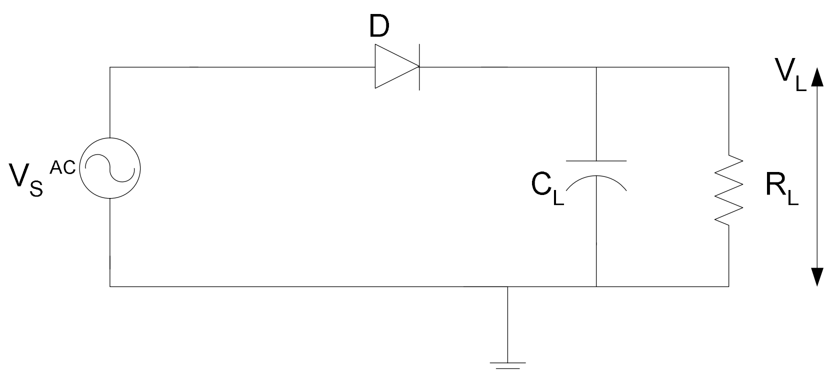

Fig. 3.9 Peak detector rectifier

3.7 Diode Clamper

1. Construct the circuit as shown in Fig. 3.10. Adjust V_S to 15 Vpp sine wave at 1kHz and V_R to 5 V_{dc}.
2. Use C = 100nF. Measure its value using the RLC meter. Use the 1N4005 (or 1N4003, perform the same in this lab) diode.

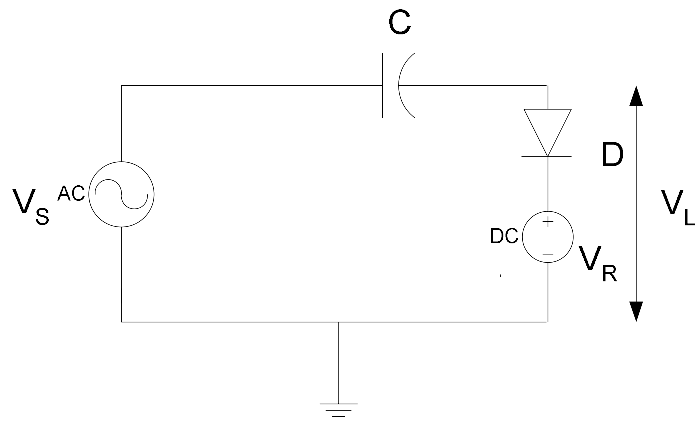

Fig. 3.10 Diode clamper

3. Using the oscilloscope (Tektronix–DPO4032), obtain the input waveform of V_S and the output waveform, V_L and relevant parameters.
4. Simulate the circuit using LTSpice. Obtain the waveform of V_S and V_L.

   Note: Use signal sine for the AC source in the LTSice schematic. VOFF=0, VAMPL=7.5, FREQ=1k.
5. Are your measured and simulated results matched?

3.8 Diode Limiter (Clipper)

1. Construct the circuit as shown in Fig. 3.11. Adjust V_S to 15 Vpp Sine Wave at 1kHz and V_R to 5 V_{dc}.
2. Use R =1kΩ. Measure its value using the RLC meter. Use the 1N4005 (or 1N4003, perform the same in this lab) diode.
3. Using oscilloscope (Tektronix–DPO4032), obtain the input waveform of V_S and the output waveform, V_L.
4. Also, use the Tektronix DPO4032 oscilloscope to obtain the Voltage transfer characteristic V_L versus V_S.

   Set the oscilloscope to XY mode as in lab 3 but do not invert channel 2. You may leave the Yellow SPOT at the center of the graph and set the Volts/div according to the voltage in this case.

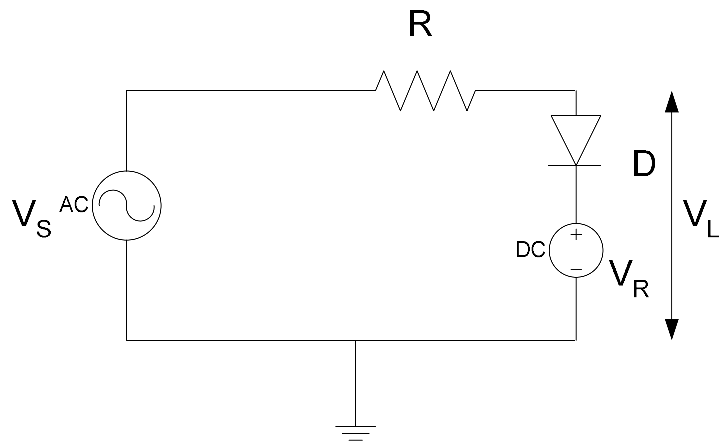

Fig. 3.11 Diode limiter

5. Simulate the circuit using LTSpice and obtain the waveforms of V_S, V_L (transient), and voltage transfer characteristics (Plot Vs as your x-axis and VL as your y-axis, i.e. DC sweep or can change the axis setting).

   Note: Use signal sine for the AC source in the LTSpice schematic. VOFF=0, VAMPL=7.5, FREQ=1k.
6. Are your measured and simulated results matched?

3.9 Zener Diode Voltage Regulator

1. Construct the circuit as shown in Fig. 3.12. Adjust V_S to 5 Vpp sinewave at 1 kHz.
2. Use $R_S = 560\Omega$ and $R_L = 1k\Omega$. Measure their values using the RLC meter. Use the 1N5237 Zener diode.
3. Using the oscilloscope (Tektronix–DPO4032), obtain the input waveform of V_S and the output waveform, V_L.

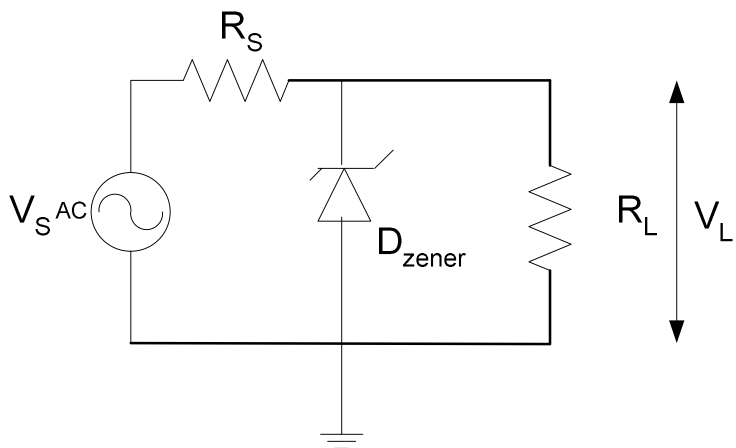

Fig. 3.12 Zener diode voltage regulator

4. Simulate the circuit using LTSPICE. Obtain the waveform of V_S and V_L.
   Note: Use signal sine for the AC source in the SPICE schematic. VOFF=0, VAMPL=2.5, FREQ=1k.
7. Are your measured and simulated results matched?

3.10 Voltage Multiplier circuit

The circuit in Fig. 3.13 is a voltage multiplier. The circuit operation is similar to that of a full wave rectifier, when the capacitor voltages are superimposed.

Procedure:

1. Construct the circuit as shown in Fig. 3.13. Adjust V_S to 20 Vpp Sine Wave at 1kHz.
2. Use C_1=C_2=1000µF, R = 10kΩ. Measure its value using the RLC meter. Use the 1N4005 (or 1N4003, perform the same in this lab) diode.
   Note: Pay attention to the capacitors polarities while connecting them.
3. Using the oscilloscope (Tektronix–DPO4032), obtain ONLY the output waveform, V_O with relevant parameters.

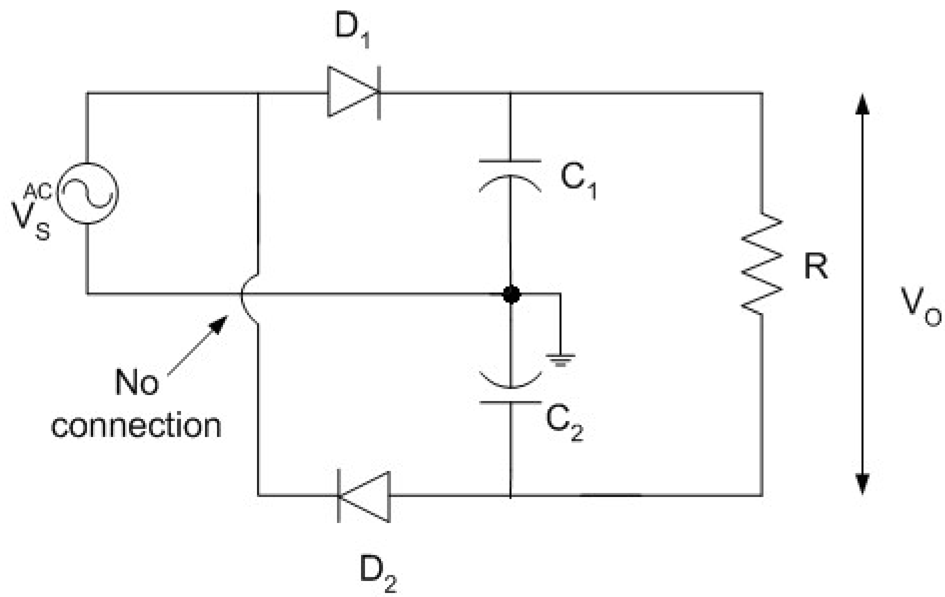

Fig. 3.13 Voltage multiplier

4. Simulate the circuit using LTSpice. Obtain the waveform of both V_S and V_O.
   Note: Use signal sine for the AC source in the LTSpice schematic. VOFF=0, VAMPL=10, FREQ=1k.
5. Determine the multiplication factor (MF) for measured and simulated results?

$$\textit{The multiplication factor (MF)} = \frac{V_O \text{ rms}}{V_S \text{ rms}} \tag{3.1}$$

   Note: *The input voltage is an AC voltage, while the output voltage is DC.*
6. Are your measured and simulated results matched?

Post-lab questions:

1. Explain the function of the Curve Tracer in this experiment

Use LTSpice to answer the following post lab questions (show LTSpice schematic and result graphs in your lab report):

2. In Fig. 3.5 (DC analysis of a diode), what would be I_d if:

a. The resistor, R, was shunted (parallel) with a resistor, R_{shunt}, of equal value (1kΩ).
b. The resistor R was connected with another 1kΩ resistor in series.
c. The diode, D, were shunted (parallel) with a diode, D_{shunt} (assumed to be matched).

3. In Fig. 3.6 (Small signal (AC) analysis of a diode), what would happen if the polarity of the DC voltage source were swapped?
4. What would happen if a capacitor C=1μF were added (in parallel with R) to the diode circuit shown in Fig. 3.6?
5. Use LTSpice to implement and verify what would happen if the capacitor were increased ten times in the Peak Detector Rectifier? Explain.
6. Draw a circuit diagram to represent DB101 chip, as shown in Fig. 3.8. Make sure that you label the input and output voltage in your drawing.

   Note: You do not have to consider the transformer diagram in your drawing.
7. Discuss the operation of the voltage multiplier circuit.
8. What would happen if the capacitors (C_1 and C_2) were 1μF in the voltage multiplier circuit? Explain.