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ELECTRONICS ENGINEERING

CONVENTIONAL PRACTICE SETS VOLUME - I

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NETWORK THEORY

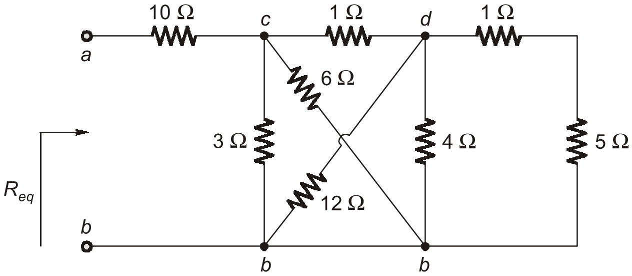
CONVENTIONAL PRACTICE SETS

Page No. 02 - 144

1 CHAPTER

Basics, Circuit Elements, Nodal & Mesh Analysis

Q.1 Calculate equivalent resistance R_{eq} in the circuit shown.



Solution:

3 Ω and 6 Ω resistors are in parallel because they are connected to same two nodes c and b. Their combined resistance is

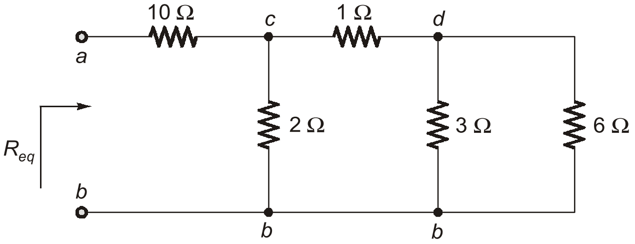
$$3\,\Omega||4\,\Omega = \frac{3\times6}{3+6} = 2\,\Omega$$

Similarly, 12 Ω and 4 Ω resistors are in parallel since they are connected to same two nodes *d* and *b*.

Hence, $$12\,\Omega||4\,\Omega = \frac{12\times4}{12+4} = 3\,\Omega$$

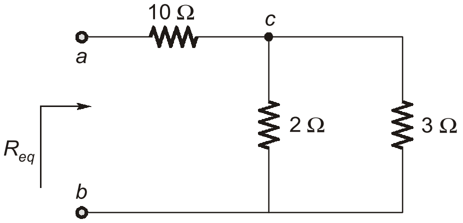
Also, 1 Ω and 5 Ω resistors are in series, hence combined resistance,

$$1\,\Omega + 5\,\Omega = 6\,\Omega$$



Further 3 Ω and 6 Ω in parallel gives equivalent resistance = $\dfrac{3\,\Omega\times6\,\Omega}{(3+6)\,\Omega} = 2\,\Omega$

This 2 Ω is in series with 1 Ω.
Given equivalent as (2 + 1) Ω = 3 Ω as shown below.

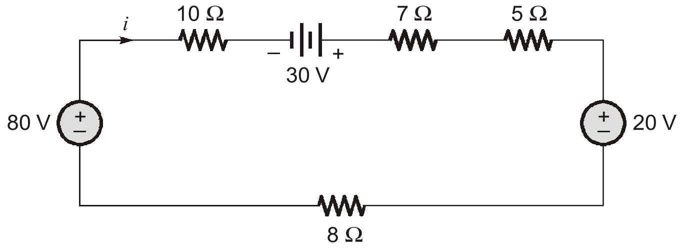


Now 2 Ω and 3 Ω parallel's combination in series with 10 Ω resistance.

Hence, $$R_{ab} = R_{eq} = 10\,\Omega + (2\,\Omega||3\,\Omega)$$

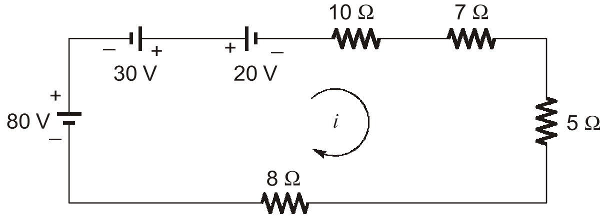
$$= 10 + \frac{2\times3}{2+3} = 11.2\,\Omega$$

Q.2 Use resistance and source combinations to determine the current *i* in figure shown and power delivered by 80 V source.



Solution:

The circuit can be redrawn as,



Further combining the three voltage sources into an equivalent source of 90 V as shown below.

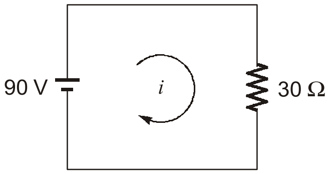
All the resistance, combined in series as,

$$R_{eq} = (10 + 7 + 5 + 8)\ \Omega = 30\ \Omega$$

Simply applying kVL, $-90 + 30i = 0$

Hence, $i = 3$ A

Power delivered by 80 V source $= 80 \text{ V} \times 3 \text{ A} = 240$ W



Q.3 The following mesh equations pertain to a network:

$$8I_1 - 5I_2 - I_3 = 110$$
$$-5I_1 + 10I_2 + 0 = 0$$
$$-I_1 + 0 + 7I_3 = 115$$

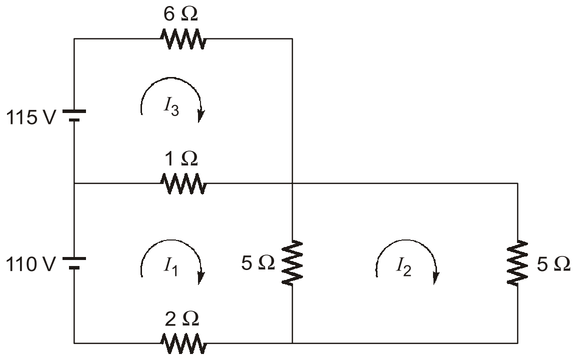
Draw network showing each element.

Solution:

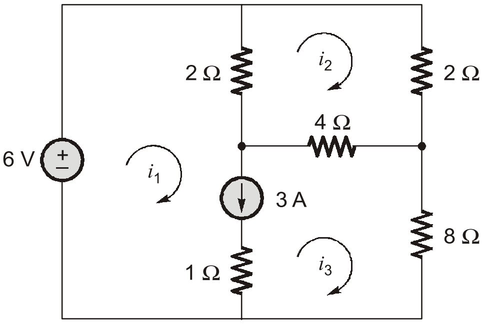
All the mesh equations can be rearrangement as,

$$8I_1 - 5I_2 - I_3 = 110$$
$$\Rightarrow \quad 5(I_1 - I_2) + (I_1 - I_3) + 2I_1 = 110 \quad \text{...(1)}$$
$$-5I_1 + 10I_2 + 0 = 0$$
$$\Rightarrow \quad 5(I_2 - I_1) + 5I_2 = 0 \quad \text{...(2)}$$
$$-I_1 + 0 + 7I_3 = 115$$
$$\Rightarrow \quad (I_3 - I_1) + 6I_3 = 115 \quad \text{...(3)}$$

On the basis of equation (1), (2) and (3), we can draw the network as,



Q4 Find mesh currents in the circuit,



Solution:

$$i_1 - i_3 = 3\text{ A} \quad \text{...(1)}$$

BY KVL for super mesh,

$$2(i_1 - i_2) + 4(i_3 - i_2) + 8i_3 = 6$$

$$2i_1 - 6i_2 + 12i_3 = 6 \quad \text{...(2)}$$

By KVL for second mesh,

$$2i_2 + 4(i_2 - i_3) + 2(i_2 - i_1) = 0$$

$$8i_2 - 4i_3 - 2i_1 = 0 \quad \text{...(3)}$$

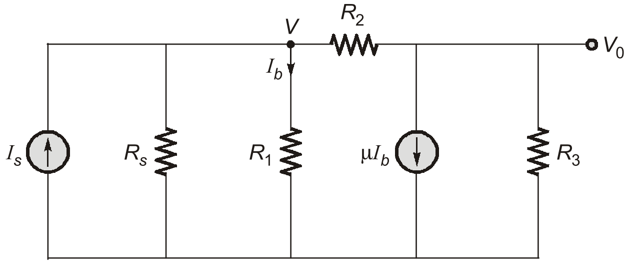
Solving equations (1), (2) and (3), we get

$$i_1 = 3.473\text{ A}$$

$$i_2 = 1.105\text{ A}$$

$$i_3 = 0.473\text{ A}$$

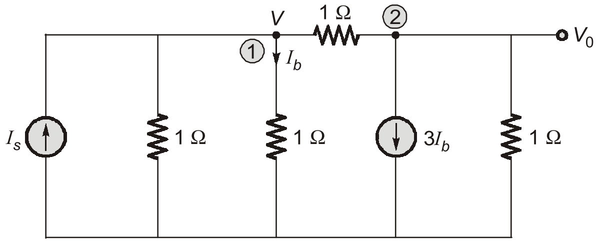
Q5 For the circuit shown in the figure determine V_0/I_S using nodal analysis.



$R_1 = R_2 = R_3 = R_s = 1\ \Omega$, $\mu = 3$

Solution:

$$V = I_b \quad \text{...(1)}$$



$R_1 = R_2 = R_3 = R_s = 1\ \Omega$, $\mu = 3$

Node (1),

$$\frac{V}{1} + \frac{V}{1} + \frac{V - V_0}{1} - I_s = 0$$

$$3V - V_0 = I_s \quad \text{...(2)}$$

Node (2),

$$\frac{V_0}{1} + \frac{V_0 - V}{1} + 3I_b = 0$$

$$2V_0 - V = -3I_b \quad \text{...(3)}$$

From equation (1), $I_b = V$ put in equation (3)

$$2V_0 - V = -3V$$

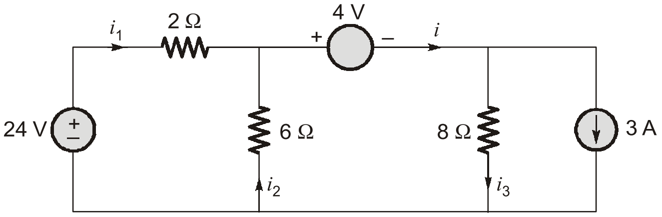
$$2V_0 = -2V$$

$$\Rightarrow \quad V = -V_0$$

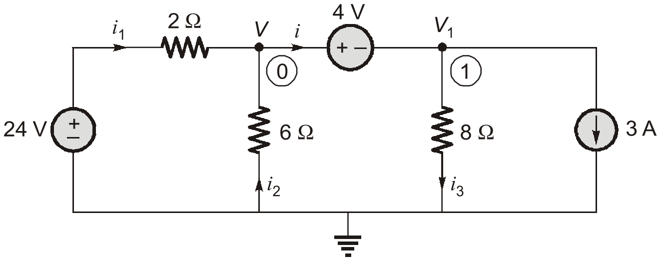
Putting, $V = -V_0$ in equation (2)

$$3(-V_0) - V_0 = I_s$$
$$-4V_0 = I_s$$
$$\frac{V_0}{I_s} = -\frac{1}{4} = -0.25$$

Q.6 For the circuit shown in figure, determine the currents i_1, i_2 and i_3 using nodal analysis.



Solution:



By nodal analysis, $-i_1 - i_2 + i = 0$

$$-\left(\frac{24-V}{2}\right) + \left[-\frac{0-V}{6}\right] + i = 0$$

$$\frac{V-24}{2} + \frac{V}{6} + i = 0 \qquad \text{...(1)}$$

$$V_1 = V - 4$$

KCL at node 1,

$$-i + \frac{V_1}{8} + 3 = 0$$

$$i = \left(\frac{V-4}{8} + 3\right) \qquad \text{...(2)}$$

Combining (1) and (2),

$$\frac{V-24}{2} + \frac{V}{6} + \frac{V-4}{8} + 3 = 0$$

Solving, $V = 12$ V

$$V_1 = 8\text{ V}$$

$$i_1 = \frac{24-12}{2} = 6\text{ A}$$

$$i_2 = -\frac{12}{6} = -2\text{ A}$$

$$i = i_3 + 3 \qquad \because i = i_1 + i_2$$

$$i_3 = i_1 + i_2 - 3$$
$$i_3 = 6 - 2 - 3 = 1\text{ A}$$
$$i_3 = 1\text{ A}$$

CONTROL SYSTEMS

CONVENTIONAL PRACTICE SETS

Page No. 145 - 244

1

CHAPTER

Introduction

Q.1 (a) A control system is defined by following mathematical relationship

$$\frac{d^2x}{dt^2} + \frac{6dx}{dt} + 5x = 12(1 - e^{-2t})$$

Find the response of the system at $t \to \infty$

(b) A function $y(t)$ satisfies the following differential equation

$$\frac{dy(t)}{dt} + y(t) = \delta(t)$$

Where $\delta(t)$ is delta function. Assuming zero initial condition and denoting unit step function by $u(t)$. Find $y(t)$.

Solution:

(a) Taking *LT* on both sides

$$(s^2 + 6s + 5)\, X(s) = 12\left[\frac{1}{s} - \frac{1}{s+2}\right]$$

$$(s + 1)\,(s + 5)\, X(s) = \frac{24}{s(s+2)}$$

$$X(s) = \frac{24}{s(s+1)\,(s+2)\,(s+5)}$$

Response at $t \to \infty$

Using final value theorem,

$$\boxed{\lim_{t \to \infty} x(t) = \lim_{s \to 0} [sX(s)]} = \lim_{s \to 0} \frac{s \times 24}{s(s+1)\,(s+2)\,(s+5)} = 2.4$$

(b) Taking Laplace transform on both sides

$$Y(s)\,[s + 1] = 1$$

$$Y(s) = \frac{1}{s+1}$$

By taking inverse Laplace transform

$$y(t) = e^{-t}\, u(t)$$

Q.2 (a) The Laplace equation for the charging current, $i(t)$ of a capacitor arranged in series with a resistance is given by

$$I(s) = \frac{sC}{1 + sRC} \cdot E(s)$$

The circuit is connected to a supply voltage of E. If E = 100 V, R = 2 MΩ, C = 1 μF. Calculate the initial value of the charging current.

(b) A series circuit consisting of resistance R and an inductance of L is connected to a d.c. supply voltage of E. Derive an expression for the steady-state value of the current flowing in the circuit using final value theorem.

Solution:

(a) Since, $E = 100\,v(t)$

Taking Laplace Transform, $E = 100\,(t)$ volts,

$$\therefore \quad E(s) = \frac{100}{s}$$

Substituting the given values,

$$I(s) = \frac{1\times 10^{-6}s}{(2\times 10^{6}\times 1\times 10^{-6}s+1)}\cdot\frac{100}{s} = \frac{10^{-6}s}{2s+1}\cdot\frac{100}{s}$$

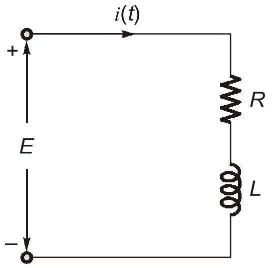
Applying the initial value theorem,

$$\boxed{i(0^{+}) = \lim_{t\to 0} i(t) = \lim_{s\to\infty} s\,I(s)}$$

$$i(0^{+}) = \lim_{s\to\infty} s\cdot\frac{10^{-4}}{1+2s} = \lim_{s\to\infty}\cdot\frac{10^{-4}}{\frac{1}{s}+2} = 50\ \mu\text{A}$$

(b) The differential equation relating the current $i(t)$ flowing in the circuit and the input voltage E is given by

$$E = R\,i(t) + L\frac{di(t)}{dt}$$



Taking Laplace transform of the equation yields,

$$E(s) = R\,I(s) + L[(sI(s) - i(0^{+}))]$$

Assume, $i(0^{+}) = 0$

$$\therefore \quad E(s) = R\,I(s) + Ls\,I(s)$$

$\because$ E is constant (d.c. voltage)

$$E(s) = \frac{E}{s} = RI(s) + Ls\,I(s)$$

$$I(s) = \frac{E}{s(R+sL)}$$

Applying the final value theorem,

$$i_{ss} = \lim_{t\to\infty} i(t) = \lim_{s\to 0} s\,I(s) = \lim_{s\to 0}\frac{sE}{s(R+sL)}$$

$$i_{ss} = \frac{E}{R}$$

Q.3 The impulse response of a system S_1 is given by $y_1(t) = 4e^{-2t}$. The step response of a system S_2 is given by $y_2(t) = 2(1 - e^{-3t})$. The two systems are cascaded together without any interaction. Find response of the cascaded system for unit ramp input.

Solution:

(a) Taking the Laplace transform of the response of S_1, we get

$$Y_1(s) = \frac{4}{s+2},$$

$$X_1(s) = 1 \ \ldots\ (x(t) = \delta(t))$$

Therefore, $$G_1(s) = \frac{Y_1(s)}{X_1(s)} = \frac{4}{s+2} \qquad [\because Y_1(s) = 1]$$

Taking the Laplace transform of the response of S_2, we get

$$Y_2(s) = 2\left(\frac{1}{s} - \frac{1}{s+3}\right) = \frac{6}{s(s+3)}$$

$$Y_2(s) = \frac{1}{s} \quad \ldots (x_2(t) = u(t))$$

Thus, $$G_2(s) = \frac{Y_2(s)}{X_2(s)} = \frac{6}{s(s+3)} \cdot s = \frac{6}{s+3}$$

(b) The transfer function of the cascaded system is

$$G(s) = G_1(s)G_2(s) = \frac{24}{(s+2)(s+3)}$$

The Laplace transform of unit ramp is $R(s) = \frac{1}{s^2}$. Therefore,

$$G(s) = \frac{C(s)}{R(s)}$$

$$C(s) = \frac{24}{(s+2)(s+3)} \cdot \frac{1}{s^2}$$

$$\equiv \frac{A}{s^2} + \frac{B}{s} + \frac{C}{s+2} + \frac{D}{s+3}$$

$$A = \left.\frac{24}{(s+2)(s+3)}\right|_{s=0} = 4$$

$$B = \frac{d}{ds}\left[s^2 C(s)\right]_{s=0}$$

$$= \frac{d}{ds}\left[\frac{24}{(s+2)(s+3)}\right] = -\left.\frac{24(2s+5)}{(s+2)^2(s+3)^2}\right|_{s=0}$$

$$= -\frac{10}{3}$$

$$C = \left.\frac{24}{s^2(s+3)}\right|_{s=-2} = 6$$

$$D = \left.\frac{24}{s^2(s+2)}\right|_{s=-3} = -\frac{8}{3}$$

$$C(s) = \frac{4}{s^2} - \frac{10}{3}s + \frac{6}{s+2} - \frac{8}{3}e^{-3t}$$

Taking inverse Laplace transform.

Therefore, $$c(t) = 4t - \frac{10}{3}u(t) + 6e^{-3t} - \frac{8}{3}e^{-3t}$$

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ELECTRONIC DEVICES AND CIRCUITS

CONVENTIONAL PRACTICE SETS

Page No. 245 - 307

1

CHAPTER

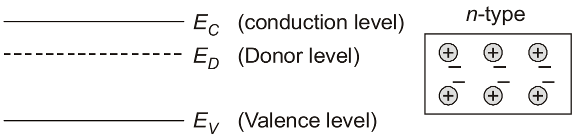
Basic Semiconductor Physics

Q.1 What is doping? Give the advantage of doping.

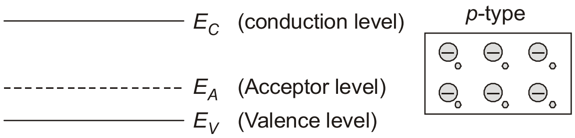
Solution:

Addition of impurities to the pure semiconductor and making it impure is called doping.

Adding pentavalent impurity can cause 4 covalent bonds with the semiconductor and 1 electron is left free. Adding this donor causes a new energy level, below the conduction band.



Adding trivalent impurity causes 3 covalent bonds and there is absence of 1 electron which will get occupied in acceptor level just above valence band.



Doping increases the conductance of semiconductor.

Q.2 A semiconductor has a bandgap of 0.62 eV. Find the maximum wavelength for resistance change in the material by photon absorption. (Note: 1 eV = 1.6 × 10^{-19} Joules)

Solution:

We know that $$E = \frac{hc}{\lambda}$$

Where, E = Energy bandgap = 0.62 eV (given)

h = Planck constant = 6.626×10^{-34} Joule-sec

c = Velocity of light in free space = 3×10^{8} m/sec

λ = Wavelength

So, $$\lambda = \frac{hc}{E} = \frac{6.626\times10^{-34}\times3\times10^{8}}{0.62\times1.6\times10^{-19}}$$

$$\lambda = 2.004 \times 10^{-6} = 2.004\ \mu\text{m}$$

Q.3 (a) Describe the 'Einstein Relationship'?

(b) Find the probability of finding an electron 0.2 eV above the Fermi level at 300°K?

Solution:

(a) Since both diffusion and mobility are statistical thermodynamic phenomena so diffusion constant (D) and mobility (μ) are not independent. The relationship between the D and μ is given by the **'Einstein Relationship'**, which is mathematically given as,

$$\frac{D_p}{\mu_p} = \frac{D_n}{\mu_n} = V_T \quad \text{...(i)}$$

where, V_T is the 'Volt-equivalent of temperature' and is defined by,

$$V_T = \frac{\bar{k}T}{q} = \frac{T}{11600} \quad \text{...(ii)}$$

where, $\bar{k}$ is the Boltzmann constant in J/°K

At room temperature i.e. $T = 300°\text{K}$,

$V_T = 0.026 \text{ V} = 26 \text{ mV}$

and $\mu = 39\, D$

∴ $D_n \text{ for Ge} = \mu_n V_T = 99 \text{ cm}^2/\text{sec}$

and $D_p = \mu_p\, V_T = 13 \text{ cm}^2/\text{sec}$

(b) Given that, $T = 300°\text{K}$

and $E - E_F = 0.2 \text{ eV}$

i.e. $E = E_F + 0.2 \text{ eV}$

also, $V_T = K \cdot T = 0.026 \text{ V}$

∴ Probability of finding an electron 0.2 eV above the Fermi level is given by,

$$f(E = E_F + 0.2 \text{ eV}) = \frac{1}{1 + \exp\left(\frac{0.2}{0.026}\right)} = \frac{1}{1 + \exp(7.692)} = 4.561 \times 10^{-4}$$

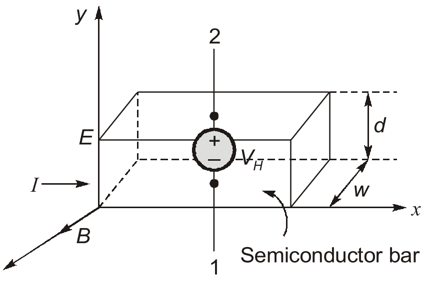
$$\approx 0.0004561$$

Q.4 Explain Hall effect.

An n-type germanium sample is 2 mm wide and 0.2 mm thick. A current of 10 mA is passed through the sample (x-direction) and a field of 0.1 Weber/m2 is directed perpendicular to the current flow (z-direction). The developed Hall voltage is – 1.0 mV. Calculate the Hall constant and the number of electrons/m^3.

Solution:

Hall effect:



- If a specimen (metal or semiconductor) carrying a current 'I' is placed in a transverse magnetic field 'B', an electric field 'E' is induced in the direction perpendicular to both I and B. This phenomenon known as the Hall effect. It is used to determine whether a semiconductor is n-type or p-type and to find the carrier concentration.
- As shown in the figure above, if 'I' is in the positive x-direction and 'B' is in the positive z-direction, a force will be exerted in the negative y-direction on the current carriers. The current I may be due to holes moving from left to right or to free electrons travelling from right to left in the semiconductor specimen. Hence, independently of whether the carriers are holes or electrons, they will be forced downward towards side 1 in the figure. Hence a potential, called the Hall voltage, V_H appears between surface 1 and 2. If the polarity of V_H is positive at terminal 2 with respect to terminal 1, then the carriers must be electrons. If terminal 1 becomes charged positively with respect to terminal 2, the semiconductor must be p-type.

Given that, $w = 2$ mm; $d = 0.2$ mm; $I = 10$ mA; $B = 0.1$ Weber/m$^{2;}$ $V_H = -1.0$ mV

∴ $$|V_H| = \frac{BI}{\rho w} = 1.0 \text{ mV}$$

where, ρ = change density (C/m^3)

⇒ $$\rho = \frac{BI}{V_H w} = \frac{0.1 \times 10 \times 10^{-3}}{1 \times 10^{-3} \times 2 \times 10^{-3}} = 0.5 \times 10^3 \text{ C/m}^3$$

Hall constant R_H is defined by

$$R_H \equiv 1/\rho$$

∴ $R_H = 1/0.5 = 2 \times 10^3\ \text{m}^3/\text{C}$

since $\rho = nq$

where n = number of electrons /m^3

and q = charge of electron = 1.6×10^{-19} Coulomb

⇒ $$n = \frac{0.5 \times 10^3}{1.6 \times 10^{-19}} = 3.125 \times 10^{21}$$

Therefore, Hall constant, $R_H = 2 \times 10^3\ \text{m}^3/\text{C}$

and number of electrons per m^3, $n = 3.125 \times 10^{21}$.

Q.5 **A sample of Germanium is doped to the extent of 10^{14} donor atoms/cm^3 and 5×10^{13} acceptor atoms/cm^3. At 300°K, the resistivity of the intrinsic Germanium is 60 Ω-cm. If the applied electric field is 2 V/cm. Find the total conduction current density? (Assume $\mu_p/\mu_n = 1/2$ and $n_i = 2.5 \times 10^{13}$/cm^3 at 300°K)**

Solution:

Given that, $n_i = 2.5 \times 10^{13}/\text{cm}^3$ at 300°K and $\mu_n = 2\,\mu_p$ and $E = 2$ V/cm

$$N_D = 10^{14}\ \text{atoms/cm}^3 \quad \Rightarrow \quad N_D > N_A$$

$$N_A = 5 \times 10^{13}\ \text{atoms/cm}^3$$

and also, $\rho_i = 60\ \Omega\text{-cm}$

∴ $$\sigma_i = \frac{1}{\rho_i} = \frac{1}{60} = 0.0166\ (\Omega\text{-cm})^{-1}$$

For an intrinsic "Ge" semiconductor,

$$\sigma_i = n_i q[\mu_n + \mu_p]$$

or $0.0166 = 2.5 \times 10^{13} \times 1.6 \times 10^{-19} \times 3\mu_p$

or $\mu_p = 1388.8\ \text{cm}^2/\text{V-sec} \approx 1389\ \text{cm}^2/\text{V-sec}$

∴ $\mu_n \approx 2\,\mu_p \approx 2778\ \text{cm}^2/\text{V-sec}$

As we know that when semiconductor is simultaneously doped with donor and acceptor impurities then the type of semiconductor it is can be determined as:

⇒ If $N_D > N_A$ then this semiconductor turns into the n-type semiconductor and in this case conductivity (σ_n) is equal to,

$$\sigma_n = q\,\mu_n[N_D - N_A] = 1.6 \times 10^{-19} \times 2778\,[10^{14} - 5 \times 10^{13}]$$

∴ $\sigma_n = 0.02215\ (\Omega\text{-cm})^{-1}$

So, the total current density (here assume only n-type semiconductor, so only electrons are majority carriers) is,

$$J = \sigma_n |E| = 0.02215 \times 2 = 0.0443\ \text{A/cm}^2$$

∴ $J = 44.3\ \text{mA/cm}^2$

Q.6 **Consider the intrinsic germanium and silicon at room temperature i.e. at 300°K. By what percentage does the conductivity increases per degree rise in temperature?**

Solution:

The conductivity of an intrinsic semiconductor is given by the relation,

$$\sigma_{\text{int.}} = n_i(\mu_n + \mu_p)q \qquad \text{...(i)}$$

where, n_i = intrinsic concentration

μ_n = mobility of electrons

μ_p = mobility of holes

q = electronic charge in Coulomb

As we know that with increasing the temperature, the density of hole-electron pairs increases and correspondingly, the conductivity increases.

From equation (i) it is clear that 'σ_{int}' depends upon 'n_i' as well as μ_n and μ_p. For finding the percentage change in conductivity per degree change in temperature, we take an assumption that mobility (μ) does not vary with temperature i.e. it is more or less constant. In this situation, the conductivity (σ_{int}) varies as 'n_i'

$$\because \quad n_i^2 = A_0 T^3 e^{-E_{G0}/kT} \qquad \text{...(ii)}$$

where, A_0 = Constant independent of T

E_{G0} = Energy gap at 0°K

k = Boltzmann constant

Now, from equation (ii),

$$n_i = A_0^{1/2} T^{3/2} e^{-E_{G0}/2kT}$$

Taking '*ln*' both sides we get,

$$ln\, n_i = \frac{1}{2} ln A_0 + \frac{3}{2} lnT - \frac{E_{G0}}{2kT}$$

$$\Rightarrow \quad \left(\frac{dn_i}{n_i}\right) = \frac{3}{2}\cdot\frac{dT}{T} + \frac{E_{G0}}{2kT^2}\cdot dT = \left(\frac{3}{2} + \frac{E_{G0}}{2kT}\right)\cdot\frac{dT}{T}$$

$$\therefore \quad \frac{dn_i}{n_i} = \left(1.5 + \frac{E_{G0}}{2kT}\right)\cdot\frac{dT}{T} \qquad \text{...(iii)}$$

At $T = 300°\text{K}$, $kT = V_T = 26\text{ mV} = 0.026\text{ V}$

Case-I: For Germanium (Ge):

$$\left(\frac{dn_i}{n_i}\right) = \left[1.5 + \frac{0.785}{0.052}\right]\left(\frac{1}{300}\right) \times 100\%$$

$\therefore$ $\sigma_{int.}$ increases = 5.53% per degree rise in temperature

Case-II: For Silicon (Si):

From equation (iii) we have,

$$\left(\frac{dn_i}{n_i}\right) = \left[1.5 + \frac{1.21}{0.052}\right]\left(\frac{1}{300}\right) \times 100\%$$

$\therefore$ $\sigma_{int.}$ increases = 8.25% per degree rise in temperature.

Q.7 Derive the expression for the Fermi-Energy level (E_F) in an intrinsic semiconductor. For the same effective masses of holes and electrons, show that 'E_F' lies in the centre of the forbidden energy band. Draw the appropriate diagram for this.

Solution:

Fermi level is the energy level where probability of finding electrons is 50% (when temperature is not 0°K). As we know that the concentration of electrons in C.B is given by,

$$n = N_c e^{-(E_C - E_F)/kT} \qquad \text{...(i)}$$

where, N_c = a material constant

$$\therefore \quad N_c = 2\left[\frac{2\pi m_n \bar{k} T}{h^2}\right]^{3/2} \qquad \text{...(ii)}$$

and similarly the concentration of holes in the V.B is given by,

$$p = N_v e^{-(E_F - E_v)/kT} \qquad \text{...(iii)}$$

where, N_v = a material constant

$$\therefore \quad N_v = 2\left[\frac{2\pi\, m_p \bar{k} T}{h^2}\right]^{3/2} \qquad \text{...(iv)}$$

In equation (ii) and (iv),

m_n = effective-mass of electrons
m_p = effective-mass of holes
$\bar{k}$ = Boltzmann constant (in joules/°K)
h = Planck's constant

In an intrinsic material, $n = p = n_i$ and since the crystal must be electrically neutral so, from equation (i) and (iii) we get,

$$\Rightarrow \qquad n = p$$

or
$$N_c\, e^{-(E_c - E_F)/kT} = N_v\, e^{-(E_F - E_v)/kT}$$

or
$$\frac{N_c}{N_v} = \frac{e^{-(E_F - E_v)/kT}}{e^{-(E_c - E_F)/kT}}$$

or
$$\frac{N_c}{N_v} = e^{(-E_F + E_v + E_c - E_F)/kT} \qquad \text{...(v)}$$

Taking the logarithm of both sides in equation (v) we have,

$$\ln\left(\frac{N_c}{N_v}\right) = \frac{E_c + E_v - 2E_F}{kT}$$

or
$$E_c + E_v - 2\,E_F = kT\,\ln\left(\frac{N_c}{N_v}\right)$$

$$\therefore \qquad E_F = \frac{E_c + E_v}{2} - \frac{kT}{2}\ln\left(\frac{N_c}{N_v}\right) \qquad \text{...(vi)}$$

This equation (vi) represents the expression of Fermi-Energy level (E_F) in an intrinsic semiconductor.

Now if the effective masses of hole and electrons are equal i.e. $m_n = m_p$ then from equation (ii) and (iv) we can conclude,

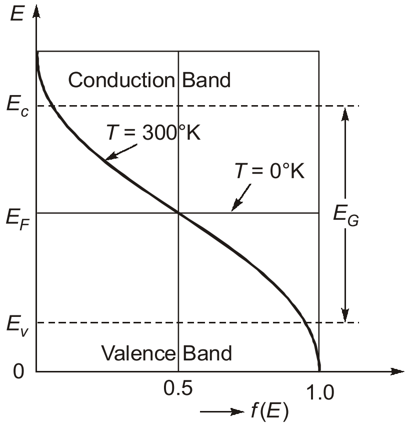
$$N_c = N_v$$

In this case,
$$\ln\left(\frac{N_c}{N_v}\right) = \ln(1) = 0$$

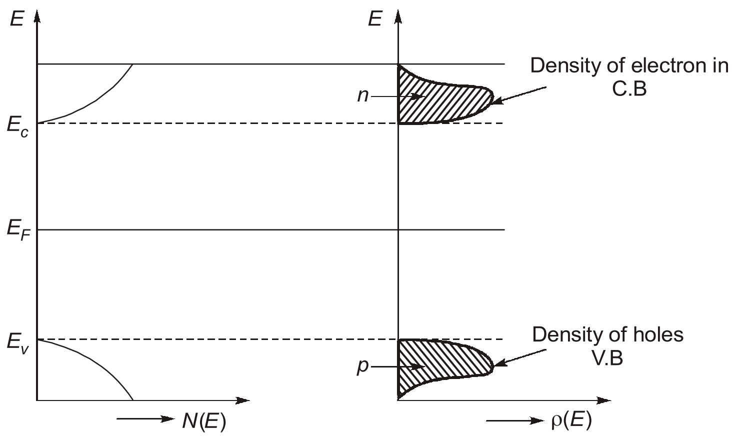
so, equation (vi) may reduced to,

$$\text{Fermi-energy level } (E_F) = \frac{E_c + E_v}{2} \qquad \text{...(vii)}$$

This equation (vii) represents that Fermi level lies in the centre of the forbidden energy band which is shown in the diagram below:



(Energy band diagram for an intrinsic semiconductor and Fermi-dirac probability function $f(E)$ at 0°K and at 300°K).



(Density of status) (Density of carriers)

Q.8 The Fermi-level of an *n*-type Germanium film is at 0.2 eV above the intrinsic Fermi level (towards the conduction band). The thickness of the film is 0.5 μm. Calculate the sheet resistance of the film? (Assume : $n_i = 10^{13}$ cm^{-3}, $\mu_n = 3500$ cm^2/V-sec, $\mu_p = 1500$ cm^2/V-sec and $kT/q = 0.026$ V).

Solution:

Let us consider all the values of 'E_F' and 'E_i' are in eV. For this we have,

$$E_F - E_i = kT\,ln\left(\frac{n_0}{n_i}\right)$$

$$\Rightarrow \quad 0.2\,q = 0.026\,q\,ln\left(\frac{n_0}{n_i}\right)$$

$$\Rightarrow \quad n_0 = \text{antilog}\left[\frac{0.2}{0.026}\right]\times 10^{13}$$

$$\therefore \quad n_0 = \text{Free (–)ve charge concentration}$$
$$= 2191.4\times 10^{13}\text{ cm}^{-3} \quad \text{...(i)}$$

Now, from the concept of Mass-Action Law, we have,

$$p_0 = \frac{n_i^2}{n_0} = \frac{(10^{13})^2}{2191.4\times 10^{13}}$$

$$\therefore \quad p_0 = \text{Free (+)ve charge concentration}$$
$$= 4.5633\times 10^{9}\text{ cm}^{-3} \quad \text{...(ii)}$$

The conductivity of this type of semiconductor is given by,

$$\sigma = q(n_0\mu_n + p_0\mu_p)$$

$$\Rightarrow \quad \sigma = 1.6\times 10^{-19}\left[(2191.4\times 10^{13}\times 3500) + (4.5633\times 10^{9}\times 1500)\right]$$
$$= (76699.0069\times 10^{15})\times 1.6\times 10^{-19}$$

$$\therefore \quad \sigma = 12.272\,(\Omega\text{-cm})^{-1} \quad \text{...(iii)}$$

Since, Resistivity $(\rho) = \dfrac{1}{\sigma}$

$$\therefore \quad \rho = 0.0815\ \Omega\text{-cm}$$

So, sheet resistance of the film

$$= R = \frac{\rho\cdot L}{A} = \frac{\rho\cdot L}{L\times t} \qquad [\because \text{Area} = \text{Length}\times\text{Width}]$$

$$\Rightarrow \quad R = \frac{0.0815}{0.5\mu\text{m}}\ \Omega\text{-cm} = \frac{0.163}{10^{-6}}\times 10^{-2}\ \Omega$$

$$\therefore \quad R = 1630\ \Omega$$

ANALOG CIRCUITS

CONVENTIONAL PRACTICE SETS

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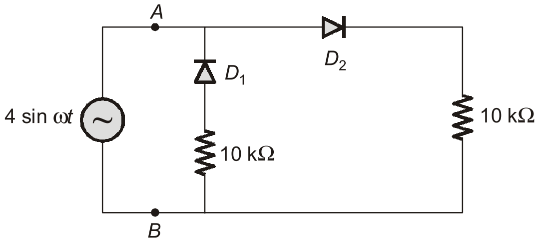
1

CHAPTER

Diode Circuits

Q.1 A voltage source $V_{AB} = 4 \sin \omega t$, is applied across the terminals A and B of the circuit. The diodes are assumed to be ideal. Find the impedance offered by the circuit across the terminals A and B in kilo ohm.

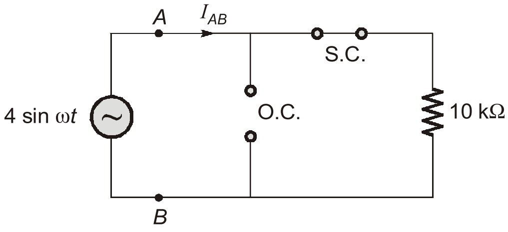


Solution:

In +ve half cycle D_1 – off (R.B.)

D_2 – on (F.B.)

∴ Equivalent circuit will be



$$\therefore \quad V_{AB} = 4 \sin\omega t$$

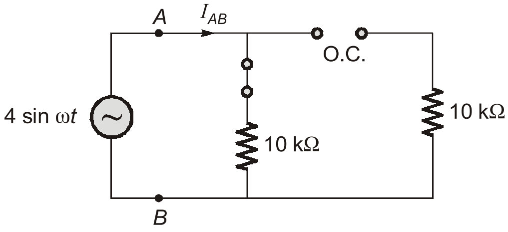
$$I_{AB} = \frac{V_{AB}}{10\,\text{k}\Omega}$$

$$\therefore \quad R_i = \frac{V_{AB}}{I_{AB}} = 10\,\text{k}\Omega$$

For –ve half cycle,

D_1 on, D_2 off

Equivalent circuit,

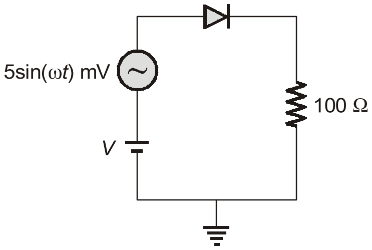


$$V_{AB} = 4 \sin\omega t$$

$$I_{AB} = \frac{4 \sin\omega t}{10\,\text{k}\Omega}$$

$$\therefore \quad \frac{V_{AB}}{I_{AB}} = R_i = 10\,\text{k}\Omega$$

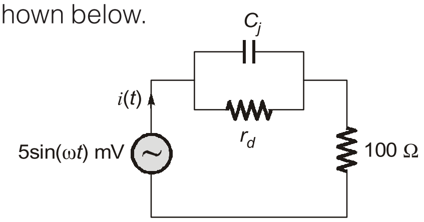
Q.2 A DC current of 26 μA flows through the circuit shown. The diode in the circuit is forward biased and it has an ideality factor of one. At the quiescent point, the diode has a junction capacitance of 0.5 nF. Its neutral region resistances can be neglected. Assume that the room temperature thermal equivalent voltage is 26 mV.



For $\omega = 2 \times 10^6$ rad/s, the amplitude of the small-signal component of diode current.

Solution:

The small-signal equivalent model of the given circuit can be drawn as shown below.



Given that,

$$\omega = 2\times10^6 \text{ rad/sec}$$
$$C_j = 0.5 \text{ nF}$$
$$I_{DC} = 26\ \mu\text{A}$$
$$V_T = 26 \text{ mV}$$
$$\eta = 1$$

Since, small signal incremental diode resistance, $r_d = \dfrac{\eta V_T}{I_{DC}} = \dfrac{26\text{ mV}}{26\ \mu\text{A}} = 1\text{k}\Omega$

and impedance due to junction capacitance, $\dfrac{1}{\omega C_j} = \dfrac{1}{2\times10^6\times0.5\times10^{-9}}\Omega = 1\text{k}\Omega$

So, total impedance of the circuit will be,

$$Z = \left(r_d \| \frac{1}{j\omega C_j}\right) + 100\ \Omega$$

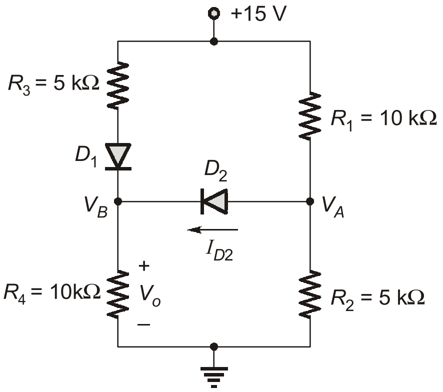
$$\left(r_d \| \frac{1}{j\omega C_j}\right) = \frac{(1000)(-j1000)}{1000 - j1000}\Omega = \frac{-j(1+j)}{2}\text{k}\Omega = \frac{1}{2}(1-j)\text{ k}\Omega = (500 - j500)\ \Omega$$

$$\therefore \quad Z = 600 - j500\ \Omega$$

$$|Z| = 100\sqrt{36+25} = 100\sqrt{61}\,\Omega$$

$$I_m = \frac{V_m}{|Z|} = \frac{5\text{ mV}}{100\sqrt{61}\,\Omega} = \frac{50}{\sqrt{61}}\mu\text{A} = 6.40\ \mu\text{A}$$

Q3 Determine the current I_{D2} and the voltage V_o in the multidiode circuit shown in the figure below. Assume that, cut-in voltage $V_\gamma = 0.7$ V for each diode.



Solution:

To begin, initially assume that, both the diodes D_1 and D_2 are in their conducting state.

By applying KCL at A and B nodes, we have

$$\frac{15 - V_A}{10} = I_{D2} + \frac{V_A}{5} \qquad \text{...(i)}$$

and $$\frac{15 - (V_B + 0.7)}{5} + I_{D2} = \frac{V_B}{10} \qquad \text{...(ii)}$$

We note that $V_B = V_A - 0.7$. Combining the two equations and eliminating I_{D2}, we find

$$V_A = 7.62 \text{ V} \quad \text{and} \quad V_B = 6.92 \text{ V}$$

From equation (i) above, we obtain

$$\frac{15-7.62}{10} = I_{D2} + \frac{7.62}{5} \Rightarrow I_{D2} = -0.786 \text{ mA}$$

We assumed that D_2 was ON, so a negative current is inconsistent with that initial assumption.

Now assume that diode D_2 is OFF and D_1 is ON. To find the node voltages, we can simply use voltage divider principle as

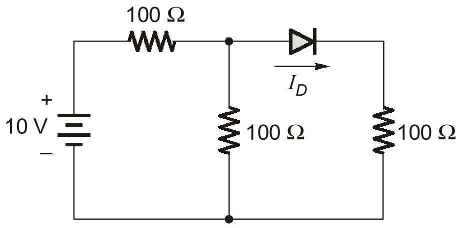
$$V_A = \left(\frac{5}{5+10}\right)(15) = 5 \text{ V}$$

and

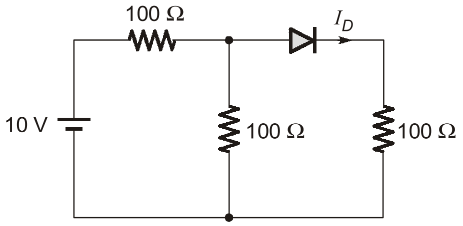
$$V_B = V_o = \left(\frac{10}{10+5}\right)(15-0.7) = 9.53 \text{ V}$$

These voltages show that diode D_2 is indeed reverse biased so that $I_{D2} = 0$.

Q.4 Find the diode current I_D in the circuit shown below when the diode has cut in voltage, $V_\gamma = 0.7$ V and forward resistance, $R_f = 25\ \Omega$.

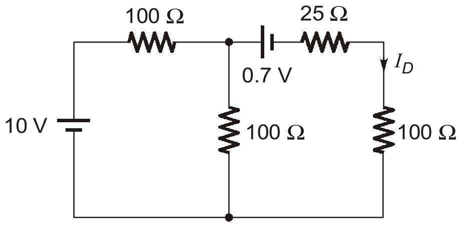


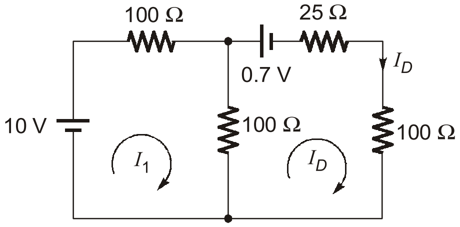
Solution:



Given : Diode cut-in voltage = 0.7 V and diode forward resistance = 25 Ω

Replacing the diode with its equivalent, we get,





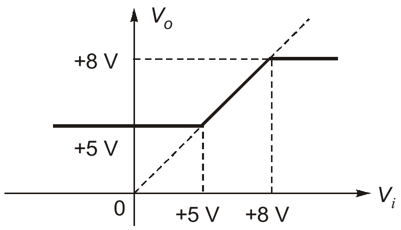
Using KVL,
$$10 - 100I_1 - 100(I_1 - I_D) = 0 \quad \text{...(i)}$$
$$-0.7 - 125I_D + 100(I_1 - I_D) = 0 \quad \text{...(ii)}$$

Solving equation (i) and (ii)
$$10 - 200I_1 - 100I_D = 0 \quad \text{...(iii)}$$
$$-0.7 - 225I_D + 100I_1 = 0 \quad \text{...(iv)}$$

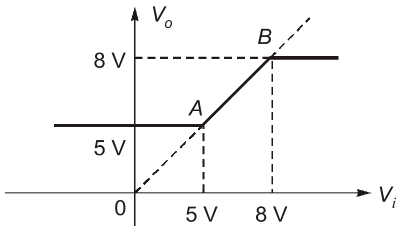
Multiplying equation (iv) by 2 and adding, we get
$$10 - 1.4 - 450I_D - 100I_D = 0$$
$$8.6 = 550I_D$$

$$\therefore \qquad I_D = \frac{8.6}{550} = 15.63 \text{ mA}$$

Q.5 The ideal transfer characteristic of a particular circuit is given in figure. Design the circuit. Draw the output waveform with proper explanation, if $V_i = 10 \sin \omega t$.



Solution:



Slope of the curve between *A* and *B* is

$$m = \frac{(8-5)}{(8-5)} = 1$$

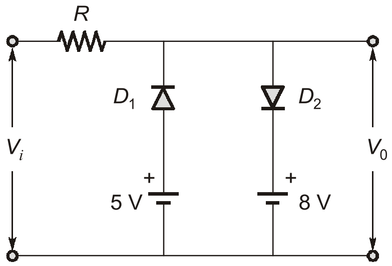
The circuit diagram for the above input-output (transfer) characteristic is a two-level clipper as shown below.

Cut in voltages of diodes are zero.

For $V_i < 5$ V → diode D_1 will be on and D_2 will be off

and $\boxed{V_0 = 5\text{ V}}$

For $V_i > 8$ V → diode D_1 will be off and diode D_2 will be on



and $\boxed{V_0 = 8\text{ V}}$

For $5 < V_i < 8$ V → both the diodes will be off

and $\boxed{V_0 = V_i}$

Given that $V_i = 10 \sin \omega t$

or $V_i = 10 \sin\theta$ $(\omega t = \theta)$

For $V_i < 5$; $10\sin\theta < 5 \Rightarrow 0 < \theta < 30°$ and $150° < \theta < 360°$

$V_o = 5$ V

For $V_i > 8$ V; $10\sin\theta > 8 \Rightarrow 53.13° < \theta < 126.869°$

$V_o = 8$ V

For $5 < V_i < 8$ V; $30° < \theta < 53.13°$ and $126.87° < \theta < 150°$

$V_o = V_i$

The required voltage-current characteristics can be written as

$$V_o = \begin{cases} 5\text{ V} & ; \quad V_i < 5\text{ V} \\ V_i & ; \quad 5\text{ V} < V_i < 8\text{ V} \\ 8\text{ V} & ; \quad V_i > 8\text{ V} \end{cases}$$