Tutorial 1

1. A sample of silicon at $T = 300$ K is doped to $N_d = 8 \times 10^{15}$ cm^{-3}. (a) Calculate n_o and p_o. (b) If excess holes and electrons are generated such that their respective concentrations are $\delta n = \delta p = 10^{14}$ cm^{-3}, determine the total concentrations of holes and electrons.

   $n_0 = (1.5*10^{10})^2$
   As $N_d >> n_0$, n_0 is nearly equal to N_d
   $n_0 = 8*10^{15}$ cm^{-3}
   $p_0 = (n_i)^2/N_d = 2.81*10^4$ cm^{-3}

   $n = n_0 + \delta n = 8.1*10^{15}$ cm^{-3}
   $p = p_0 + \delta p = 10^{14}$ cm^{-3}

2. A silicon PN junction at T= 300K is doped at $N_d = 10^{16}$cm^{-3} and $N_a = 10^{17}$cm^{-3}. The junction capacitance is to be $C_j = 0.8$ pF when a reverse-bias voltage of $V_R = 5$V is applied. Find the zero-biased junction capacitance C_{j0}.

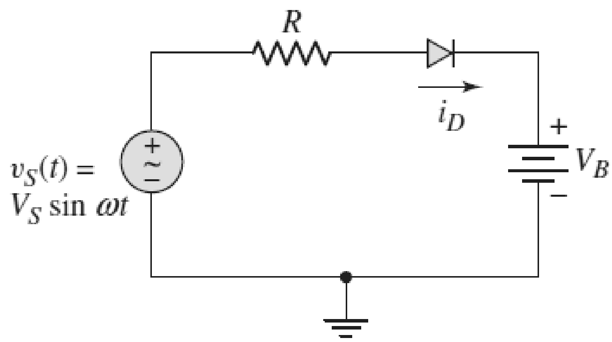
$$V_{bi} = V_T \ln\left(\frac{N_a N_d}{n_i^2}\right)$$

$V_{bi} = 0.757$ V

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

$C_{j0} = 2.21$ pF

3. Consider the circuit shown below. Assume V_B =12V, R = 100Ω, and V_γ=0.6V. Also assume $v_S(t)$=24sin$w$t. Calculate the maximum reverse-bias voltage, the peak diode current and the fraction of the cycle over which the diode is conducting.



Diode current $i_D(peak) = \dfrac{V_S - V_B - V_\gamma}{R}$ =114mA

Max Reverse bias voltage = V_s+V_B = 24+12 = 36V

A half-wave rectifier uses a diode with an equivalent forward resistance of 0.3Ω. If the input ac voltage is 10 V (rms) and the load is a resistance of 2.0Ω, calculate $\mathbf{I_{dc}}$ and $\mathbf{I_{rms}}$ in the load.

Solution

Given supply voltage V_S=10 V

So peak value of supply voltage, V_{Smax}= $10\sqrt{2}$

Forward resistance, $R_F = 0.3\Omega$ and load resistance R_L =2Ω

Peak value of current at load, $I_{max} = \frac{V_{Smax}}{R_L+R_F} = \frac{10\sqrt{2}}{2+0.3} = 6.15A$

DC output current $I_{DC} = \frac{I_{max}}{\pi} = \frac{6.15}{\pi} = 1.958A$

RMS value of output current, I_{rms} = $\frac{I_{max}}{2} = \frac{6.15}{2} = 3.075$A

A half-wave rectifier uses a diode with a forward resistance of 100Ω. If th
input ac voltage is 200 V (rms) and the load resistance is 2 kΩ, determine

a. $\mathbf{I_{max}}$, $\mathbf{I_{dc}}$ and $\mathbf{I_{rms}}$

b. Peak inverse voltage when the diode is ideal

c. Load output voltage

d. dc output and ac input power

e. Ripple factor

f. Rectification efficiency

Solution

RMS value of supply voltage, $V_{Srms} = 220$ V

Maximum value of supply voltage, $V_{Smax} = 220\sqrt{2}$ V

Forward resistance, $R_F = 100\Omega = 0.1k\Omega$

Load resistance, $R_L = 2\ k\Omega$

So (a) the maximum value of current, $I_{max} = \frac{V_{Smax}}{R_L+R_F} = \frac{220\sqrt{2}}{(2+0.1)\times10^3} = 1.48.156\ mA$

Average value of output current, $I_{dc} = \frac{I_{max}}{\pi} = \frac{148.156}{\pi} = 74.078$ Ma

(b) Peak inverse voltage = $V_{Smax} = 220\sqrt{2}$ V

(c) Load output voltage, $V_{dc} = I_{dc} \times R_L = 47.16 \times 10^{-3} \times 2 \times 10^3 = 94.32$ V

(d) DC output power, $P_{dc} = I_{dc}^2 \times R_L = (47.16 \times 10^{-3})^2 \times 2 \times 10^3 = 4.448$ W

AC input power, $P_{ac} = \frac{{I_{max}}^2}{4}(R_F + R_L)$= 11.524 W

(e) Ripple factor=1.21

(f) Efficiency = η=$\frac{P_{dc}}{P_{ac}} \times 100 = 38.6\%$

8. The load resistance of a centre-tapped full-wave rectifier is 500Ω and the necessary end to end voltage is 60 sin (100πt). Calculate

a. Peak, average and rms values of current.
b. Ripple factor
c. Efficiency of the rectifier

Each diode has an idealized I-V characteristics having slope corresponding to a resistance of 50Ω.

Solution

Maximum value of supply voltage, $V_{Smax} = 60$ V

Forward resistance, $R_F = 50\Omega$

Load resistance, $R_L = 500\ \Omega$

(a) The maximum value of current, $I_{max} = \frac{V_{Smax}}{R_L+R_F} = \frac{60}{500+50} = 0.109\ A$

Average value of output current, $I_{dc} = \frac{2.I_{max}}{\pi} = \frac{2\times0.109}{\pi} = 0.0695$ A

RMS value of current, $I_{rms} = \frac{I_{max}}{\sqrt{2}} = \frac{0.109}{\sqrt{2}} = 0.077$ A

(b) Ripple factor= $\sqrt{(\frac{I_{max}}{I_{dc}})^2 - 1} = 0.482$

(c) Efficiency of rectifier= $\eta = \frac{0.812}{1+\frac{R_F}{R_L}} \times 100 = 73.82\%$

9. A centre-tapped transformer has a 220 V primary winding and a secondary winding rated at 12-0-12 V and is used in a full-wave rectifier circuit with a load of 100Ω. What is the dc output voltage, dc load current.

Solution

Maximum value of supply voltage, $V_{Smax} = 12\sqrt{2}$ V

Load resistance, $R_L = 100\ \Omega$

DC load current, $I_{dc} = \frac{2.I_{max}}{\pi} = \frac{2\times V_{Smax}}{\pi\times R_L} = 108$ mA

DC output voltage, $V_{dc} = I_{dc} \times R_L = 108 \times 10^{-3} \times 100 = 10.8$ V

10. In a certain copper conductor, the current density is 2.4 A/$\boldsymbol{mm^2}$ and the electron density is $\mathbf{5 \times 10^{28}}$ free electrons per $\boldsymbol{m^3}$ of the copper. Determine the drift velocity of the electron.

Solution

Current density, $J = 2.4\frac{A}{mm^2} = 2.4 \times 10^6 A/m^2$

Electron density, $n = 5 \times 10^{28}$

Electron charge, $e = 1.6 \times 10^{-19}$ coulomb

It is known that $J = n \times e \times v \Rightarrow v = \frac{J}{e \times n} = 0.3 \times 10^{-3}$ m/s

11. A silicon sample is fabricated such that the hole concentration is $p_o = 2 \times 10^{17}$ cm^{-3}. (a) Should boron or arsenic atoms be added to the intrinsic silicon? (b) What concentration of impurity atoms must be added? (c) What is the concentration of electrons?

Solution

(a) Add boron atoms

(b) $N_a = p_o = 2 \times 10^{17}\ \text{cm}^{-3}$

(c) $n_o = \frac{n_i^2}{p_o} = \frac{(1.5 \times 10^{10})^2}{2 \times 10^{17}} = 1.125 \times 10^3\ \text{cm}^{-3}$

12. (a) At what reverse-bias voltage does the reverse-bias current in a silicon pn junction diode reach 90 percent of its saturation value? (b) What is the ratio of the current for a forward-bias voltage of 0.2 V to the current for a reverse bias voltage of 0.2 V?

Solution

a. $I = I_S\left[\exp\left(\frac{V_D}{V_T}\right) - 1\right] - 0.90 = \exp\left(\frac{V_D}{V_T}\right) - 1$

$$\exp\left(\frac{V_D}{V_T}\right) = 1 - 0.90 = 0.10$$

$$V_D = V_T \ln(0.10) \Rightarrow \underline{V_D = -0.0599\text{ V}}$$

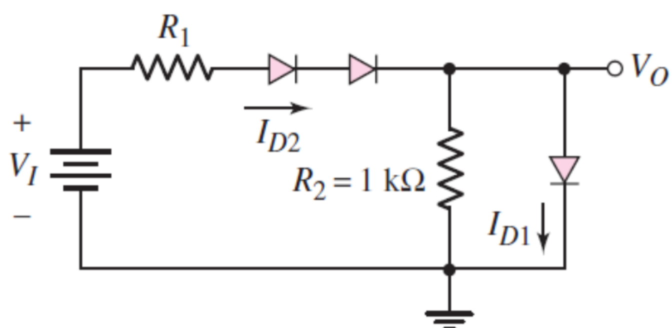
b.

$$\left|\frac{I_F}{I_R}\right| = \frac{I_S}{I_S} \cdot \frac{\left[\exp\left(\frac{V_F}{V_T}\right) - 1\right]}{\left[\exp\left(\frac{V_R}{V_T}\right) - 1\right]} = \left|\frac{\exp\left(\frac{0.2}{0.026}\right) - 1}{\exp\left(\frac{-0.2}{0.026}\right) - 1}\right|$$

$$= \left|\frac{2190}{-1}\right|$$

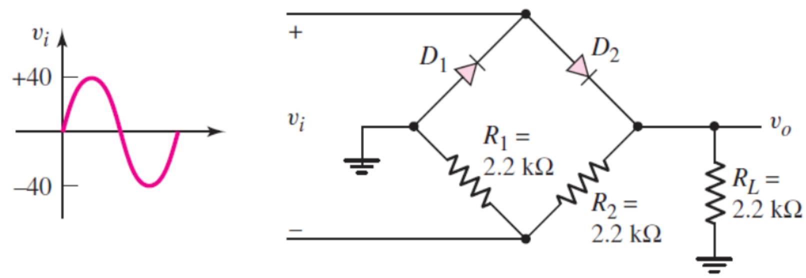
$$\underline{\frac{I_F}{I_R} = 2190}$$

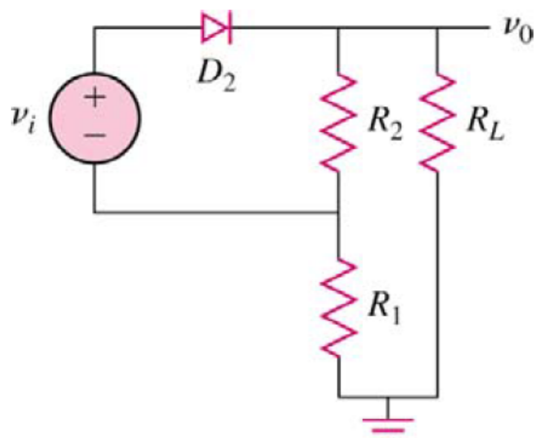
13. Assume each diode in the circuit shown in Figure has a cut-in voltage of V_γ = 0.65V. (a) The input voltage is V_I = 5V. Determine the value of R_1 required such that I_{D1} is one-half the value of I_{D2}. What are the values of I_{D1} and I_{D2}? (b) If V_I = 8V and R_1 = 2kΩ, determine I_{D1} and I_{D2}.

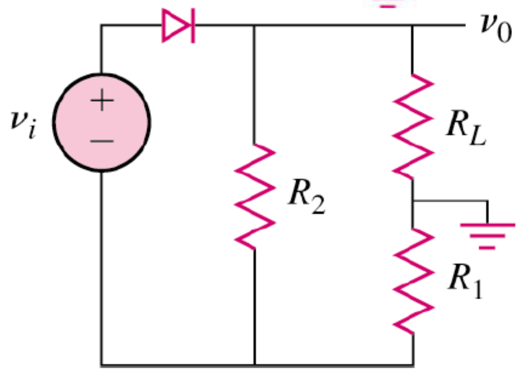


Solution

14. Sketch v_o versus time for the circuit in Figure with the input shown. Assume $V_\gamma = 0$.







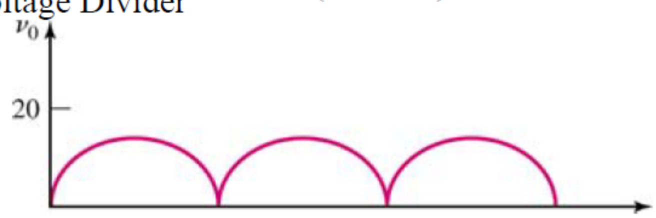
For $v_i > 0$

$V_\gamma = 0$

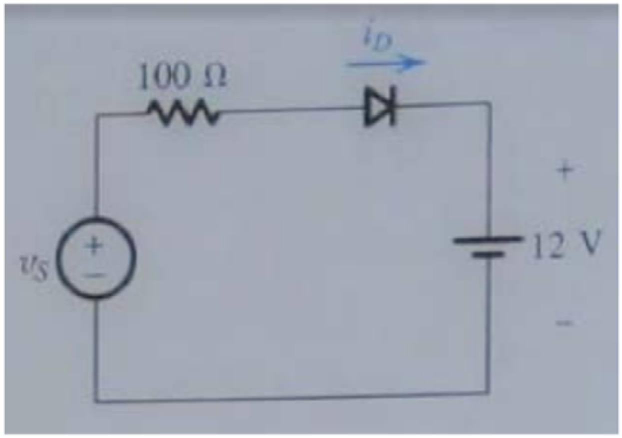
Voltage across $R_L + R_1 = v_i$

$$\Rightarrow v_0 = \left(\frac{R_L}{R_L + R_1}\right) v_i = \frac{1}{2} v_i$$

Voltage Divider



15. Figure shows a circuit for charging a 12V battery. If Vs is sinusoid with 24-V Peak amplitude, find the fraction of each cycle for which the diode conducts. Also find the peak values of the diode current and the maximum reverse bias voltage that appears across the diode?



Solution

- Conduction angle is 2θ,

$24\cos\theta = 12$, θ = 60^0, conduction angle = 120^0

Diode current I_d = $\frac{24-12}{100} = 0.12A$

Max. Reverse bias voltage across diode = 24+12 = 36V

16. A Silicon Diode said to be a 1mA device displays a forward voltage of 0.7V at a current of 1mA. Evaluate the junction scaling constant I_s. What scaling constant would apply for a 1-A Diode of the same manufacturer that conducts 1A at 0.7V?

Ans - $i = I_S e^{\frac{V}{V_T}}$

$$I_S = I\, e^{-\frac{V}{V_T}}$$

$$I_S = 10^{-3} e^{-\frac{700}{23}} = 6.9*10^{-16} A$$

The current for 1A diode is 1000 times that of 1mA so I_S will be also thousand times

$$I_S = 6.9*10^{-13} A$$

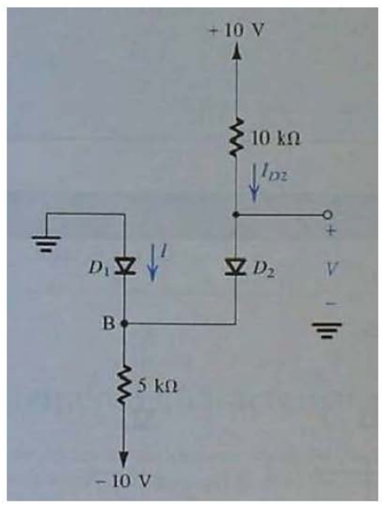
17. Consider a PN junction T=300K with a P- Type doping concentration of $N_A = 10^{18} / cm^3$. Determine the N-type doping concentration such that the maximum electric field is | $E_{\max}$ | = $3*10^5 V/cm$ at a reverse bias voltage of $V_R = 25V$

- $|E_{\max}| = \{\frac{2qV_R}{\in_s}(\frac{N_A N_D}{N_A + N_D})\}^{\frac{1}{2}}$

$$3*10^5 = \{\frac{2*1.6*10^{-19}*25}{11.7*8.85*10^{-14}}(\frac{10^{18} N_D}{10^{18}+N_D})\}^{\frac{1}{2}}$$

$$N_D = 1.18*10^{16} cm^{-3}$$

18. Assume the Diode to be ideal, Find the values of I and V in the circuit



Ans - Assuming both diode conducting , $V_B = 0, V = 0$

$$I_{D2} = \frac{10-0}{10} = 1mA$$

KVL at B, $I + 1 = \frac{0-(-10)}{5}$

$$I = 1mA$$

19. Calculate the intrinsic carrier concentration of pure Si at T= 300 k. When the pure si is doped with Arsenic (Nd) find the equilibrium electron and hole concentrations. Comment on the doped Si semiconductor based on the resulting equilibrium concentrations and find the resistivity of the resulted material. For this material find the required electric field which is to be applied in order to induce a drift current density of, 190 A/cm2

Ans: a) Intrinsic carrier concentration for silicon

$$n_i = BT^{3/2}e^{\left(\frac{-E_g}{2kT}\right)}$$

$= 1.6 \times 10^{10}\ cm^{-3}$

$T = 300K$

$K = 86 \times 10^{-6}\ eV/k$

b) Equilibrium electron and hole concentrations after doping with arsenic

here $Nd \gg n_i \Rightarrow n_0 \simeq Nd = 2 \times 10^{16}\ cm^{-3}$

$\Rightarrow P_0 = \frac{n_i^2}{Nd} = \frac{(1.5 \times 10^{10})^2}{2 \times 10^{16}} = 1.25 \times 10^{3}\ cm^{-3}$

c) Resistivity of the resulted material

$\frac{1}{\rho} = \sigma = e\mu_n n + e\mu_p p \cong e\mu_n n \Rightarrow \rho = \frac{1}{(1.6 \times 10^{-19})(1350)(2 \times 10^{16})} = \frac{1}{4.325}(\Omega\ cm)^{-1}$

$= 0.2312\ \Omega . cm$

d) E field required for desired drift current density

$J = \sigma E \Rightarrow E = \frac{J}{\sigma} \Rightarrow E = \rho J \Rightarrow E = 0.2312 \times 190$

$= 43.93\ V/cm$

20. Calculate built in potential barrier of Si pn junction at room temperature and fora given Donor and acceptor concentrations. Find the junction capacitance for an applied reverse voltage of 2V

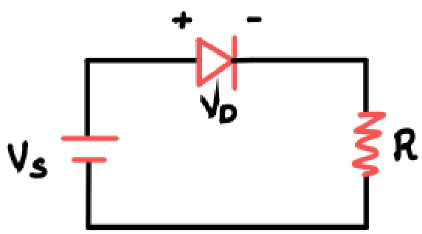
$$V_{bi} = V_T \ln\left(\frac{N_a N_d}{n_i^2}\right) = 0.026 \ln\left[\frac{10^{15} \times 10^{17}}{(1.5\times10^{10})^2}\right] = 0.6973\ \text{V}$$

$$\Rightarrow C_j = C_{jo}\left(1+\frac{V_R}{V_{bi}}\right)^{-1/2} = 0.4\left[1+\frac{1}{0.693}\right]^{-1/2} = 0.256\ \text{PF}$$

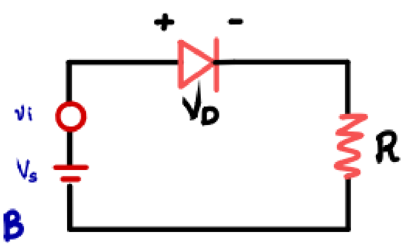
21. Assuming piece wise linear diode with parameters as given below, find the diode current and voltage and also the power dissipated in the diode When an ac signal of vi is applied in series with the supply voltage find the DC and ac component of output voltage

$V_\gamma = 0.6\text{V}$; $r_f = 12\Omega$; $V_S = 6\text{V}$; $R = 4\text{K}\Omega$

$v_i = 0.2 \sin\omega t\ (\text{V})$



$V_S = 6\text{V}$ FB



$$\Rightarrow I_D = \frac{V_S - V_\gamma}{R + r_f} = \frac{6-0.6}{4000+12} = 1.345\ \text{mA}$$

$$\Rightarrow V_D = I_D r_f + V_\gamma = 1.345\text{m} \times 12 + 0.6 = 0.616\text{V}$$

$$\Rightarrow P_D = I_D V_D = 0.828\ \text{mW}$$

DC output voltage : $V_o = I_D R = 1.345 \times 4 = 5.38\text{V}$

ac analysis

$$r_d = \frac{V_T}{I_{DQ}} = \frac{26\text{mV}}{1.345\text{mA}} = 19.33\ \Omega$$

$$\Rightarrow i_i = \frac{v_i}{r_d + R} = \frac{0.2 \sin\omega t}{4000+19.33} = 49.76\ \mu\text{A}$$

$$\Rightarrow V_o = i_i R = 199 \sin\omega t\ (\text{mV})$$

22. A power supply A delivers 10 V dc with a ripple of 0.5 V r.m.s. while the power supply B delivers 25 V dc with a ripple of 1 mV r.m.s. Which is better power supply ?

A Good power supply needs lower ripple factor

$$\text{Ripple factor} = \frac{V_{ac(rms)}}{V_{dc}}$$

Supply A : $V_{dc} = 10V$, $V_{dc(rms)} = 0.5V \Rightarrow RF = \frac{0.5}{10} = 0.05$

Supply B : $V_{dc} = 25V$; $V_{ac(rms)} = 0.001V \Rightarrow RF = \frac{0.001}{25} = 0.00004$

23. Calculate the minority carrier hole concentration at the edge of the space charge region of a pn junction when a forward bias is applied.
Consider a silicon pn junction at T = 300 K so that ***n,*** = 1.5 x 10^{10} cm^{-3}. **Assume** the n-type doping is 1 x $10^{16}$$cm^{-3}$ and assume that a forward bias of 0.60 V is applied to **the** pn junction. Calculate the minority carrier hole concentration at the edge of the space charge region.

$$p_n = p_{n0} \exp\left(\frac{eV_a}{kT}\right)$$

The thermal-equilibrium minority carrier hole concentration is

$$p_{n0} = \frac{n_i^2}{N_d} = \frac{(1.5 \times 10^{10})^2}{10^{16}} = 2.25 \times 10^4 \text{ cm}^{-3}$$

We then have

$$p_n = 2.25 \times 10^4 \exp\left(\frac{0.60}{0.0259}\right) = 2.59 \times 10^{14} \text{ cm}^{-3}$$