Tutorial

1. Calculate intrinsic carrier concentration (conc.) of germanium at 30°C.

Sol^n

$$n_i = B \cdot T^{\frac{3}{2}} \cdot e^{\left(\frac{-E_g}{2kT}\right)}$$

$$= (1.66 \times 10^{15}) \times (30+273)^{1.5} \times e^{\frac{-0.66}{\underbrace{2 \times 86.17 \times 10^{-6}}_{\frac{eV}{K}} \times 303}}$$

$$= (2.83 \times 10^{13}) \text{ per } cm^3$$

(Ans)

2. A Si block is at 300K, which is doped with Boron of conc. 5.6×10^{18} cm^3. Calculate the concentration of e^- & h^+ at thermal equilibrium.

Sol^n. $T = 300$ K ; $N_a = 5.6 \times 10^{18}$ cm^{-3}

$$n_i = B \cdot T^{\frac{3}{2}} \cdot e^{\frac{-E_g}{2kT}}$$

$$= 5.23 \times 10^{15} \times 300^{1.5} \times e^{\frac{-1.1}{2 \times 86.17 \times 10^{-6} \times 300}}$$

$$= 1.5 \times 10^{10} \ cm^{-3}$$

Now, B ~~doping~~ means tri-valent impurity addition, which further means p-type extrinsic material.

$\therefore$ $N_a \gg n_i$

$\therefore$ $p_o \cong N_a = 5.6 \times 10^{18}$ cm^{-3} (Ans)

We know,

$$n_o = \frac{n_i^2}{p_o} = \frac{n_i^2}{N_a} = \frac{(1.5 \times 10^{10})^2}{5.6 \times 10^{18}}$$

$$= 40.17 \ cm^{-3}$$ (Ans)

3. Consider a Si block at 300 K that has been doped with 'P' atoms. Assume, $\mu_n = 1380\ cm^2/V\text{-}s$, $\mu_p = 480\ cm^2/V\text{-}s$, $E = 220\ v/cm$, & $N_d = 9.1\times10^{16} cm^{-3}$. Calculate drift current density.

Sol^n. 'P' doping means pentavalent, which leads to n-type.

$\therefore\ n \cong N_d = 9.1\times10^{16}\ cm^{-3}$ (Majority conc.)

& $p = \frac{n_i^2}{n} = \frac{(1.5\times10^{10})^2}{9.1\times10^{16}} = 2.47\times10^3\ cm^{-3}$ (Minority conc.)

As, $N_d \gg p$, or $n \gg p$

Conductivity, $\sigma = q.\mu_n.n + q.\mu_p.p \cong q.\mu_n.n$

$= (1.6\times10^{-19})(1380)(9.1\times10^{16})$

$= 20.09$ per Ohm-cm

$= 20.09\ /\Omega\text{-cm}$

We know,

drift current density: $J = \sigma.E$

$= (20.09)(220)$

$= 4.42\times10^3\ A/cm^2$

(Ans)

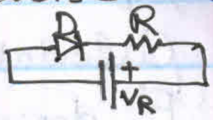
4. A block of Si has e^- concentration that linearly varies from $n = 10^{13}\ cm^{-3}$ to $10^{18}\ cm^{-3}$ over a distance $x = 0.1$ to $4\,\mu m$. If $T = 27°C$ & diffusion co-efficient $D_n = 36\ cm^2/s$, calculate diffusion I-density:

Sol^n We know, $J_n = q.D_n.\frac{dn}{dx} = q.D_n.\frac{\Delta n}{\Delta x}$

$= (1.6\times10^{-19})(36)\left(\frac{10^{18}-10^{13}}{4\times10^{-4}-0.1\times10^{-4}}\right)$

$= 14.76\times10^3\ A/cm^2$ (Ans)

5. Calculate V_{bi} & C_j of a Ge p-n junction diode at 30°C. Assume, $N_a = 10^{17}\ cm^{-3}$, $N_d = 10^{15}\ cm^{-3}$, $C_{jo} = 0.5\ pF$, reverse biased voltage $V_R = 1.1V$ & $4.5V$.



Sol^n We know, $n_i = B \cdot T^{3/2} \cdot e^{\frac{-E_g}{2kT}}$

@ 30°C for Ge, $n_i = 2.83 \times 10^{13}\ cm^{-3}$

We know,

$$V_{bi} = \underbrace{\left(\frac{kT}{q}\right)}_{V_T \approx 26mV @ 300K} \ln\left[\frac{N_a N_d}{n_i^2}\right]$$

$$= \left[\frac{1.38 \times 10^{-23} \times 303}{1.6 \times 10^{-19}}\right] \ln\left[\frac{10^{17} \cdot 10^{15}}{(2.83 \times 10^{13})^2}\right]$$

$$= 0.306\ V$$ (Ans)

We know,

$$C_j = C_{jo}\left(1 + \frac{V_R}{V_{bi}}\right)^{-\frac{1}{2}}$$

$$= (0.5 \times 10^{-12})\left(1 + \frac{1.1}{0.306}\right)^{-\frac{1}{2}}$$

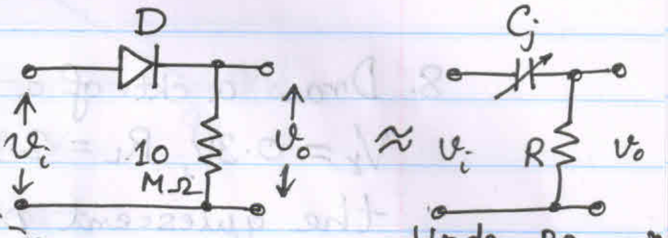
$$= 233.25\ fF \quad [@\ V_R = 1.1V]$$ (Ans)

Also, $$C_j = (0.5 \times 10^{-12})\left(1 + \frac{4.5}{0.306}\right)^{-\frac{1}{2}}$$

$$= 126.16\ fF \quad [@\ V_R = 4.5V]$$

6. Consider all the given & calculated parameters in the previous problem. Calculate time constants if a high pass filter like ckt is realized by using a 10 MΩ resistor and the diode.

Sol^n. $\tau = RC_j$



$\tau_1 = 10\times10^6 \times 233.25\times10^{-15}$
$= 2.33\ \mu s$ (Ans) @ $V_R = 1.1V$

$\tau_2 = 10\times10^6 \times 126.16\times10^{-15}$
$= 1.26\ \mu s$ (Ans) @ $V_R = 4.5V$

7. Calculate diode voltages while current flowing through it is $+4.2\,mA$ & $+1.2\times10^{-14}\,A$. Assume, $T = 300K$, $I_S = 10^{-14}\,A$, $n = 1$. Find the material of the diode.

Sol^n. We know, $i_D = I_S\left[e^{\frac{v_D}{nV_T}} - 1\right]$

$$\Rightarrow e^{\frac{v_D}{V_T}} = \frac{i_D}{I_S} + 1$$

$$\Rightarrow \frac{v_D}{V_T} = \ln\left[\frac{i_D}{I_S} + 1\right]$$

$$\Rightarrow v_D = V_T.\ \ln\left[\frac{i_D}{I_S} + 1\right]$$

At, $i_D = 4.2\,mA$,

$$v_D = (26\,mV)\ \ln\left(\frac{4.2\,mA}{10^{-14}} + 1\right) = 0.6958^V$$

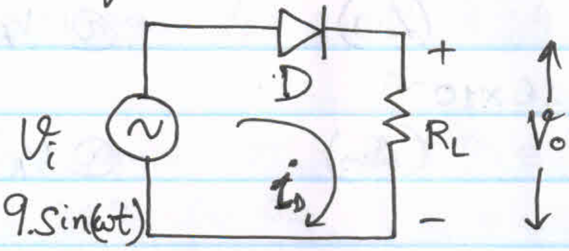
At, $i_D = +1.2\times10^{-14}\,A$,

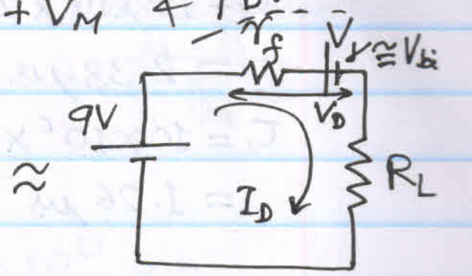
$$v_D = (26\times10^{-3})\ \ln\left[\frac{+1.2\times10^{-14}}{10^{-14}} + 1\right] = +0.0204V$$

Since, $v_D \cong 0.7V$, the diode is made of Si.

8. Draw a ckt. of a simple half wave rectifier. Let, $V_\gamma = 0.3V$, $R_L = 3.3k\Omega$, $v_i(AC) = 9V\sin\omega t$, $r_f = 5\Omega$. Find the quiescent point at $v_i = +V_M$ & P_D.

Sol^n.





$v_i = 9.\sin(\omega t)$

Assume, $f = 50Hz$

(During forward bias & $v_i = V_M$)

By applying KVL in the above ckt., (@ $v_i = +V_M$)

$$I_D = \frac{V_M - V_\gamma}{R_L + r_f} = \frac{9 - 0.3}{3.3\times10^3 + 5} = 2.63\,mA \quad \text{(Ans)}$$

Also,

$$V_D = V_\gamma + I_D . r_f = 0.3 + (2.63m)\times 5 = 313.15\,mV \quad \text{(Ans)}$$

We know, $P_D = V_D . I_D = (2.63mA)(313.15mV)$

$= 823.58\,\mu W$ (Ans)

9. Find the DC load line for the above problem.

Sol^n. Load line intersects the V-I characteristics:

@ $v_i = +V_M$; x: axis: $V_{F_{max}} = V_M = 9V$

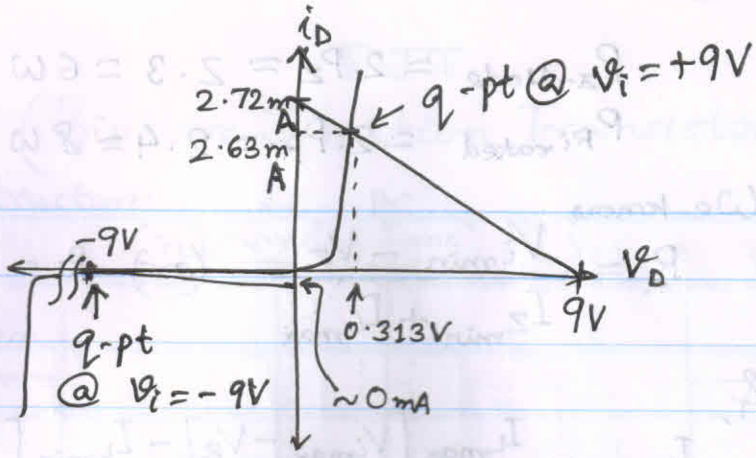
y: axis: $I_y = \frac{V_{F_{max}}}{R_L + r_f} = \frac{9}{3.3k + 5} = 2.72mA$

@ $v_i = -V_M$; x: axis: $V_{F_{min}} = -V_M = -9V = V_R = V_D$

y: axis: $I_y = i_D = I_S\left[e^{\frac{V_D}{nV_T}} - 1\right]$

Assume, $I_S = 10^{-14}$ A.

$$\Rightarrow I_y = 10^{-14}\left[e^{\frac{-9}{1\times 26mV}} - 1\right] = 0\,mA$$



10. A full-wave rectifier is operated at a 50Hz ac with an input of 12. sin ωt. If a load resistance is 2.2kΩ & allowed ripple voltage is 0.5V, calculate the value of a filter capacitor.

Sol^n. $V_M = 12V$, $f = 50Hz$, $V_r = 0.5V$, $R_L = 2.2k\Omega$, Assume Si, $r_f \approx 0$, let $V_\gamma = 0.7V$

We know,

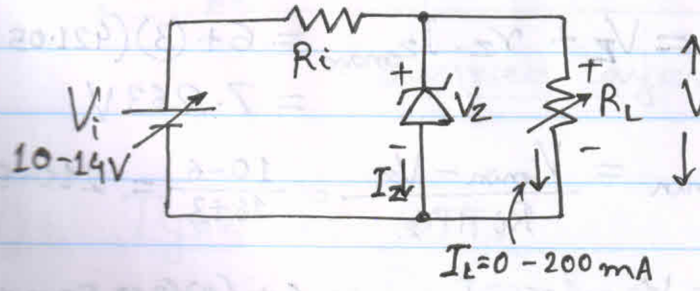
$$C_{filter} = \frac{V_M - V_\gamma}{2f \cdot R_L \cdot V_r}$$

$$= \frac{12 - 0.7}{2 \times 50 \times 2.2 \times 10^3 \times 0.5} = 102 \mu F$$ (Ans)

Now, voltage rating of C_{filter} is: $\geq 2.V_M$
$= 25$ V (Ans)

11. Draw a zener voltage regulator. Assume, $V_i = 10$ to $14V$, $I_L = 0$ to 200 mA, $V_L = 6V$. Design the ckt.

Sol^n.



$V_{imin} = 10V$
$V_{imax} = 14V$
$I_{Lmin} = 0$ mA
$I_{Lmax} = 0.2A$
$V_L = 6V$

We know, $V_Z = V_L = 6V$

~~$I_{Zmax} = \frac{I_{Lmax}(V_{imax} - V_Z) - I_{Lmin}}{V_{imax} - V_Z}$~~

$$P_{z\text{-diode}} = 2 \cdot P_Z = 2 \cdot 3 = 6\,W$$
$$P_{R_i\,rated} = 2 \cdot P_{R_i} = 2 \cdot 4 = 8\,W$$
(Ans)

We know,

$$R_i = \frac{V_{i\,min} - V_Z}{I_{Z_{min}} + I_{L_{max}}} \quad (or) \quad R_i = \frac{V_{i\,max} - V_Z}{I_{Z_{max}} + I_{L_{min}}}$$

&,

$$I_{Z_{max}} = \frac{I_{L_{max}}[V_{i\,max} - V_Z] - I_{L_{min}}[V_{i\,min} - V_Z]}{V_{i\,min} - 0.9V_Z - 0.1V_{i\,max}}$$

$$\Rightarrow I_{Z_{max}} = \frac{0.2[14-6] - 0[10-6]}{10 - (0.9)(6) - (0.1)(14)} = 0.5\,A \quad \text{(Ans)}$$

$$\therefore R_i = \frac{14-6}{0.5+0} = 16\,\Omega \quad \text{(Ans)}$$

Max. Power loss across R_i is:

$$P_{R_i} = \frac{(V_{i\,max} - V_Z)^2}{R_i} = \frac{(14-6)^2}{16} = 4W \quad \text{(Ans)}$$

Now, $$I_{Z_{min}} = \frac{V_{i\,min} - V_Z}{R_i} = \frac{10-6}{16} = 0.25\,A \quad \text{(Ans)}$$

$$P_Z = V_Z \cdot I_{Z_{max}} = 6 \cdot 0.5 = 3W \quad \text{(Ans)}$$

12. Calculate line & load regulation, if $r_Z = 3\,\Omega$

Sol^n. We know, $$I_{Z_{max}} = \frac{V_{i\,max} - V_Z}{R_i + r_Z} = \frac{14-6}{16+3} = 421.05\,mA$$

$$\therefore V_{L_{max}} = V_Z + r_Z \cdot I_{Z_{max}} = 6 + (3)(421.05 \times 10^{-3})$$
$$= 7.263\,V$$

Also, $$I_{Z_{min}} = \frac{V_{i\,min} - V_Z}{R_i + r_Z} = \frac{10-6}{16+3} = 210.52\,mA$$

$$\therefore V_{L_{min}} = V_Z + r_Z \cdot I_{Z_{min}} = 6 + (3)(210.52 \times 10^{-3})$$
$$= 6.631\,V$$

$$V_o = \underset{@10V}{6.631} \text{ to } \underset{@14V\ V_i}{7.263V}$$

$$I_L = 0 \text{ to } 200\,mA$$

$$7.263V \quad 6.663V \ @ \ V_o$$

12. (cont.) We know, line regulation or Source regulation:

$$\%\text{ line reg.} = \frac{\Delta V_L}{\Delta V_{i_{DC}}} \times 100$$

$$= \frac{7.263 - 6.631}{14 - 10} = 15.8\% \qquad \text{(Ans)}$$

Consider, the effect of change in I_L at $V_i = 14V$:

For, $I_L = 0\,mA$: $I_Z = \frac{14-6}{16+3} = 421.05\,mA$

$$\therefore V_{L_{no\text{-}load}} = V_Z + r_Z \cdot I_Z = 6 + (3)(421.05m) = 7.263\,V$$

For, $I_L = 200mA$: $I_Z = \frac{V_{i\,max} - [V_Z + I_Z \cdot r_Z]}{R_i} - I_{L_{max}}$

$$= \frac{14 - [6 + (3)(.421)]}{16} - 0.2$$

$$= 221.06\,mA$$

$$\therefore V_{L_{Full\text{-}load}} = V_Z + r_Z I_Z = 6 + (3)(.221) = 6.663\,V$$

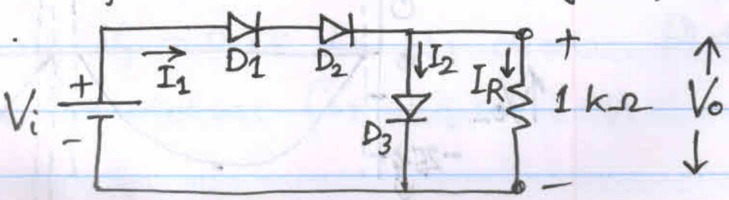
We know,

$$\%\text{ load reg.} = \frac{V_{L_{no\text{-}load}} - V_{L_{full\text{-}load}}}{V_{L_{full\text{-}load}}} \times 100$$

$$= \frac{7.263 - 6.663}{6.663} \times 100$$

$$= 9.004\,\% \qquad \text{(Ans)}$$

13. Consider the ckt. and find the input voltage, if $V_o = 0.6V$ and $I_S = 2 \times 10^{-13}\,A$.



Sol^n. $I_2 = I_S . e^{\left(\frac{V_o}{V_T}\right)} = 2\times10^{-13} . e^{\left(\frac{0.6}{.026}\right)} = 2.105 \text{ mA}$

$I_R = \frac{V_o}{R} = \frac{0.6}{1k} = 0.6 \text{ mA}$

$I_1 = I_2 + I_R = 2.105m + 0.6m = 2.705 \text{ mA}$

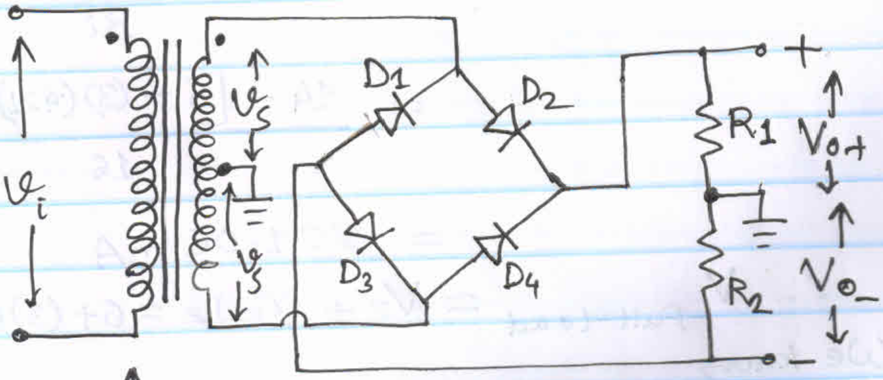
$V_D = V_T . \ln\left(\frac{I_1}{I_S}\right) = 26\times10^{-3} . \ln\left(\frac{2.705\times10^{-3}}{2\times10^{-13}}\right)$

$= 0.6065 \text{ V}$

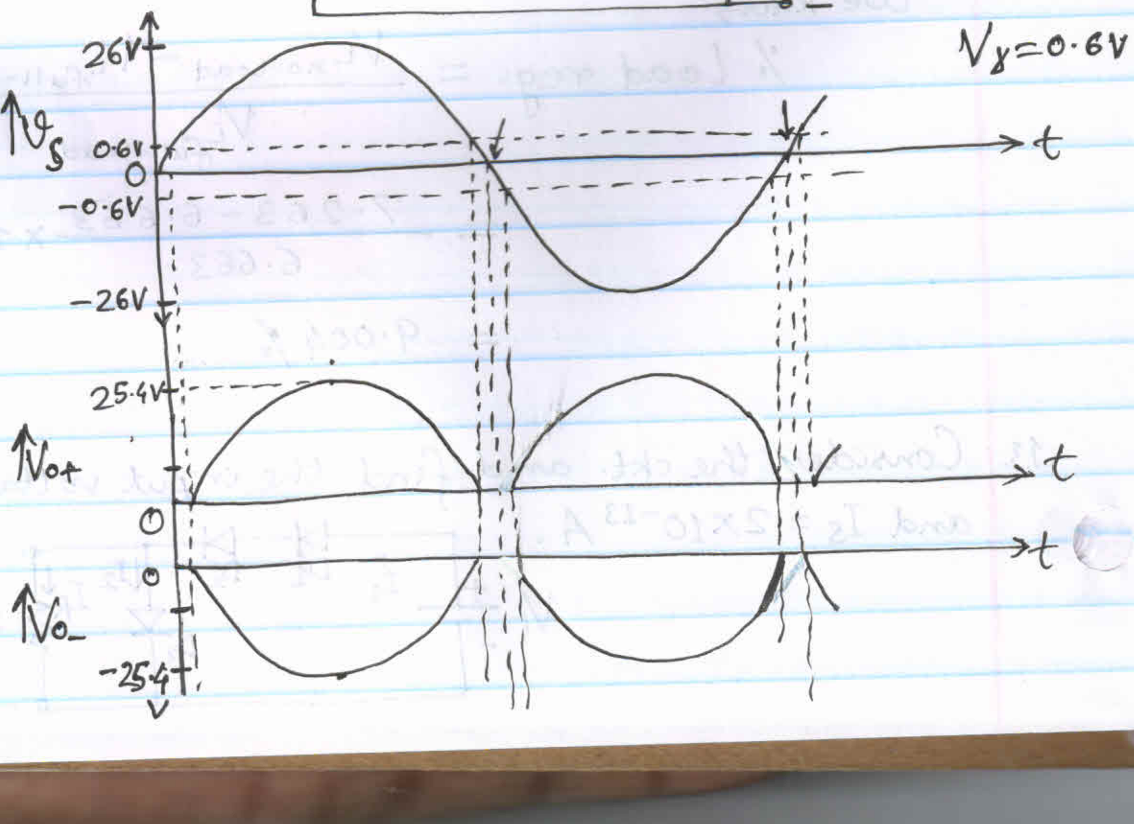
$V_i = 2.V_D + V_o = 2(.6065) + 0.6 = 1.81\text{V}$ (Ans)

14. Draw the output waveforms of the following ckt:

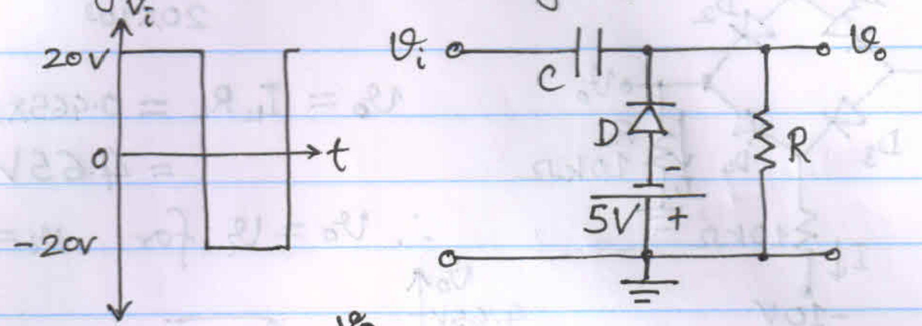
$v_s = 26 . \sin(2\pi 60 t)$



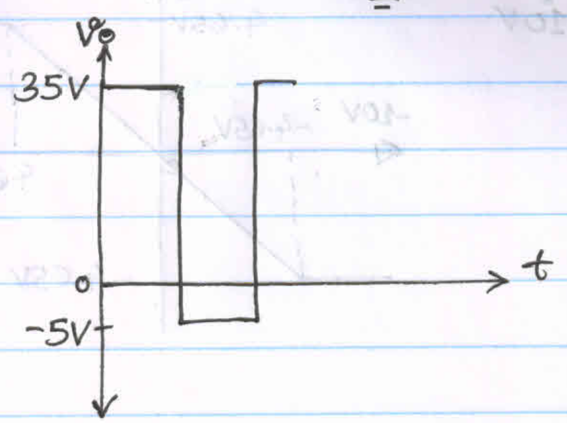
Sol^n.



15. Draw the steady-state output waveform if RC time constant is Large and cut-in voltage of the diode is 0V.



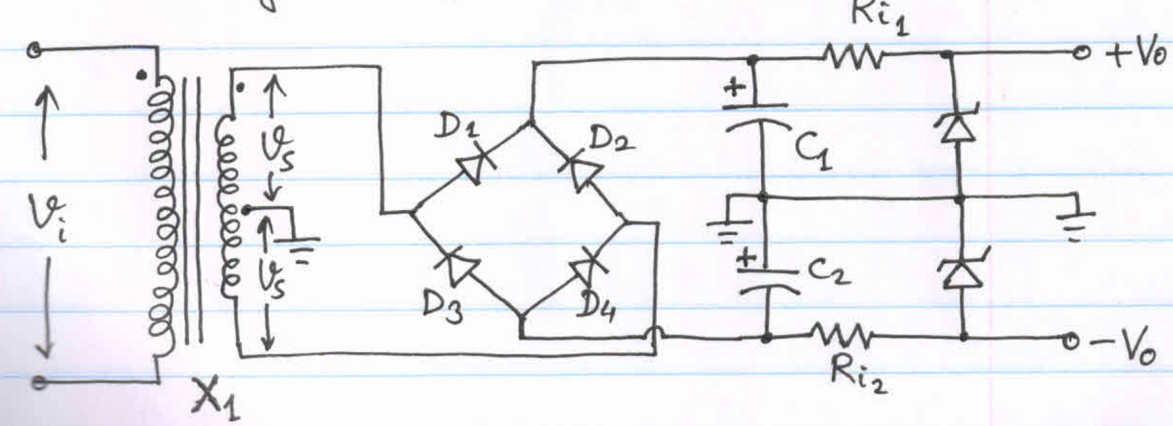
Sol^n.



Steps?

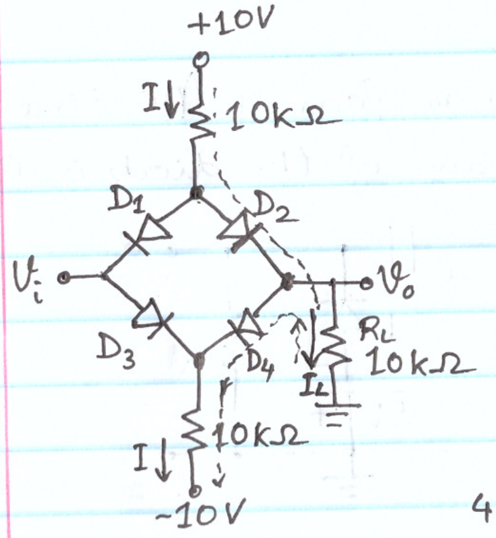
16. Draw the ckt. of a bipolar regulated linear power supply by using a center-tapped transformer and a bridge rectifier.

Sol^n.



17. For the ckt. shown, $V_\gamma = 0.7V$ for Si diodes. Plot the transfer characteristics for $v_i = \pm 10V$.

Sol^n:

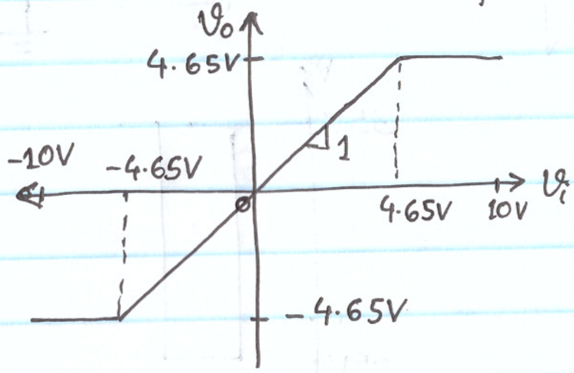


For, $v_i > 0$, D_1 & D_4 are off.

$$\boxed{I_L \cong I} = \frac{10-0.7}{20\times10^3} = 0.465\,mA$$

$$v_o = I_L R_L = 0.465\times10^{3}\times10\times10^{3}$$
$$= 4.65V$$

$\therefore v_o = v_i$ for $v_i = \pm 4.65V$

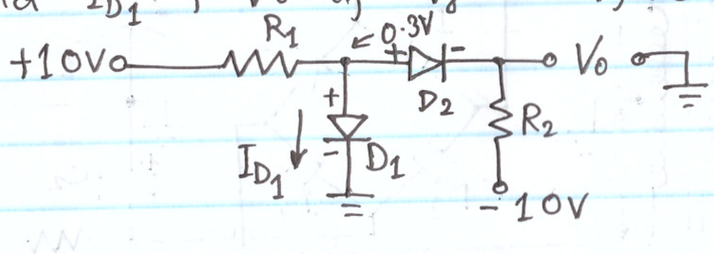


Similarly, while $v_i < 0$, D_2 & D_3 are off.

$$-I_L \boxed{=} I = \frac{10-0.7}{20k} = 0.465\,mA$$

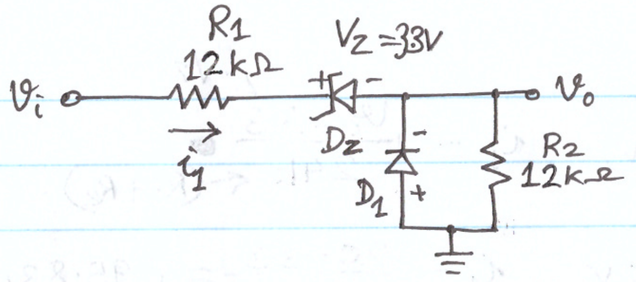
$$\&, \; -v_o = -I_L . R_L = -4.65V$$

18. Find I_{D_1} & V_o if $V_\gamma = 0.3V$, $R_1 = 6.8k\Omega$ & $R_2 = 12k\Omega$



Sol^n: While, D_1 & D_2 are ON, $V_o = +.3 - .3 = 0V$ (Ans)

Now, $I_{D_1} = \frac{10-0.3}{6.8k} - \frac{0-(-10)}{12k} = 0.593\,mA$ (Ans)

19. 

$V_\gamma = 0$

$v_i = -20V$ to $+20V$

Plot: v_o Vs v_i (&) i_1 Vs v_i

Sol^n. During, $v_i = 0$ to $-20V$, zener & normal D are conducting (FB) $\Rightarrow V_{o\,(-20V \text{ to } 0V)} = 0$

For, $v_i = 0$ to $+3.3V$, zener is in reverse blocking mode (not in breakdown) $\Rightarrow i_1 = 0$ & $V_{o\,(0-3.3V)} = 0$

For, $v_i > 3.3V$, Z-diode enters into brk-dwn state.

$$i_1 = \frac{v_i - 3.3}{12k + 12k} \text{ A}$$

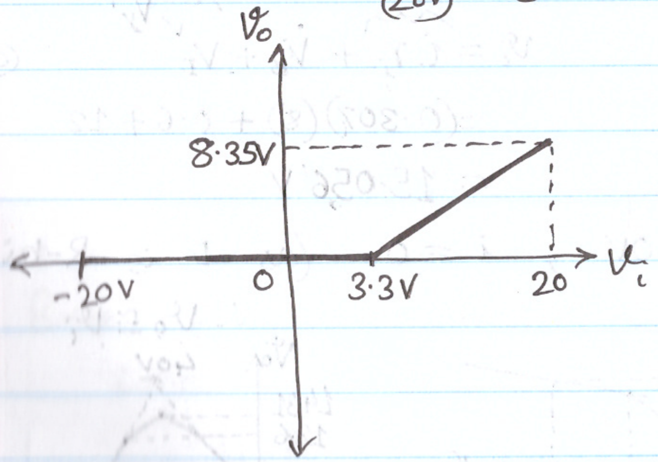
&, $$V_{o\,(3.3 \text{ to } 20V)} = \left[\frac{v_i - 3.3}{12k + 12k}\right](12k) = \frac{v_i - 3.3}{2}$$

R2

At, $v_i = +20V$,

$$i_1 = \frac{20 - 3.3}{24k} = 695.83\ \mu A$$

$$V_{o(20V)} = 8.35V$$



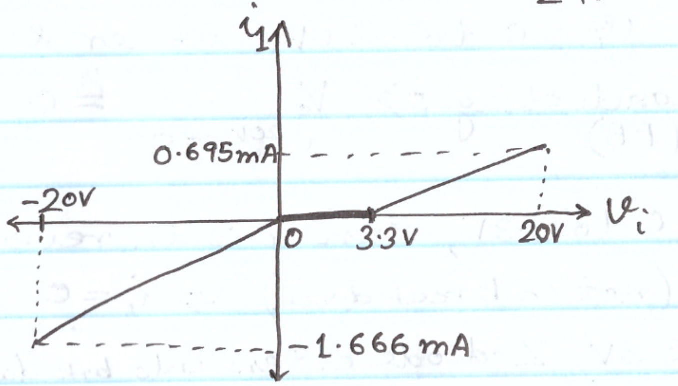
For, $v_i < 0$, $V_o = 0V$ & $-i_1 = \frac{0 - v_i}{12k} = \frac{0 - (-20)}{12k}$

R1

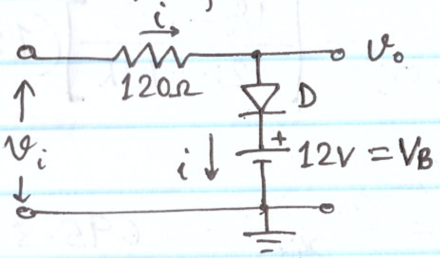
$i_1 = -1.666$ mA

For, $v_i > 3.3V$, $i_1 = \frac{v_i - \overset{\swarrow V_Z}{3.3}}{24k \leftarrow (R_1+R_2)}$

At, $v_i = +20V$, $i_1 = \frac{20-3.3}{24k} = 695.83\mu A$



20. If $V_\gamma = 0.6V$, $r_f = 8\Omega$, $v_i = \pm 40V$, plot v_o Vs. v_i



Draw v_o if v_i is a triangular wave of ±40V.

Soln. For, $v_i = +40V$, $i = \frac{40-0.6-12}{120+8} = \underline{214.06\text{ mA}}$

$v_o = i.r_f + V_B + V_D$ (with $V_D = V_\gamma$) @ D_1 is FB

$= (0.214)(8) + 0.6 + 12$

$= 14.31V$

For, $v_i = -40V$, $i = 0$ (as D is R-biased)

$\therefore v_o \cong v_i$