1) Built-in Voltage

$$V_{bi} = \frac{kT}{q} \ln\left(\frac{N_A N_D}{n_i^2}\right)$$

$\boxed{T = 300\,K}$. $n_i = 1e10$ ; $kT/q = 0.026$ V

$N_A = 3e18$. $N_D = 1e16$

$$\Rightarrow V_{bi} = 0.026 \ln\left[\frac{3e18 \times 1e16}{(1e10)^2}\right] \approx 0.867 \text{ (V)}$$

2) Depletion width

$$\begin{cases} x_n = \left[\dfrac{2k_s\varepsilon_0}{q} \cdot \dfrac{N_A}{N_D(N_A+N_D)} V_{bi}\right]^{1/2} \\ x_p = \dfrac{N_D}{N_A} x_n \\ W = x_p + x_n \end{cases}$$

$k_s = 11.8$
$\varepsilon_0 = 8.85e(-14)$
$q = 1.6e(-19)$
$N_A = 3.0e18$
$N_D = 1e16$
$V_{bi} = 0.867$

$$\Rightarrow \begin{cases} x_n = 33.59 \ (\mu m) \\ x_p = 0.11 \ (\mu m) \\ W = 33.70 \ (\mu m) \end{cases}$$

3) Due to different doping on P-side & n-side.

$N_A \neq N_D \Rightarrow x_p \neq x_n$

4) Leakage Current Density

$$J_0 = q\left(\frac{D_N}{L_N}\frac{n_i^2}{N_A} + \frac{D_P}{L_P}\frac{n_i^2}{N_D}\right)$$

where $L_N \equiv \sqrt{D_N \tau_n}$ $\quad L_P \equiv \sqrt{D_P \tau_P}$

$$\frac{D_N}{\mu_N} = \frac{kT}{q} \doteq 0.026 \qquad \frac{D_P}{\mu_P} = \frac{kT}{q} \doteq 0.026$$

$\mu_N = 1000\ cm^2/V\cdot s$ $\quad \mu_P = 200\ cm^2/V\cdot s$

$\tau_n = 10\ \mu s$ $\quad \tau_P = 1.2\ \mu s$.

$$\therefore J_0 = q\left(\sqrt{\frac{D_N}{\tau_n}}\frac{n_i^2}{N_A} + \sqrt{\frac{D_P}{\tau_P}}\frac{n_i^2}{N_D}\right)$$

$$= q\left(\sqrt{\frac{kT}{q}\frac{\mu_N}{\tau_n}}\frac{n_i^2}{N_A} + \sqrt{\frac{kT}{q}\cdot\frac{\mu_P}{\tau_P}}\frac{n_i^2}{N_D}\right)$$

$$= 1.6e(-19)\left[\sqrt{\frac{0.026\times1000}{10\times10^{-6}}}\frac{(10^{10})^2}{3\times10^{18}} + \sqrt{\frac{0.026\times200}{1.2\times10^{-6}}}\frac{(10^{10})^2}{10^{16}}\right]$$

$$\doteq 3.339e{-12}\ (A/cm^2)$$

5) $$J = q\left(\frac{D_N}{L_N}\frac{n_i^2}{N_A} + \frac{D_P}{L_P}\frac{n_i^2}{N_D}\right)\left(e^{qV_A/kT} - 1\right)$$

$$= \underbrace{q\left(\frac{D_N}{L_N}\frac{n_i^2}{N_A} + \frac{D_P}{L_P}\frac{n_i^2}{N_D}\right)\left(e^{qV_A/kT}\right)}_{\text{Diffusion}} - \underbrace{q\left(\frac{D_N}{L_N}\frac{n_i^2}{N_A} + \frac{D_P}{L_P}\frac{n_i^2}{N_D}\right)}_{\text{Drift}}$$

6) $V_A = 0V$

area $= 2\times10^{-5}$ cm$^2$

$$\frac{C_J}{A} = \frac{K_S\epsilon_0}{W}$$

$$W = \sqrt{\frac{2K_S\epsilon_0}{q}\frac{(N_A+N_D)}{N_AN_D}(V_{bi}-V_A)}$$

$$\Rightarrow \frac{C_{J0}}{A} = \sqrt{\frac{qK_S\epsilon_0}{2}\frac{N_AN_D}{N_A+N_D}\frac{1}{V_{bi}}}$$

where $K_S = 11.8$, $\epsilon_0 = 8.85e{-14}$, $N_A = 3e18$

$q = 1.6e{-19}$, $V_{bi} = 0.867$, $N_D = 1e16$

$$\therefore \frac{C_{J0}}{A} \doteq 3.1e{-8} \quad (F/cm^2)$$

$$g_d = \frac{I_D + I_s}{V_T} \qquad V_A = 0 \Rightarrow I_D = I_0(e^{V_A/V_T}-1) = 0$$

$$\Rightarrow r_d = 1/g_d = \frac{V_T}{I_s} = \frac{V_T}{J\times area} = \frac{kT/q}{I_0\times area}$$

$$= \frac{0.026}{3.339\times10^{-12}\times2\times10^{-5}} \doteq 3.90\times10^{14}(\Omega)$$

7) $V_A = -3V$

$$\frac{C_J}{A} = \frac{C_{J0}}{A} \Big/ \sqrt{1 - \frac{V_A}{V_{bi}}} \doteq 1.470e\text{-}8 \quad (F/cm^2).$$

$$g_d \simeq \frac{-I_s + I_s}{V_T} \simeq 0 \Rightarrow r_d = \infty$$

$$g_d = \frac{I_D + I_s}{V_T} = \frac{I_s(e^{V_A/V_T} - 1) + I_s}{V_T} \quad \left( V_A = -3V,\ V_T = 0.026V \Rightarrow e^{V_A/V_T} - 1 \simeq -1 \right)$$

$$\simeq \frac{-I_s + I_s}{V_T} = 0$$

8) $V_A = 0.5V$

$$\frac{C_J}{A} = \frac{C_{J0}}{A} \Big/ \sqrt{1 - \frac{V_A}{V_{bi}}} \doteq 4.77e\text{-}8 \quad (F/cm^2).$$

$$g_d \doteq \frac{I_D}{V_T} = \frac{I_0 e^{V_A/V_T}}{V_T} = \frac{J_0 \times Area\, e^{V_A/V_T}}{V_T}$$

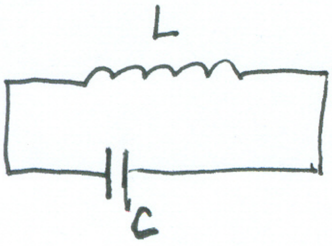
$$r_d = \frac{1}{g_d} = \frac{V_T}{J_0 \times Area\, e^{V_A/V_T}} = 1.735 \times 10^6 \ (\Omega)$$

$$\left( g_d = \frac{I_D + I_s}{V_T} = \frac{I_s(e^{V_A/V_T} - 1) + I_s}{V_T} \right.$$

for $V_A = 0.5$, $V_T = 0.026$. $I_D \doteq 8.2703e^7\, I_s \gg I_s$

$$\left. \therefore g_d \simeq \frac{I_D}{V_T} \right)$$

9).




$$f_0 = \frac{1}{2\pi\sqrt{LC_J}} \Rightarrow C_J = \frac{1}{L(2\pi f)^2} = \frac{1}{12\times10^{-9}\times(2\pi\times3\times10^{9})^2}$$

$$\approx 2.345e-13 \ (F)$$

$V = 3V$

$$A = \frac{2.345e-13}{1.470e-8} \doteq 1.596e-5 \ (cm^2)$$

10) $V = -1V$

$$\left.\frac{C_J}{A}\right|_{-1V} = \frac{C_{J0}}{A} \Big/ \sqrt{1+\frac{1}{0.867}} \approx 2.115e-8 \ (F/cm^2)$$

$$C_J|_{-1V} = 1.596(e-5)\times 2.115(e-8) \doteq 3.376e-13 \ (F)$$

$$\Rightarrow f|_{-1V} = \frac{1}{2\pi\sqrt{L\,C_J|_{-1V}}} = \frac{1}{2\pi\sqrt{12\times10^{-9}\times3.376\times10^{-13}}}$$

$$\approx 2.50e9 \ (Hz) \sim 2.5 \ GHz$$

$$\Delta f = f_0 - f|_{-1V}$$

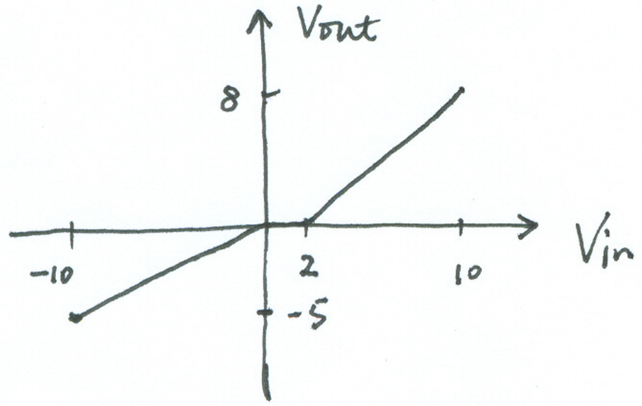
$$= 0.5 \ GHz$$

11) Ideal:

$V_{in} > 2V$. $D_2$ ON . $D_1$ off $V_{out} = V_{in} - 2$

$0 < V_{in} < 2V$ $D_1$ off. $D_2$ off $V_{out} = 0$

$V_{in} < 0$ $D_1$ ON $D_2$ off $V_{out} = V_{in}/2$

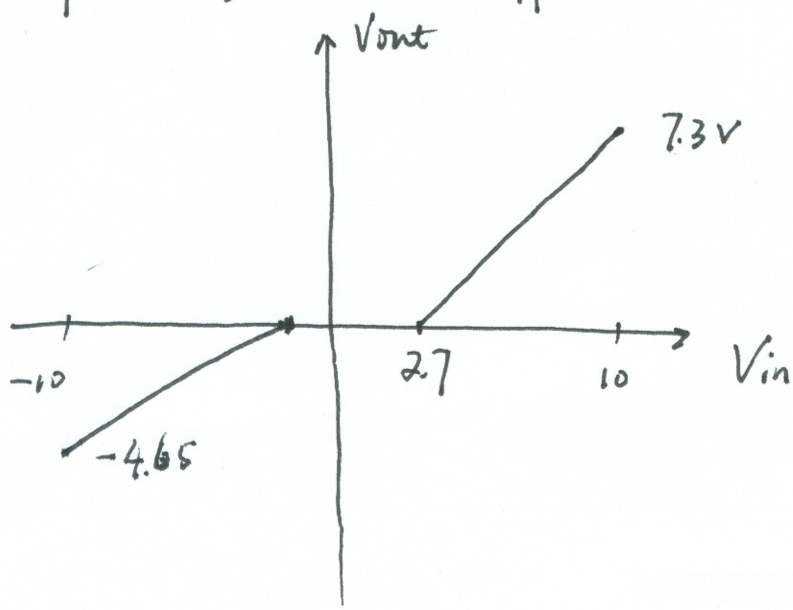



CVD:

$V_{in} > 2.7V$ $D_1$ off , $D_2$ ON $V_{out} = V_{in} - 2.7$

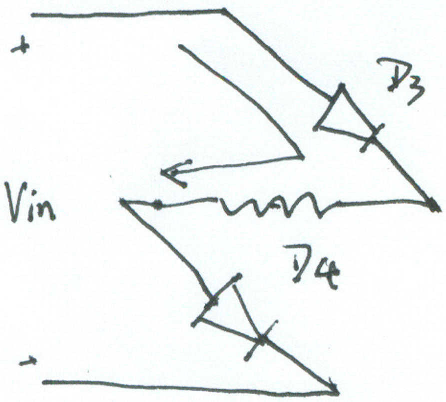
$-0.7 < V_{in} < 2.7$ $D_1$ off. $D_2$ off $V_{out} = 0$

$V_{in} < -0.7$ $D_1$ ON . $D_2$ off $V_{out} = \frac{V_{in} + 0.7}{2}$



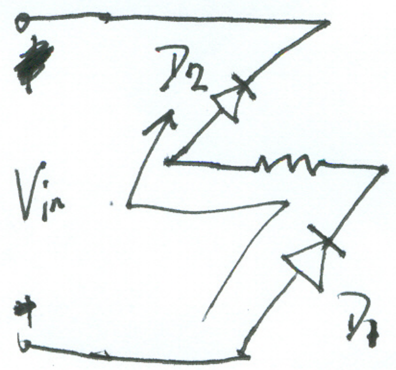
12)

a.



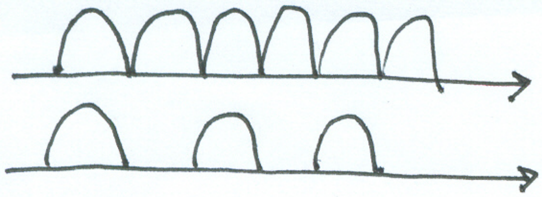

$D_3, D_4$ ON

b.




$D_1$. $D_2$ ON

c.

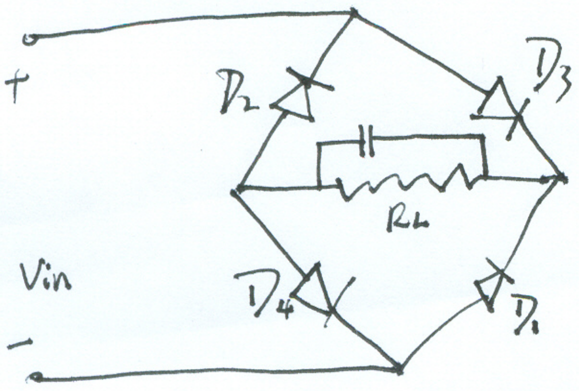


Full-wave rectifier : No power wasted

Half-wave rectifier : half is wasted

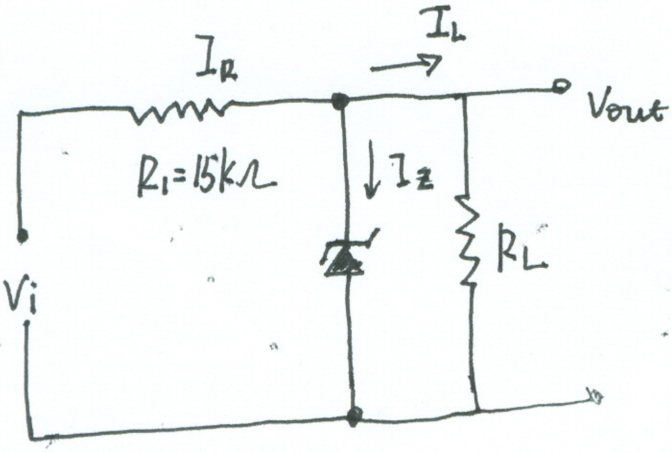
d. Current passing through the load remains the same.

e.




Add a capacitor in parallel with $R_L$.

13) a.




$$I_Z = I_R - I_L > 0$$

$$\Rightarrow \frac{27-9}{15} - \frac{9}{R_L} > 0 \Rightarrow R_L > 7.5\ (k\Omega)$$

b. $I_L < I_R = \dfrac{27-9}{15} = 1.2\ (mA)$

c. $R = 5k\Omega < 7.5$. Zener cut off

thus. $V_{out} = V_{in} \dfrac{R_L}{R_L + R_1} = 27 \dfrac{5}{5+15} = 6.75\ (V)$