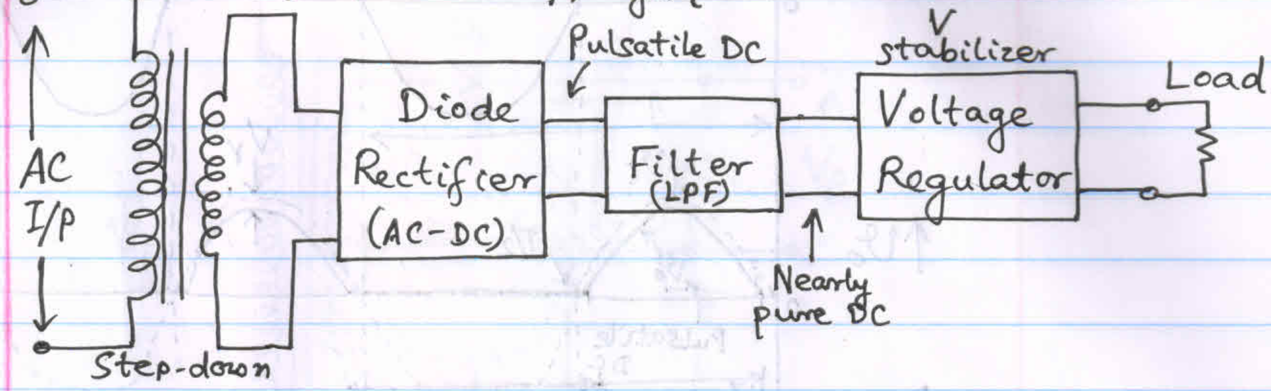
Diode Circuits

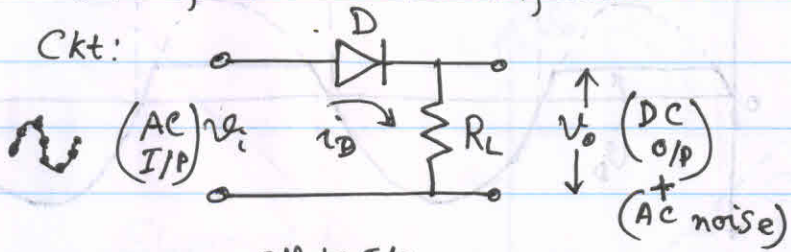
1. Power supply architecture (DC Linear)

Power Transformer → Low f, high η



2. Half-wave rectifier:

Ckt:

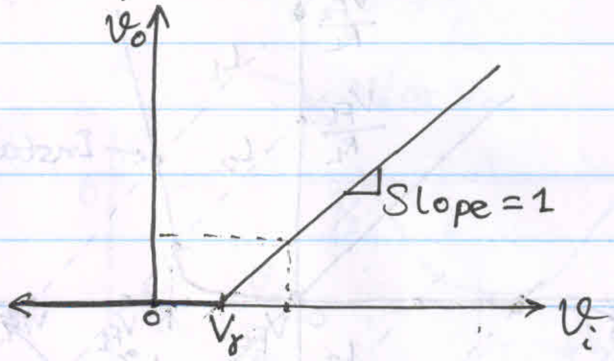


V-drop across D

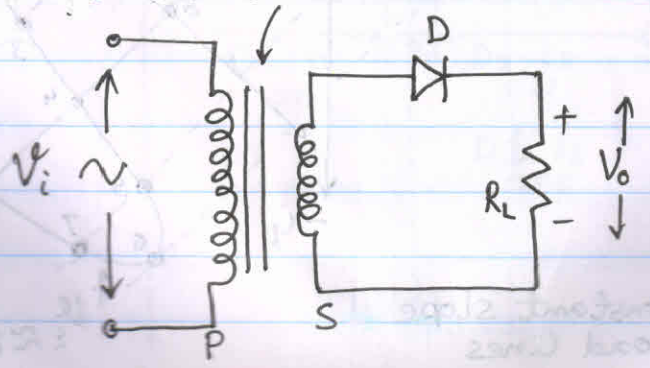
$$i_D = \frac{v_i - V_\gamma}{R_L}$$

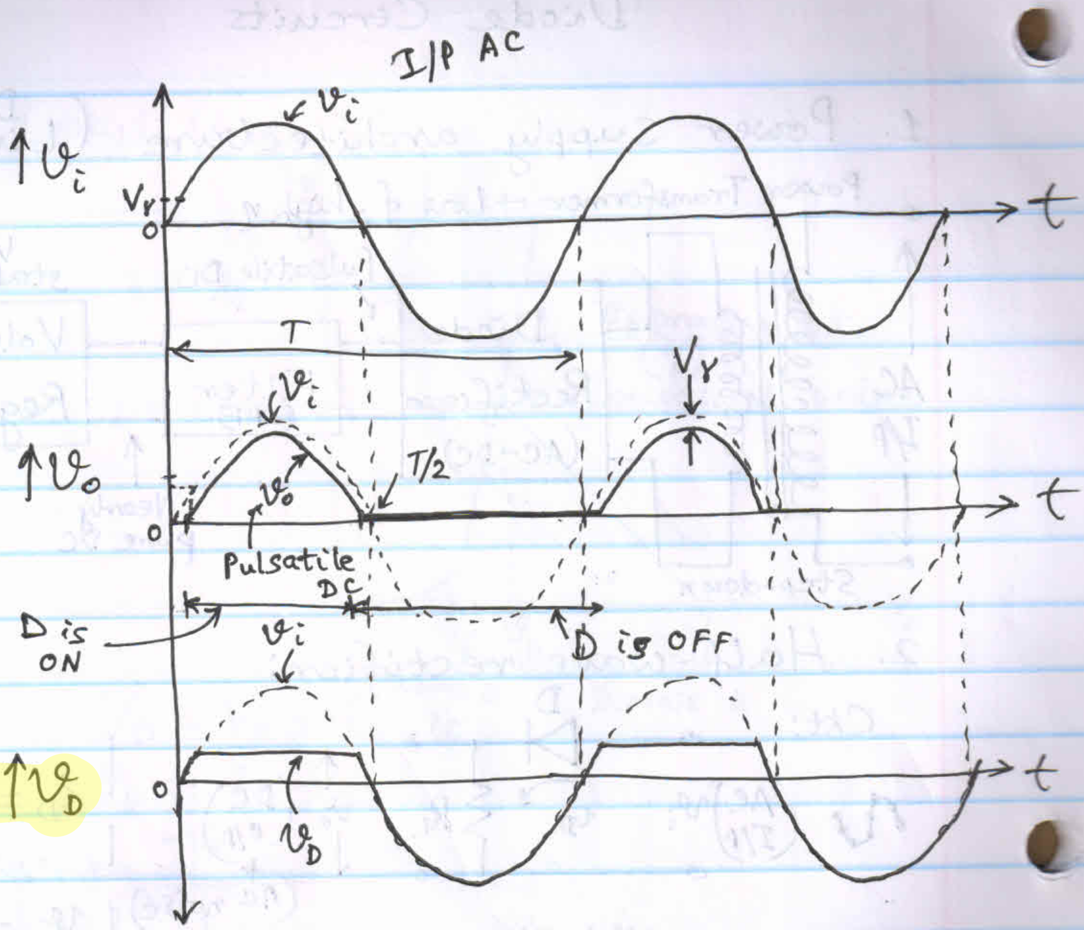
$$v_o = v_i - V_\gamma = i_D . R_L$$

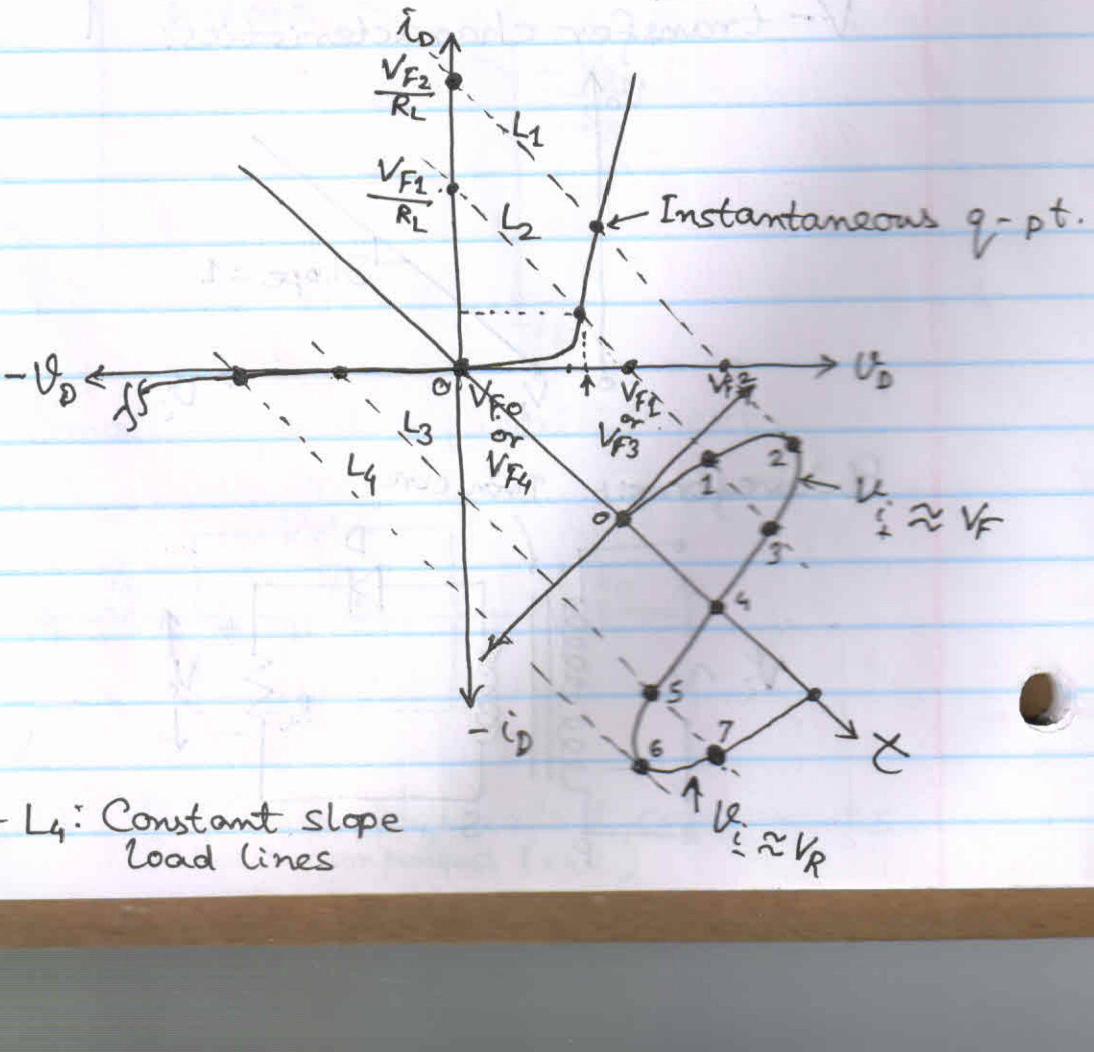
V-transfer characteristics: (→ O/P to I/P)



Practical ckt: Iron core



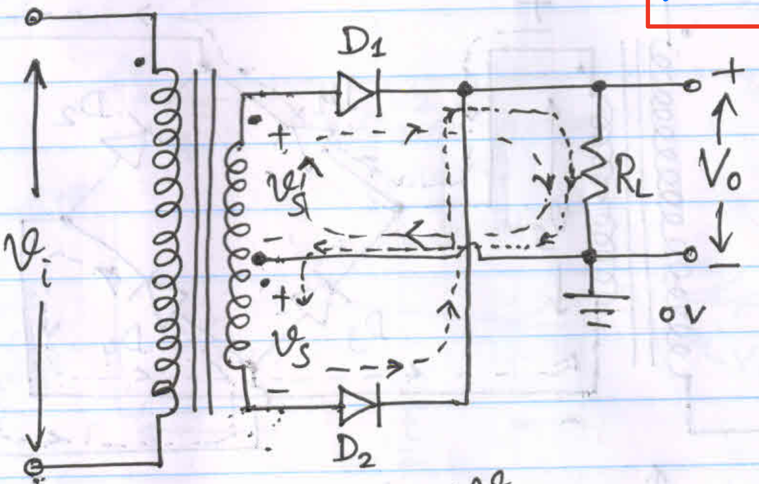


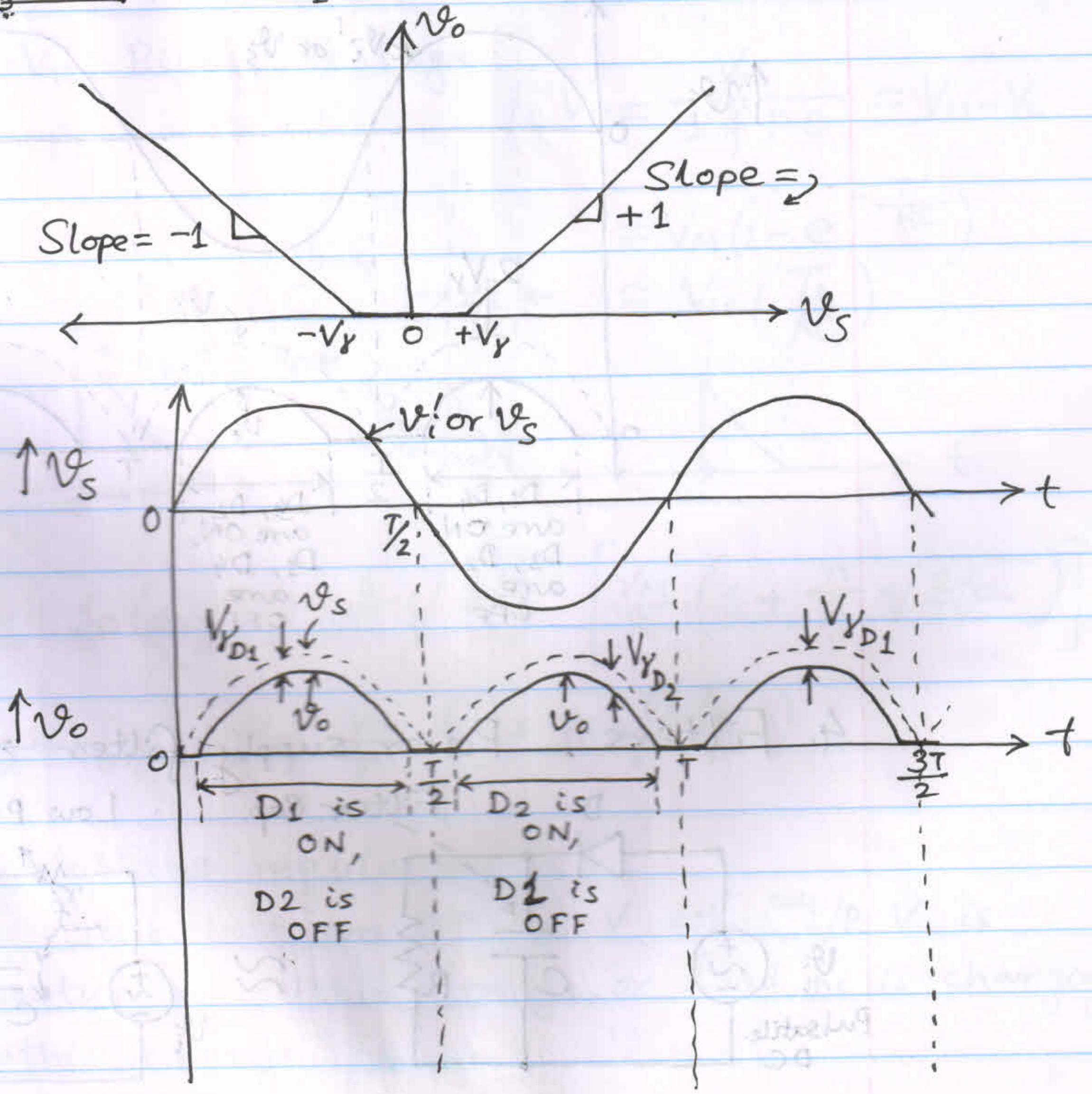


$L_1 - L_4$: Constant slope load lines

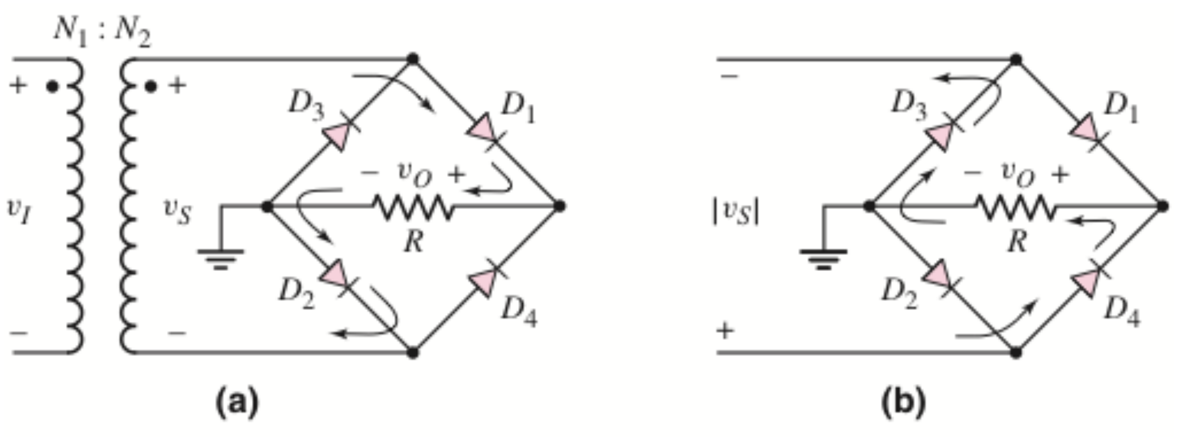
$$\boxed{\begin{aligned} V_o &= V_s + V_\gamma \\ PIV &= 2V_s - V_\gamma \end{aligned}}$$

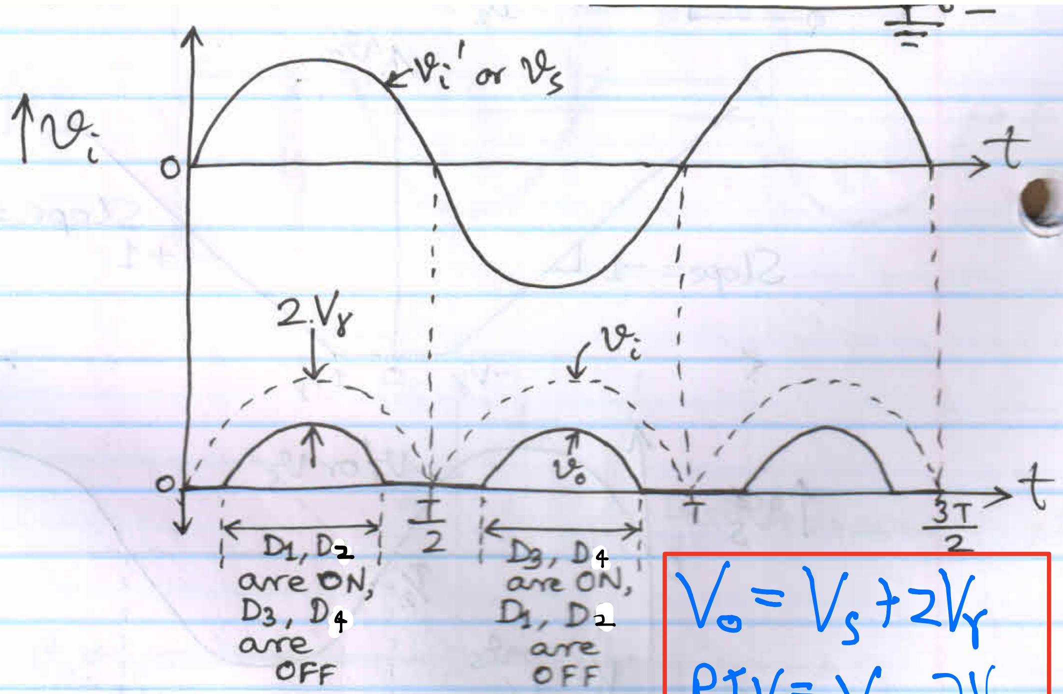
2. Full-wave rectifier:





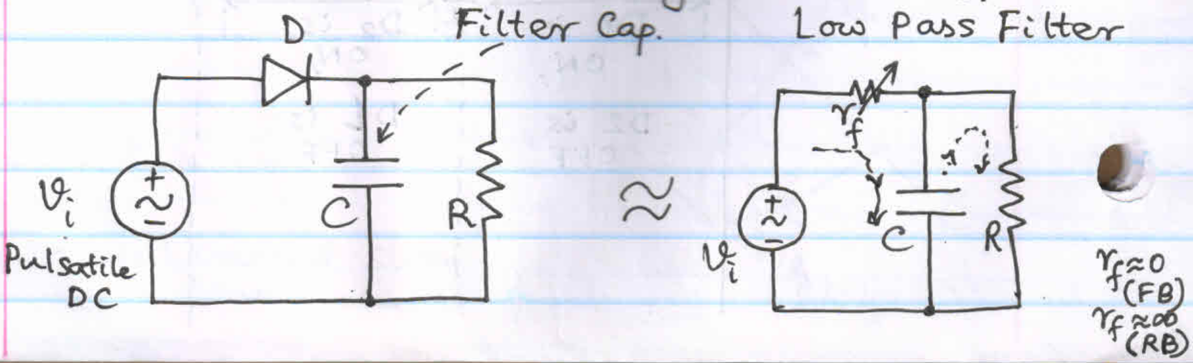
3. Bridge Rectifier:





$$\boxed{\begin{array}{l} V_o = V_s + 2V_\gamma \\ PIV = V_s - 2V_r \end{array}}$$

4. Filters: Power supply filter → LPF or Low Pass Filter



To a good approximation, the output voltage, that is, the voltage across the capacitor or the RC circuit, can be written as

$$v_O(t) = V_M e^{-t'/\tau} = V_M e^{-t'/RC} \tag{2.3}$$

where t' is the time after the output has reached its peak value, and RC is the time constant of the circuit.

The smallest output voltage is

$$V_L = V_M e^{-T'/RC} \tag{2.4}$$

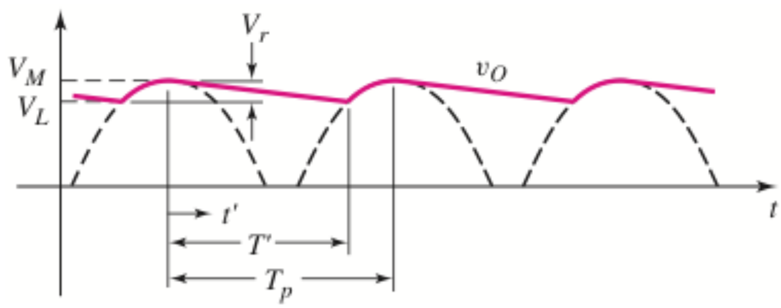
where T' is the discharge time, as indicated in Figure 2.9.

The **ripple voltage** V_r is defined as the difference between V_M and V_L, and is determined by

$$V_r = V_M - V_L = V_M(1 - e^{-T'/RC}) \tag{2.5}$$

Normally, we will want the discharge time T' to be small compared to the time constant, or $T' \ll RC$. Expanding the exponential in a series and keeping only the linear terms of that expansion, we have the approximation[2]

$$e^{-T'/RC} \cong 1 - \frac{T'}{RC} \tag{2.6}$$



The ripple voltage can now be written as

$$V_r \cong V_M \left(\frac{T'}{RC}\right) \tag{2.7}$$

Since the discharge time T' depends on the RC time constant, Equation (2.7) is difficult to solve. However, if the ripple effect is small, then as an approximation, we can let $T' = T_p$, so that

$$V_r \cong V_M \left(\frac{T_p}{RC}\right) \tag{2.8}$$

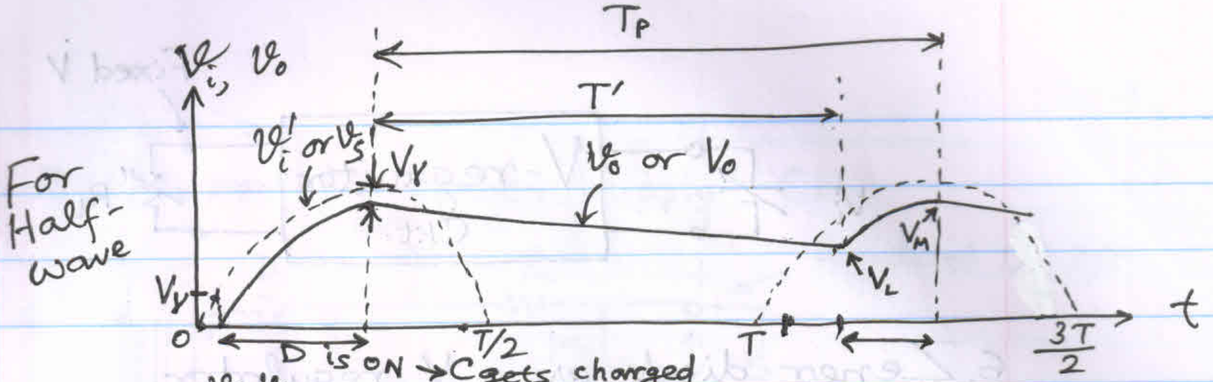
where T_p is the time between peak values of the output voltage. For a full-wave rectifier, T_p is one-half the signal period. Therefore, we can relate T_p to the signal frequency,

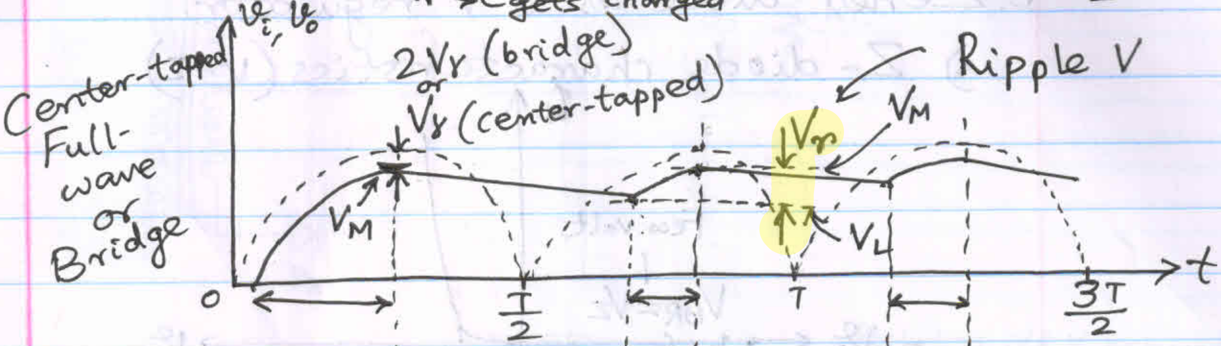
$$f = \frac{1}{2T_p}$$

The ripple voltage is then

$$\boxed{V_r = \frac{V_M}{2fRC}} \tag{2.9}$$

For a half-wave rectifier, the time T_p corresponds to a full period (not a half period) of the signal, so the factor 2 does not appear in Equation (2.9). The factor of 2 shows that the full-wave rectifier has half the ripple voltage of the half-wave rectifier.



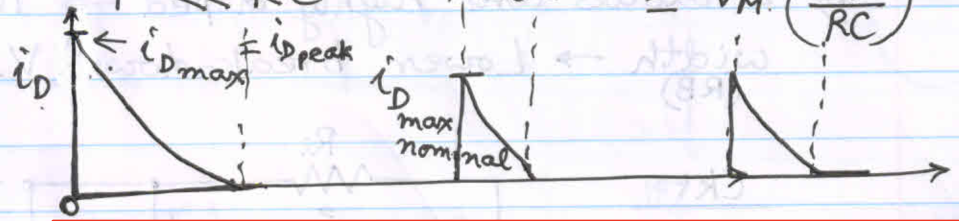


V_r: Ripple Voltage

$$\boxed{V_r = \frac{V_M}{2fRC} = V_M - V_L}$$

$$= V_M\left(1 - e^{-\frac{T'}{RC}}\right)$$

$$T' \ll \underbrace{RC}_{\tau_{dis\text{-}chg}} \qquad \rightarrow \Delta t \leftarrow \qquad \cong V_M \cdot \left(\frac{T_p}{RC}\right)$$



Neaman Pg 78-80

$$\boxed{i_D(\text{avg.}) = \frac{1}{\pi}\sqrt{\frac{2 \cdot V_r}{V_M}} \cdot \left[\frac{V_M}{R} \cdot \left(1 + \frac{\pi}{2}\sqrt{\frac{2V_M}{V_r}}\right)\right]}$$

$$\boxed{i_{D_{max}} \cong i_D(\text{peak}) = \frac{V_M}{R} \cdot \left(1 + \pi \cdot \sqrt{\frac{2V_M}{V_r}}\right)}$$

5. Voltage regulator:

Stabilizes an O/P DC V while an I/P V is fluctuating within a range, or Load R_L is changing within a range.

DESIGN EXAMPLE 2.4

Objective: Design a full-wave rectifier to meet particular specifications.

A full-wave rectifier is to be designed to produce a peak output voltage of 12 V, deliver 120 mA to the load, and produce an output with a ripple of not more than 5 percent. An input line voltage of 120 V (rms), 60 Hz is available.

Solution: A full-wave bridge rectifier will be used, because of the advantages previously discussed. The effective load resistance is

$$R = \frac{V_O}{I_L} = \frac{12}{0.12} = 100\ \Omega$$

Assuming a diode cut-in voltage of 0.7 V, the peak value of v_S is

$$v_S(\max) = v_O(\max) + 2V_\gamma = 12 + 2(0.7) = 13.4\ \text{V}$$

For a sinusoidal signal, this produces an rms voltage value of

$$v_{S,\text{rms}} = \frac{13.4}{\sqrt{2}} = 9.48\ \text{V}$$

The transformer turns ratio is then

$$\frac{N_1}{N_2} = \frac{120}{9.48} = 12.7$$

For a 5 percent ripple, the ripple voltage is

$$V_r = (0.05)V_M = (0.05)(12) = 0.6\ \text{V}$$

The required filter capacitor is found to be

$$C = \frac{V_M}{2fRV_r} = \frac{12}{2(60)(100)(0.6)} \Rightarrow 1667\ \mu\text{F}$$

The peak diode current, from Equation (2.21), is

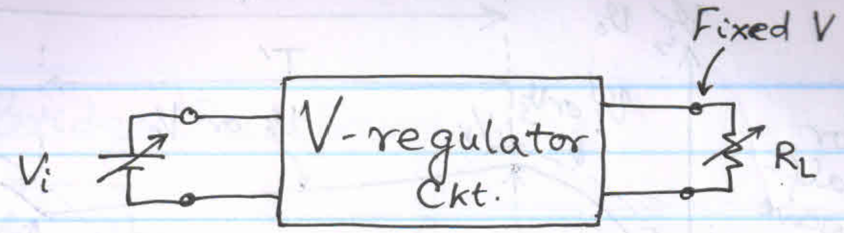
$$i_{D,\text{peak}} = \frac{12}{100}\left[1 + \pi\sqrt{\frac{2(12)}{0.6}}\right] = 2.50\ \text{A}$$

and the average diode current over the entire signal period, from Equation (2.25), is

$$i_D(\text{avg}) = \frac{1}{\pi}\sqrt{\frac{2(0.6)}{12}}\left(\frac{12}{100}\right)\left(1 + \frac{\pi}{2}\sqrt{\frac{2(12)}{0.6}}\right) \Rightarrow 132\ \text{mA}$$

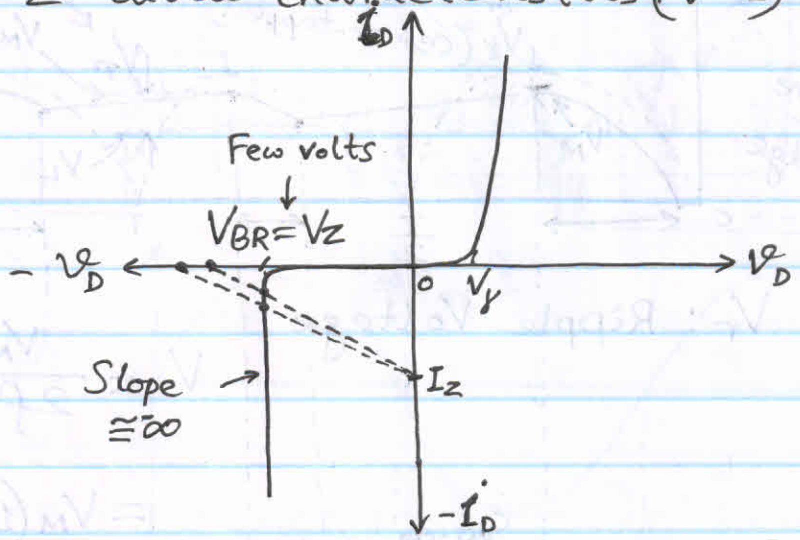
Finally, the peak inverse voltage that each diode must sustain is

$$\text{PIV} = v_R(\max) = v_S(\max) - V_\gamma = 13.4 - 0.7 = 12.7\ \text{V}$$



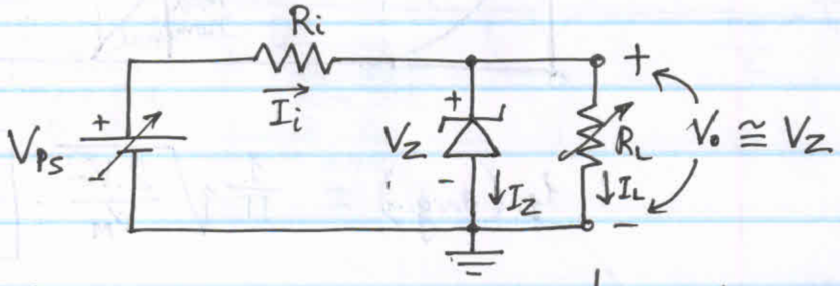
6. Zener diode as a V-regulator.

a) Z-diode characteristics (V–I)



b) Z-diodes are highly doped → Thinner junc^n^ width (RB) → Lower break-down V.

Ckt.



(Eqn. 2.26) $R_i = \dfrac{V_{PS} - V_Z}{I_i} = \dfrac{V_{PS} - V_Z}{I_L + I_Z}$ | $I_Z = \dfrac{V_{PS} - V_Z}{R_i} - I_L$

$$R_i = \frac{V_{PS_{min}} - V_Z}{I_{Z_{min.}} + I_{L_{max}}} \cong \frac{V_{PS_{max}} - V_Z}{I_{Z_{max}} + I_{L_{min}}}$$

$P_Z = V_Z \cdot I_Z$ | $I_{Z_{min}} = \dfrac{V_{PS_{min}} - V_Z}{R_i} - I_{L_{max}}$

For proper operation of this circuit, the diode must remain in the breakdown region and the power dissipation in the diode must not exceed its rated value. In other words:

1. The current in the diode is a minimum, $I_Z(\text{min})$, when the load current is a maximum, $I_L(\text{max})$, and the source voltage is a minimum, $V_{PS}(\text{min})$.
2. The current in the diode is a maximum, $I_Z(\text{max})$, when the load current is a minimum, $I_L(\text{min})$, and the source voltage is a maximum, $V_{PS}(\text{max})$.

Inserting these two specifications into Equation (2.26), we obtain

$$R_i = \frac{V_{PS}(\text{min}) - V_Z}{I_Z(\text{min}) + I_L(\text{max})} \tag{2.28(a)}$$

and

$$R_i = \frac{V_{PS}(\text{max}) - V_Z}{I_Z(\text{max}) + I_L(\text{min})} \tag{2.28(b)}$$

Equating these two expressions, we then obtain

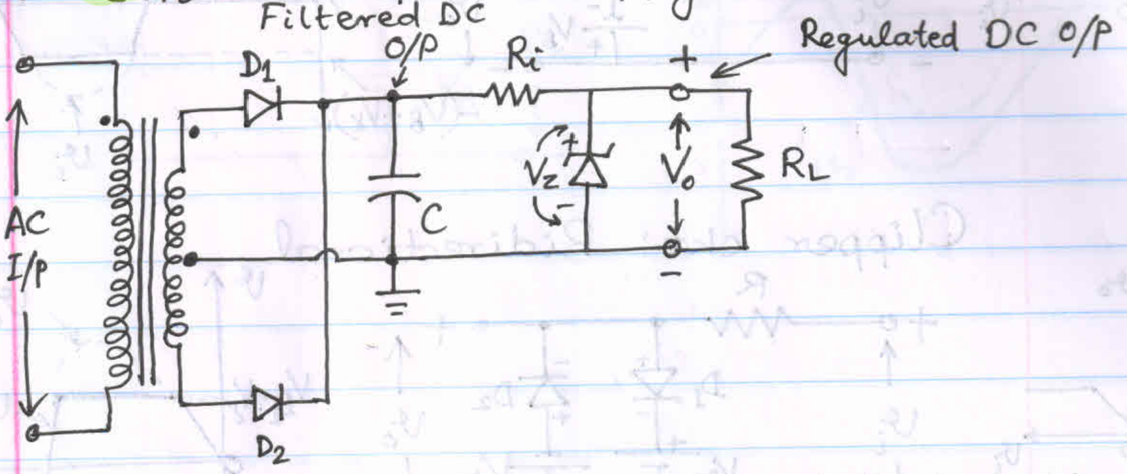
$$\begin{aligned} &[V_{PS}(\text{min}) - V_Z] \cdot [I_Z(\text{max}) + I_L(\text{min})] \\ &\quad = [V_{PS}(\text{max}) - V_Z] \cdot [I_Z(\text{min}) + I_L(\text{max})] \end{aligned} \tag{2.29}$$

Reasonably, we can assume that we know the range of input voltage, the range of output load current, and the Zener voltage. Equation (2.29) then contains two unknowns, $I_Z(\text{min})$ and $I_Z(\text{max})$. Further, as a minimum requirement, we can set the minimum Zener current to be one-tenth the maximum Zener current, or $I_Z(\text{min}) = 0.1 I_Z(\text{max})$. (More stringent design requirements may require the minimum Zener current to be 20 to 30 percent of the maximum value.) We can then solve for $I_Z(\text{max})$, using Equation (2.29), as follows:

$$I_Z(\text{max}) = \frac{I_L(\text{max}) \cdot [V_{PS}(\text{max}) - V_Z] - I_L(\text{min}) \cdot [V_{PS}(\text{min}) - V_Z]}{V_{PS}(\text{min}) - 0.9 V_Z - 0.1 V_{PS}(\text{max})} \tag{2.30}$$

Using the maximum current thus obtained from Equation (2.30), we can determine the maximum required power rating of the Zener diode. Then, combining Equation (2.30) with either Equation (2.28(a)) or (2.28(b)), we can determine the required value of the input resistance R_i.

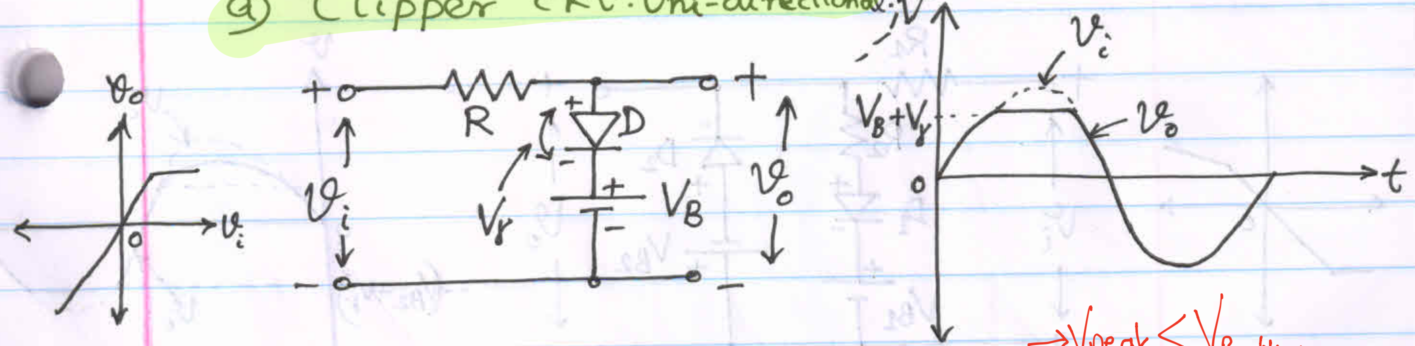
7. Linear DC power supply: Ckt.

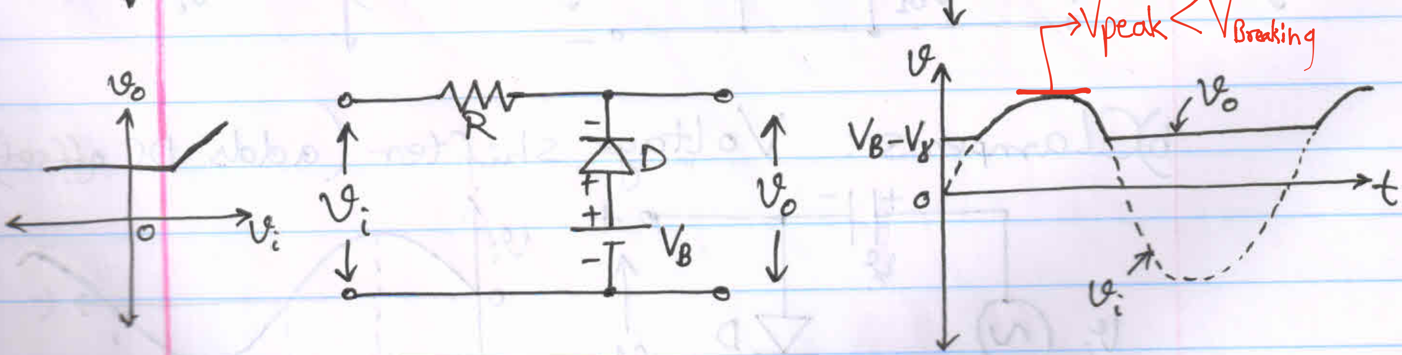


Restricts O/P V beyond a limit

8. Clipper & Clampers (Voltage limiter ckts).

a) Clipper ckt: Uni-directional:





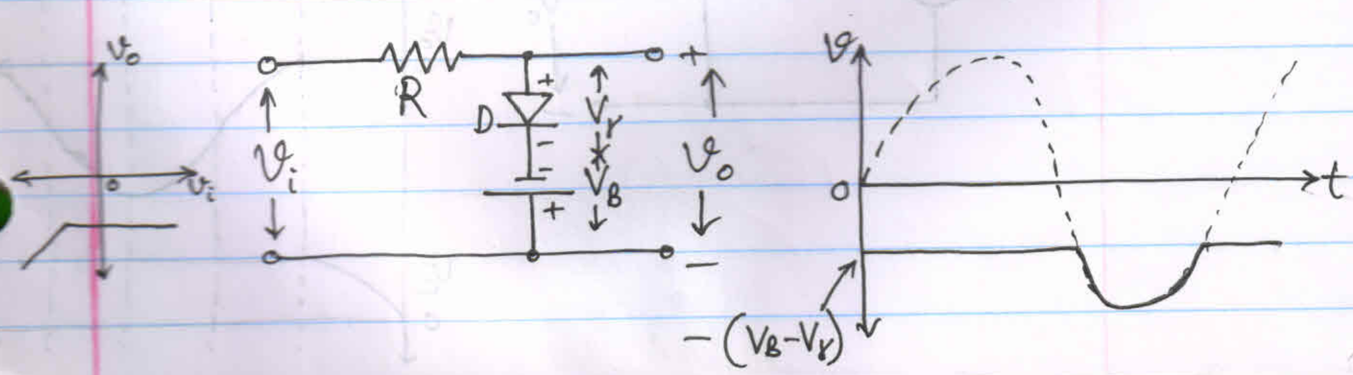


Figure 2.21(a) is a single-diode clipper circuit. The diode D_1 is off as long as $v_I < V_B + V_\gamma$. With D_1 off, the current is approximately zero, the voltage drop across R is essentially zero, and the output voltage follows the input voltage. When $v_I > V_B + V_\gamma$, the diode turns on, the output voltage is clipped, and v_O equals $V_B + V_\gamma$. The output signal is shown in Figure 2.21(b). In this circuit, the output is clipped above $V_B + V_\gamma$.

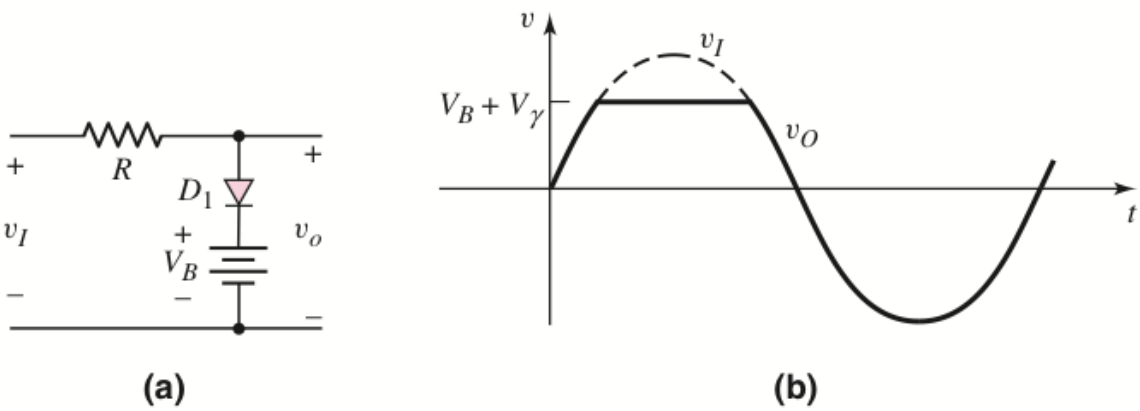
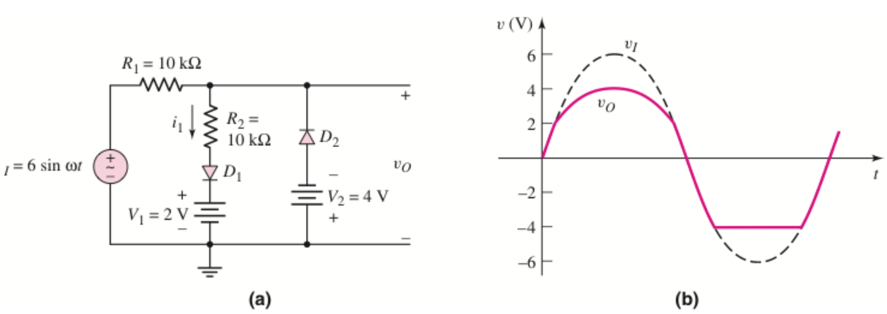


Figure 2.21 Single-diode clipper: (a) circuit and (b) output response

EXAMPLE **2.7**

Objective: Find the output of the parallel-based clipper in Figure 2.23(a).
For simplicity, assume that $V_\gamma = 0$ and $r_f = 0$ for both diodes.



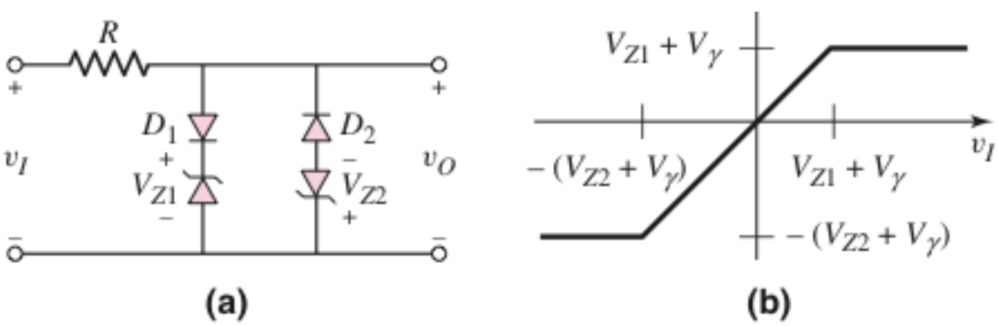
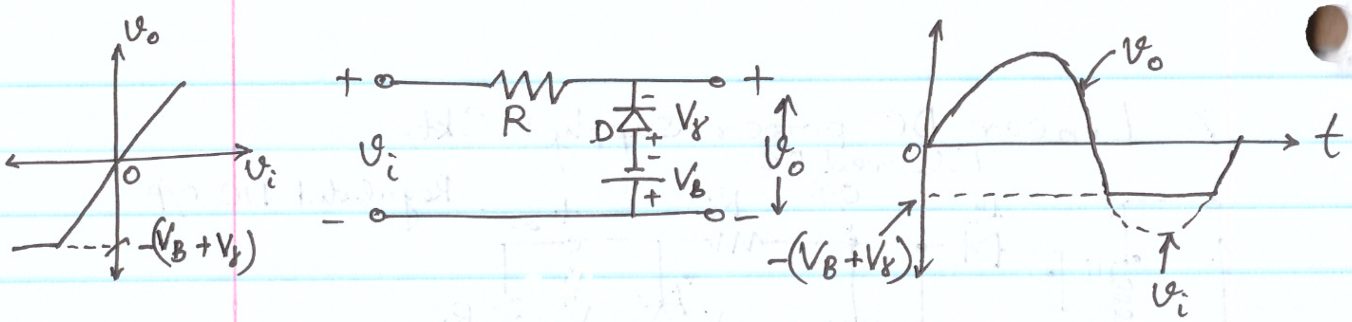
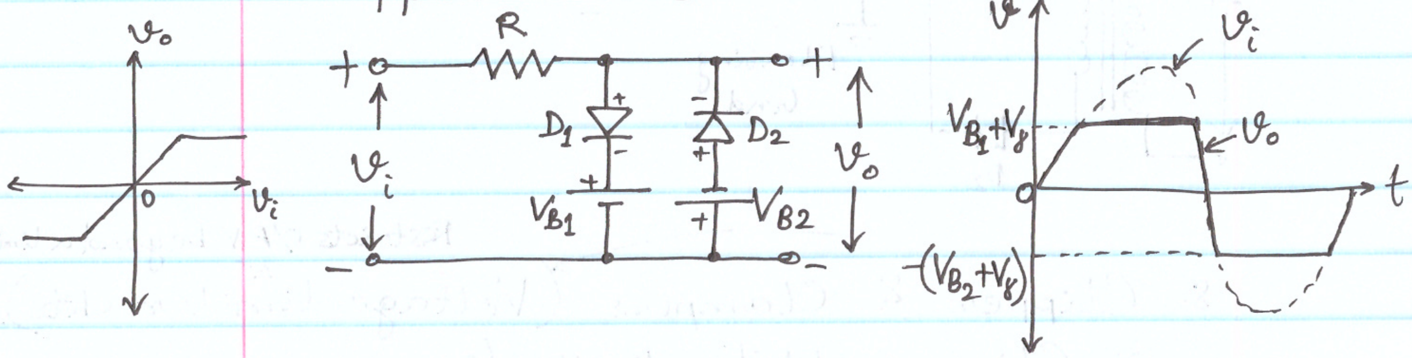
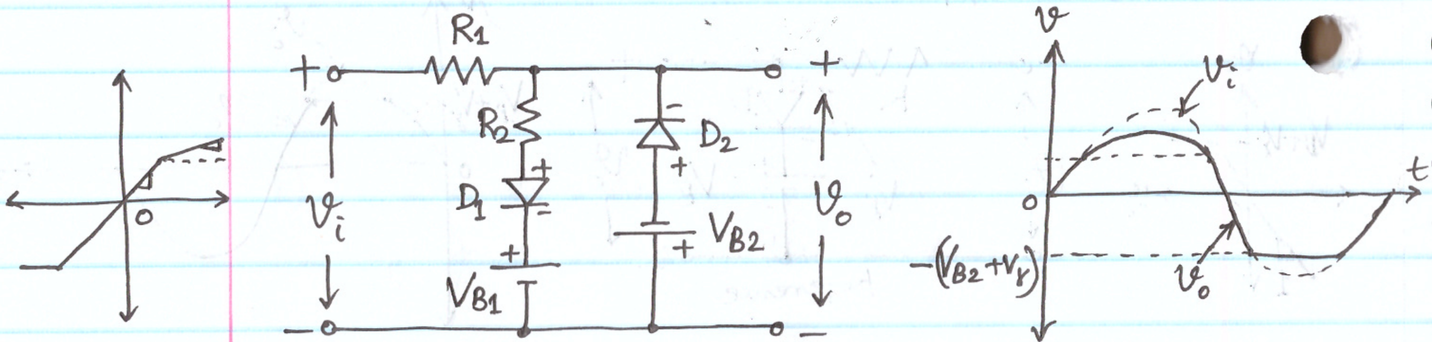


Figure 2.26 (a) Parallel-based clipper circuit using Zener diodes; (b) voltage transfer characteristics

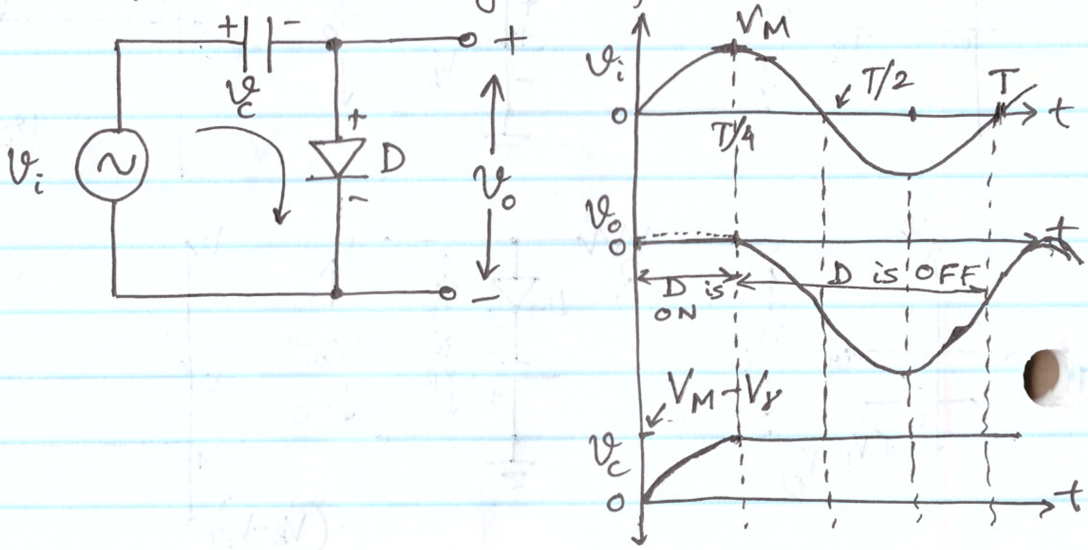


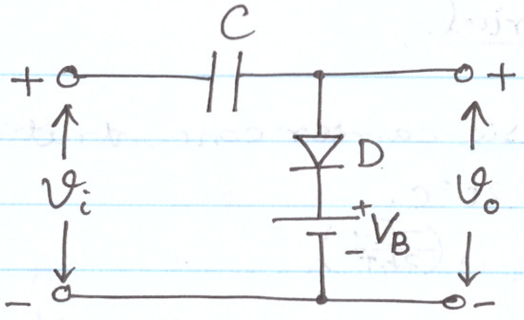
Clipper ckt: Bidirectional



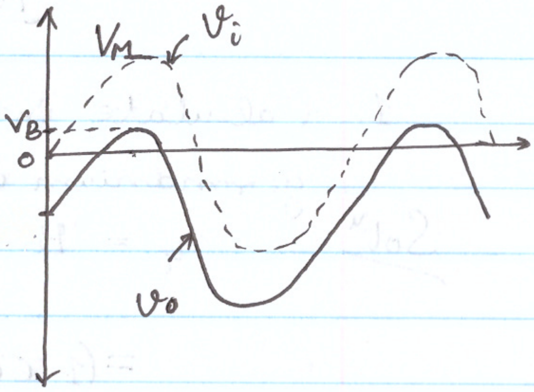


b) Clampers: Voltage shifter (adds DC offset)





C
D
V_B
v_i
v_o



V_M
v_i
V_B
0
v_o