Department of Electrical and Electronic Engineering
Shahjalal University of Science and Technology

EEE 222: Electronic Circuit Simulation Laboratory

EXPERIMENT NO. 01

Name of the Experiment: STUDY OF DIODES AND ITS APPLICATIONS.

OBJECTIVE

The objective of this experiment is to simulate

- I-V characteristics of diodes.
- Clipper and clamper circuits.
- Diode bridge rectifier.
- Regulated power supplies using diodes.

THEORY

A p-n junction diode is a two-terminal device that acts as a one-way conductor. When a diode is forward biased as shown in Fig. 1(a), current I_D flows through the diode and current is given by

$$I_D = I_S\left[e^{\frac{V_a}{nV_T}} - 1\right] \qquad (1)$$

where, n is the ideality factor and 1≥ n ≥2. I_S is the reverse-saturation current and V_T =kT/q is the thermal voltage. V_T is about 0.026V at room temperature.

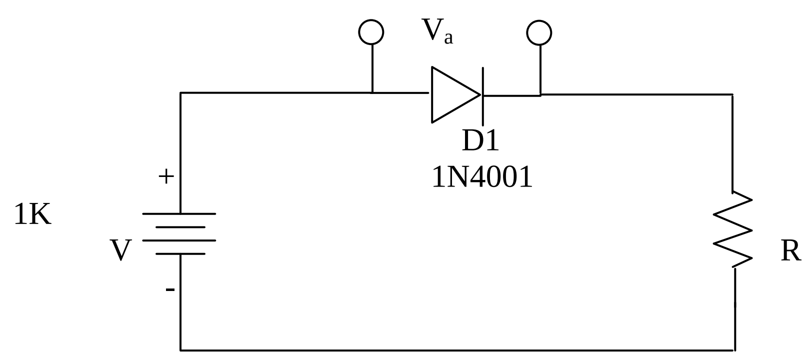


Fig.1(a)

When it is reverse biased as shown in Fig. 1(b), I_D = -I_S (for see eqn. (2)). As it is generally in pA (pico-amp) range, in many applications this current is neglected and diode is considered open.

$$I_D = I_S\left[e^{-V_R/V_T} - 1\right] = -I_S \quad \text{for } |V| >> V_T \qquad (2)$$

The material for p-n junction diode is silicon semiconductor. Semiconductors are a group of materials having electrical conductivity intermediate between metals and insulators.
Metals: Al (aluminum), Cu (copper), Au (gold).
Insulators: Ceramic, Wood, rubber.
Semiconductor: Si (silicon), Ge (germanium), GaAs (gallium-arsenide).

P-type Silicon:

When an intrinsic silicon semiconductor is doped with Al impurities, it becomes p-type. At thermal equilibrium,

$$p_o = N_A \quad \text{and} \quad n_o = n_i^2/N_A$$

Where, p_o is the hole concentration, n_o is the electron concentration, N_A is the doping density of impurities (acceptor atoms), n_i is the intrinsic concentration. $n_i = 1.5\text{x}10^{10}\text{cm}^{-3}$ for Si at room temperature .

N-type silicon:

When an intrinsic silicon semiconductor is doped with P (phosphorous) impurities it becomes n-type. At thermal equilibrium, $n_o = N_D$ and $P_o = n_i^2/N_D$. Here, N_D is the doping density of impurities (donor atoms).

In semiconductor both holes and electrons contribute to current.

Current-Voltage Characteristics

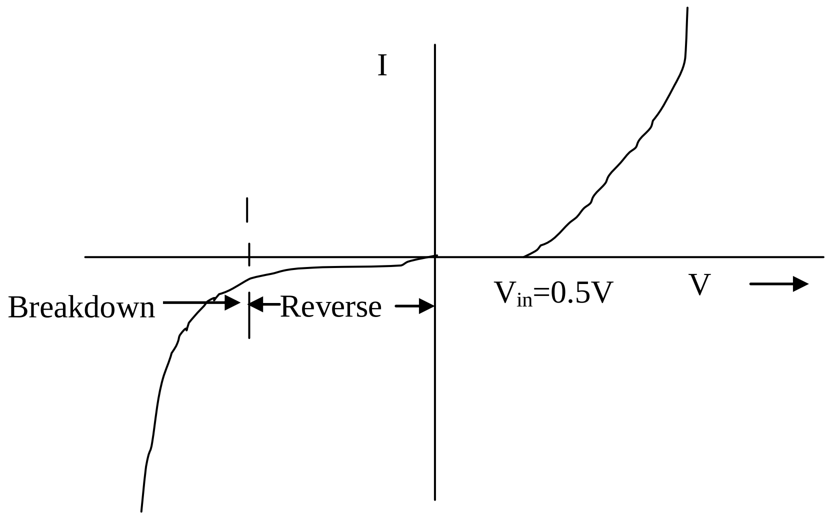
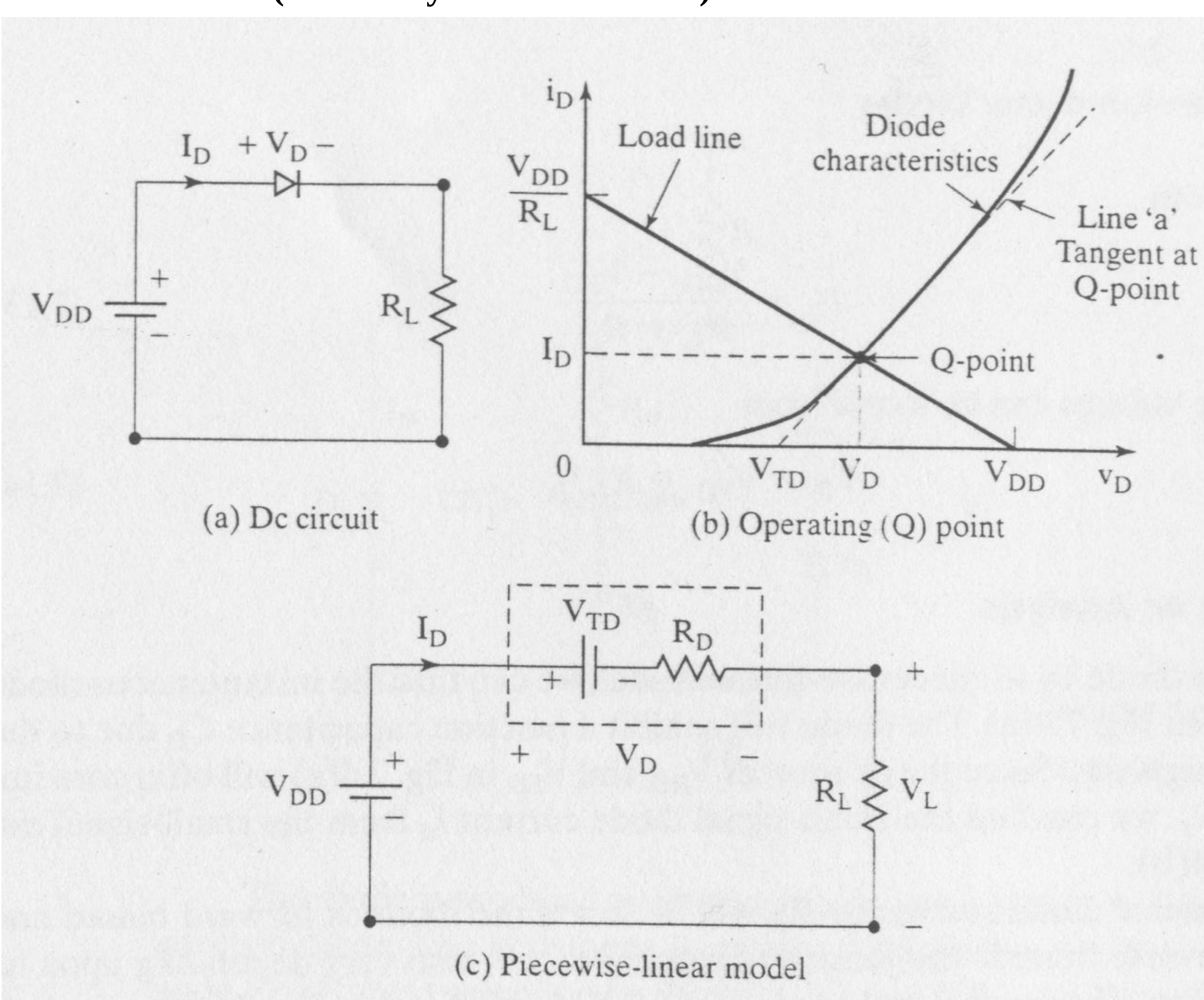


Fig. 1(b)

V_{in} is the cut-in voltage. Its value is usually 0.5V. At this voltage, diode is forward biased but even then I is very small and it is usually neglected. When diode is reverse biased and $V < V_K$, diode drives into breakdown and a large current will flow. The current can be limited by using resistor in diode circuit. If the slope (dI/dV) is very steep, the breakdown mechanism is called Zener breakdown. Zener diode can be used in regulator circuit.

Piecewise-Linear (or Battery-Plus-Resistance) model:



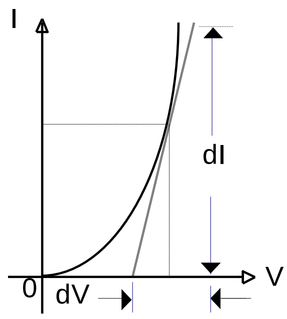
$R_D \equiv 0.0258n/I_D$

Small signal ac model

The previous models represent the dc behavior of the diode
When there are small changes of current through the diode need a small signal or ac model

• A small change in forward current through the diode will give rise to a corresponding change in forward voltage

$$\Delta I/\Delta V = (q/k_BT)I_0\exp(qV/k_BT) \approx qI/k_BT$$



- This gives rise to an effective resistance of the diode to small currents
  - The Dynamic forward resistance of the diode

$$r_D = \Delta V/\Delta I = k_BT/qI$$

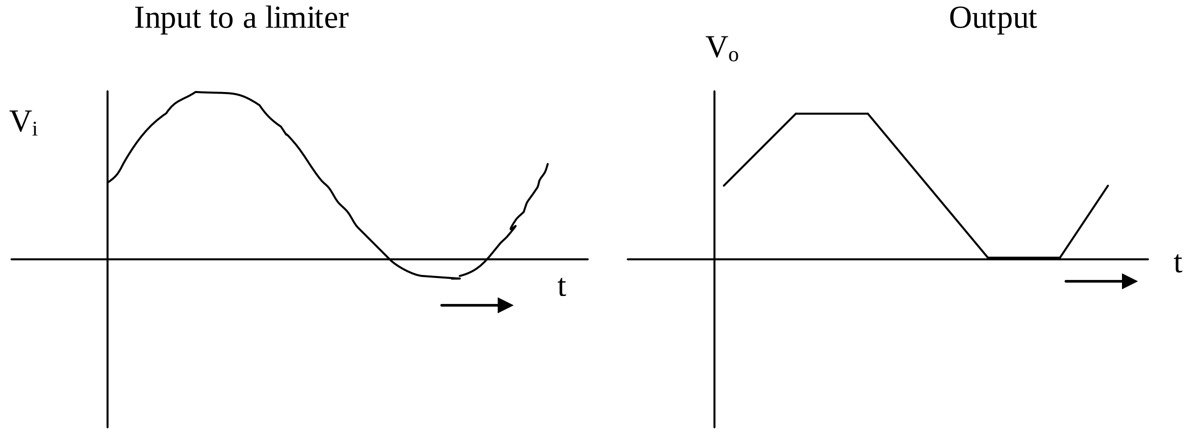
At room temp $r_D \approx 0.025/I\ \Omega = 1/40I\ \Omega$

- Dynamic resistance only changes slightly for small changes in temp.
- Ohmic resistance decreases with increase in T ≈ -2.5 mV/K

Clipper and clamper circuits:

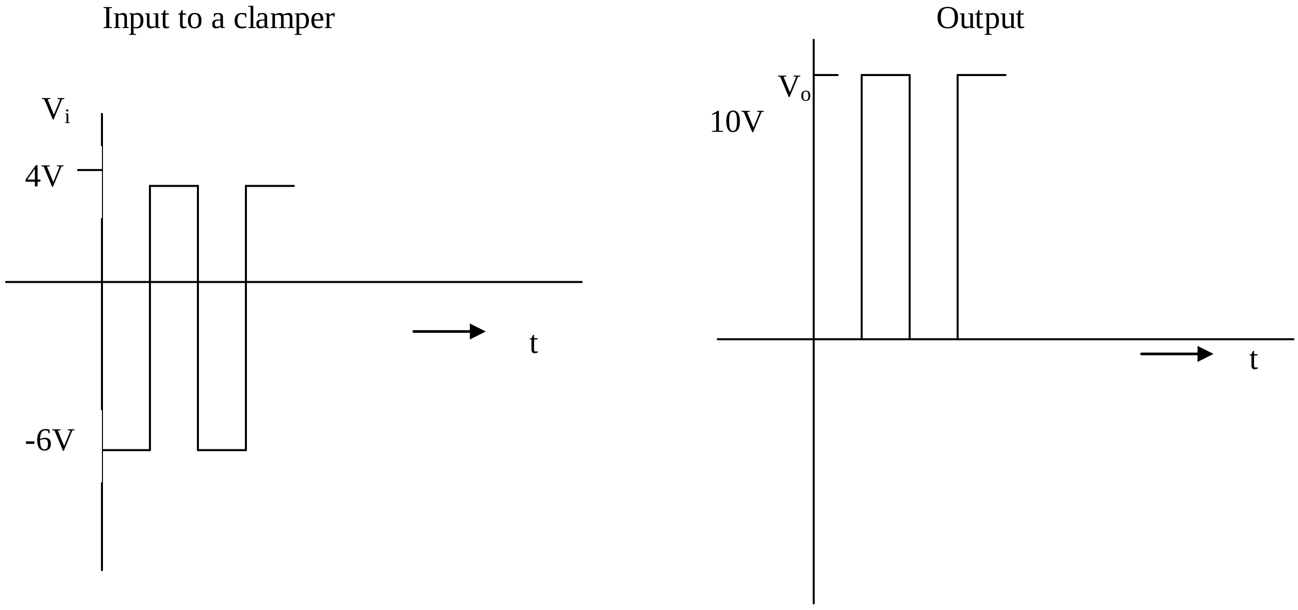
Limiter or clippers are used to cut-off or eliminate a portion of an ac signal. A limiter can be realized by using diode and resistor as shown in Fig 1.

Input to a limiter   Output



The clamper circuit is one that will clamp a signal to a different dc level.

Input to a clamper   Output



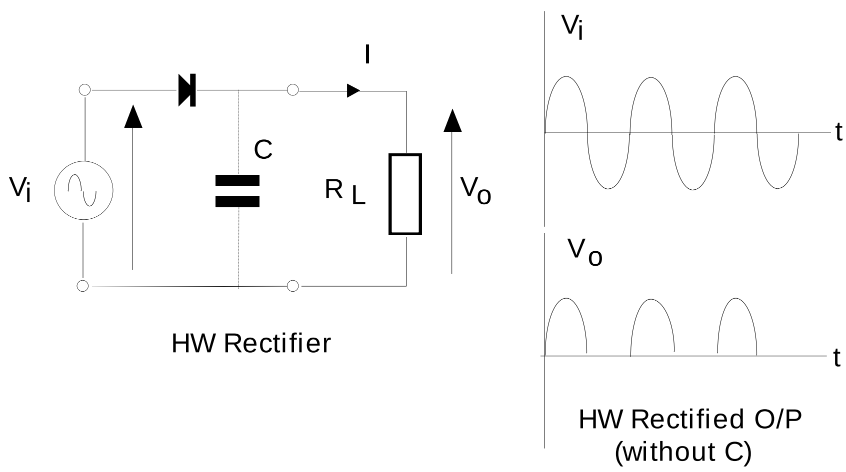
Peak Inverse Voltage)

PIV is the peak reverse voltage that appears across the diode when it is reverse-biased.

$$PIV = V_m.$$

Diode Rectifiers

- Diodes can be used to RECTIFY O/P from ac supply to produce a dc supply
  - $\rightarrow$ on +ve half cycle of I/P wave
    - $\Rightarrow$ diode is fwd. biased
    - $\Rightarrow$ diode conducts
  - $\rightarrow$ on -ve half, diode rev. biased
    - $\Rightarrow$ diode is rev. biased
    - $\Rightarrow$ diode does not conduct
  - $\rightarrow$ HALF-WAVE RECTIFIER



HW Rectifier

HW Rectified O/P
(without C)

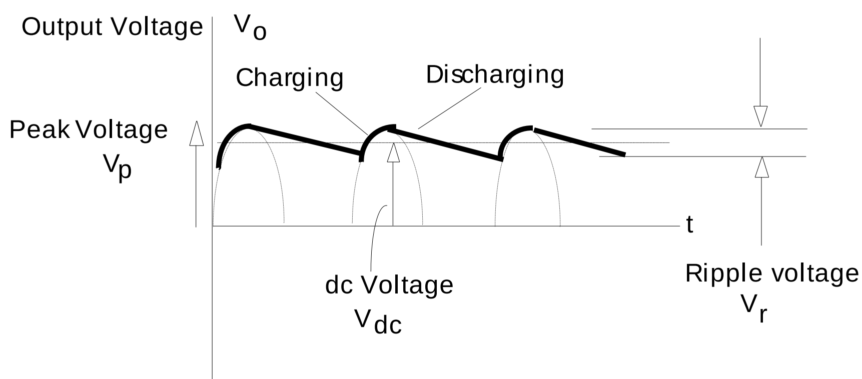
Average voltage (as seen on dc voltmeter)

$V_{ave} = V_p/\pi$

rms voltage (as seen on ac voltmeter)

$V_{rms} = V_p/\sqrt{2}$

Smoothing



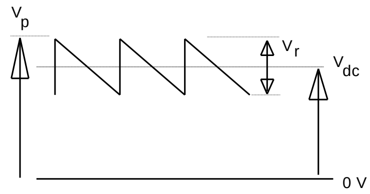
Smoothed HW Rectified O/P

If a capacitor is placed across output
- $\rightarrow$ capacitor charges on rising edge of +ve half-cycle
- $\rightarrow$ discharges on falling edge
- $\rightarrow$ O/P is smoothed

- Actual peak O/P will be reduced from peak I/P by value of forward. bias
  $V_p(out) = V_p(in) - 0.7$ V

Ripple voltage

- A finite load current I causes capacitor voltage to drop by V_r during ac cycle
  - $\rightarrow$ ripple in O/P is approx. sawtooth in shape $\rightarrow$ neglect charging time
  - $\rightarrow$ assume discharge takes one complete period (T)
- Charge flowing from capacitor in time T
  $Q = IT$



- Fall in capacitor voltage = pk-pk ripple
  $V_r = Q/C = IT/C$

$\rightarrow$ But T = 1/f (f is ac frequency)

$V_r(HW) = I/Cf$ HW Ripple Voltage

- As the ripple voltage increases the average (dc) O/P voltage decreases

$V_{dc} = V_p - 1/2(V_r)$

$V_{dc} = V_p - 0.5Cf$ HW dc Voltage

- Ripple factor defines magnitude of smoothing effect

$r = (V_r/V_{dc})\ 100\%$ Ripple factor

Full Wave Rectifier

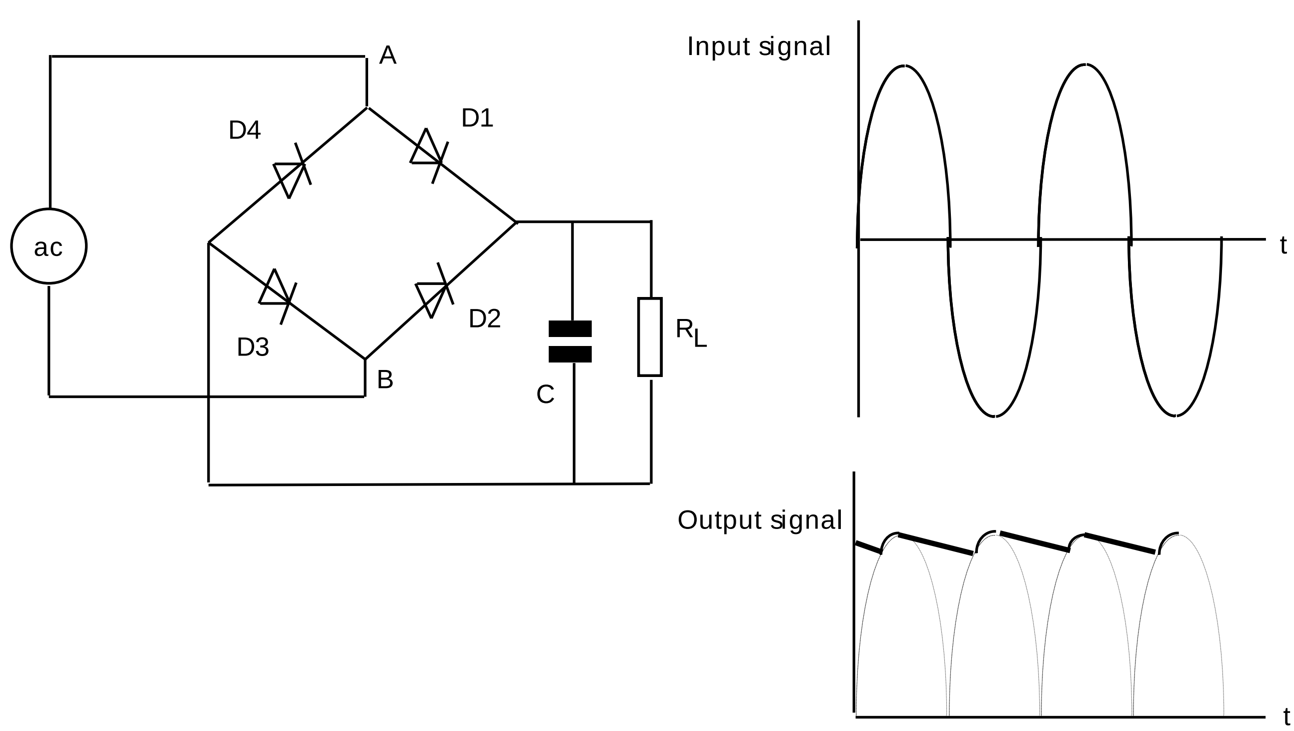
- Better rectification is obtained if circuit conducts on both I/P half-cycles
- On first half-cycle
  $\rightarrow$ When terminal A is +ve, D1 conducts to make top end of load +ve
  $\rightarrow$ At same time terminal B is -ve, D3 conducts to lower end of load
- On next half cycle
  $\rightarrow$ Terminal A is -ve and B is +ve, D2 conducts to top end of load, D4 conducts to lower end

$V_{ave} = 2V_p/\pi$ (without smoothing capacitor)

- For FW rectification, ripple frequency is twice ac I/P frequency

$V_r(FW) = 0.5\ Cf$ Ripple voltage

$V_{dc} = V_p - 0.25\ Cf$ dc Voltage (as seen on dc voltmeter)



N. B. Ripple Voltage=SQRT((RMS(V(R1:2))*RMS(V(R1:2))-AVG(V(R1:2))*AVG(V(R1:2))))

PROCEDURE

I-V Characteristics of Diode 1N4001

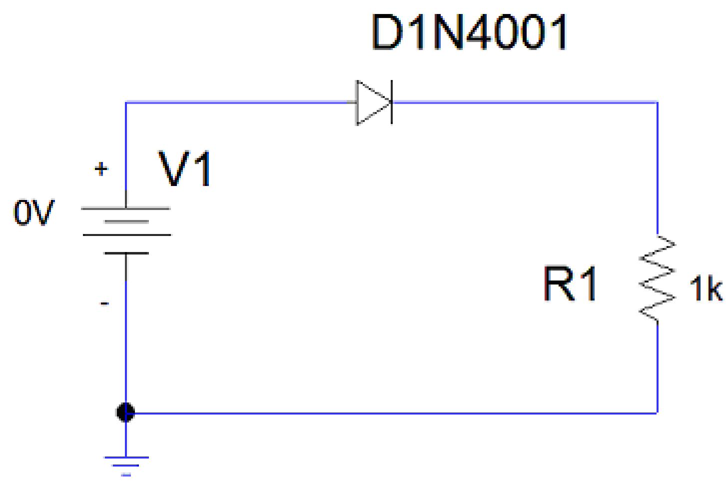


Fig.1. DC analysis of D1N4001

Draw the circuit shown in Fig. 1 in PSpice schematics. Use any of the 1N4001~1N4007 as diode module.

Here, for determining the I-V characteristics a DC Sweep of V1 from –5V to +10 volts will be needed. Set the increment of V1 to 0.1 volts in linear sweep mode.

Run the simulation.

Obtain I-V characteristic of the diode in the probe.

By changing the DC sweep determine the following:

a) Reverse saturation current.

b) Diode breakdown voltage.

Obtain Piecewise linear model for the diode when V1=10V (Home Work).

- To obtain this choose Bias Point Detail from Setup Analysis.
- Run the simulation and click on the Enable Bias Current Display.
- Note the diode current (I_D).
- Determine R_D.
- For finding V_{TD} from the I-V curve, click on the **Toggle Cursor** button. Select one point near I_D, right-click on the same point. Click another point near the first one. Obtain voltage and current magnitudes at two selected points (V_1, I_1, V_2, I_2) from the **Probe Cursor** menu. Then use the following formula:

$$V_{TD} = V_1 - I_1 * (V_1 - V_2) / (I_1 - I_2)$$

Replace the diode in Fig. 1 with a Zener diode (D1N750) and repeat steps 1 to 5(b) (Home Work).

Clipper Circuit

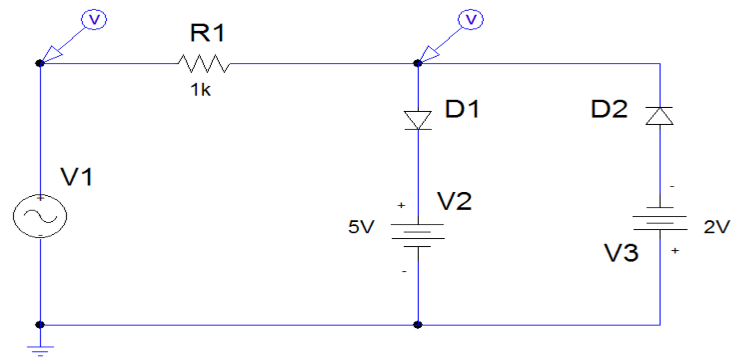


Fig.2. Clipper Circuit

2.1. Draw the circuit shown in Fig. 2 in PSpice schematics using 1N4001 (or any other) as diode module.

2.2. Here, for determining the input vs. output characteristics V1 is set to 1KHz and 10V (peak). Connect voltage markers as indicated in Fig. 2. Set transient analysis upto 5ms.

2.3. Run the simulation.

2.4. Observe the input (V1) and output (at D1's Anode terminal) voltages in the probe.

2.5. Change V2 from –1V to 4V in 1V step. Observe and notify what happens.

2.6. Explain the value of output voltage if V2 is set to –5V.

Clamper Circuit

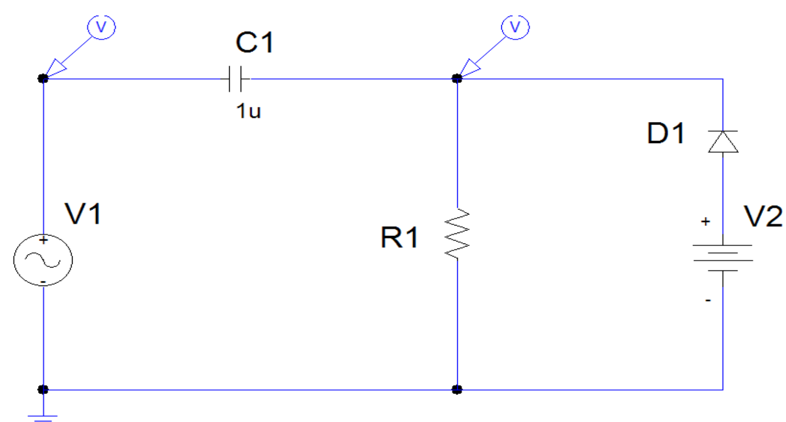


Fig.3. Clamper Circuit

3.1. Draw the circuit shown in Fig. 3 in PSpice schematics using 1N4001 (or any other) as diode module.

3.2. Here, for determining the input vs. output characteristics V1 is set to 1KHz and 10V (peak). Set R1 = 1MΩ, C1 = 1μF and V2 = 5V. Connect voltage markers as indicated in Fig. 3. Set transient analysis upto 5ms.

3.3. Run the simulation.

3.4. Observe the input (V1) and output (across R1) voltages in the probe.

3.5. Change V2 from –4V to 4V in 2V step. Observe and notify what happens.

3.6. Set R1 = 250Ω, C1 = 1μF and V2 = 0V. Observe the output voltage waveform and explain it.

3.7. Using square wave, repeat steps 2 to 6 and notify if there is any difference source is changed from sinusoidal to square.

3.8. Change the polarity of Diode and using sinusoidal source, repeat steps 2 to 6.

3.9.

Diode Bridge Rectifier and Regulated Power Supply

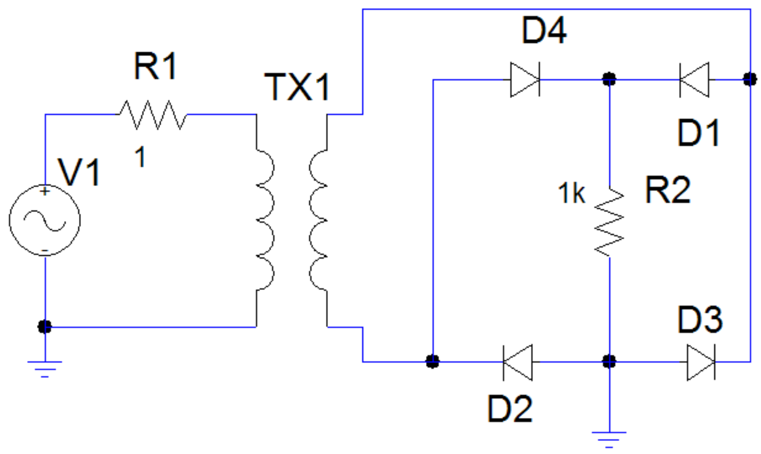


Fig.4. Diode bridge rectifier

Draw the bridge rectifier circuit as in Fig. 4. Use 1N4001 as diode module. TX1 is a transformer having part name “XFRM_LINEAR”. Double-click it and set L1 and L2 to 100mH.

Set V1 to 10V, 50 Hz. Run Simulation.

Observe the waveform across R2.

Notify the average voltage across R2 (V_{dc}) and ripple voltage across the same. Also find the RMS value of the ripple voltage (V_{ac}). Compare with theoretical values. [For finding the average and RMS values of any signal use AVG and RMS functions. Click “Add trace” icon. Then select “Analog operators and functions” from the “Function and Macros” pop-up menu. Select appropriate functions as necessary.]

Connect a capacitor across R2 and use values of 22μF, 47μF and 100μF. Repeat step 3 and 4 in each case. Comment on the results.

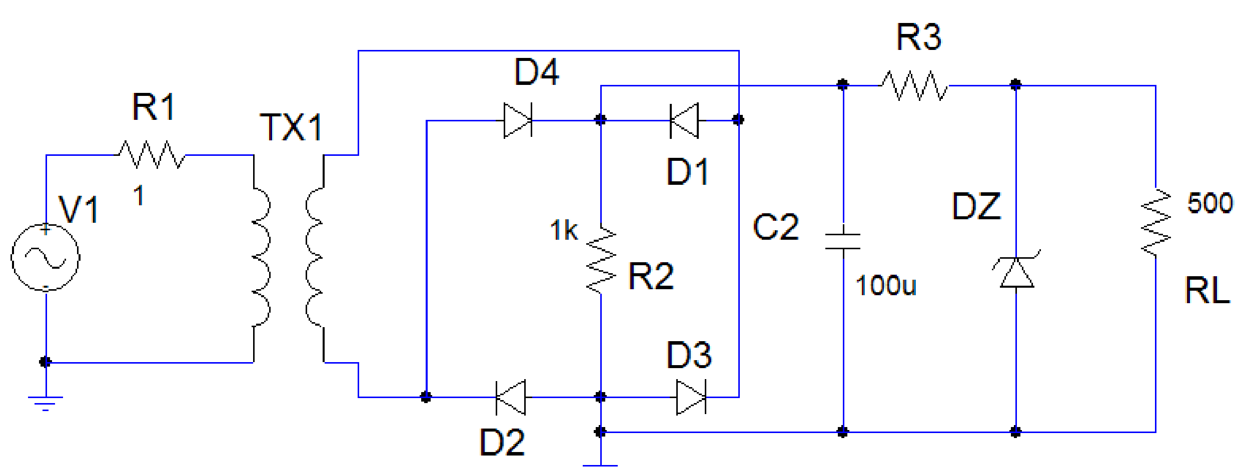


Fig.5. Regulated DC Power Supply

The final stage is to remove the ripples and get a better DC voltage using a Zener regulator. Draw the circuit of Fig. 5, using RL = 500Ω and C2 = 100μF. Configure the Zener diode model (Select the zener diode, then go to Edit → Model) with V_Z = 5V (Bv in the Edit Instant model). Chose value of R3 properly (around 200Ω). With the load R_L disconnected, design the circuit for a ripple level of 0.1V and a maximum diode current of 10mA.

For the circuit of Fig. 5 with a load R_L=500Ω, estimate the change in output voltage due to the load. What is the maximum load (minimum load resistance) that can be tolerated by the designed supply circuit?