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Main Examination

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Topicwise

Conventional Practice Book

Electrical Engineering

PAPER-II

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ESE 2027 Main Examination

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CONTENTS

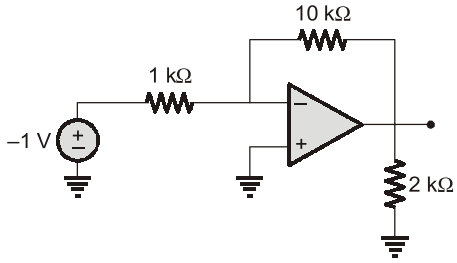
1 Analog Electronics

1. Operational Amplifiers

Level-1

1.1 (a) For the circuit shown, find the currents through all branches and the voltages at all nodes.

(b) Since the current supplied by the OP-AMP is greater than the current drawn from the input signal source, where does the additional current come from. (10 Marks)



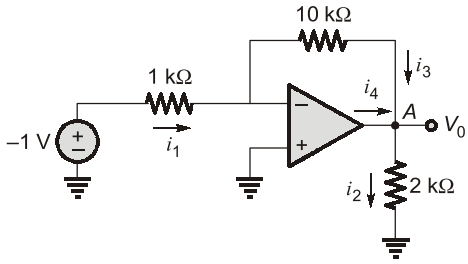
Solution:

For an inverting amplifier as we know,

$$\frac{V_0}{V_i} = \frac{-R_2}{R_1}$$

$$\Rightarrow \quad V_0 = \frac{-R_2}{R_1} \times V_i$$

$$V_0 = \left(\frac{-10}{1}\right)(-1) = 10 \text{ volts}$$



i_2 can be calculated as

$$i_2 = \frac{V_0}{2K} = 5\,\text{mA}$$

also, $$i_1 = i_3 = \frac{V_0}{10K} = 1\text{mA}$$

by KCL at point A,

$$i_4 + i_3 = i_2$$

Hence, $$i_4 = i_2 - i_3$$

$$i_4 = (5 - 1)\ \text{mA} = 4\ \text{mA}$$

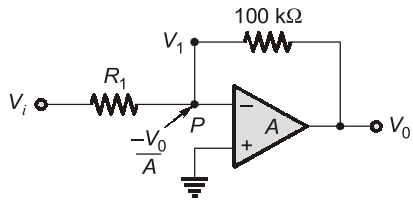
Hence the additional current comes from the output of the OP-AMP.

1.2 An inverting OP-AMP circuit for which the required gain is –50 V/V uses an OP-AMP whose open loop gain is only 200 V/V. If the larger resistor used is 100 kΩ, to what must the smaller be adjusted? With what resistor must a 2 kΩ resistor connected to the input be shunted to achieved this goal?

(Note: A resistor R_a is said is to be shunted by resistor R_b when R_b is placed in parallel with R_a)

(10 Marks)

Solution:



By drawing the figure according to the question
Let the gain of OP-AMP is A = 200 V/V

$$\because \qquad V_1 = \frac{-V_0}{A} = \frac{-V_0}{200}$$

and overall close loop gain,

$$\frac{V_0}{V_i} = -50 \text{ V/V}$$

by using KCL at point P:

$$\frac{V_i - \left(\frac{-V_0}{A}\right)}{R_1} = \frac{\left(\frac{-V_0}{A} - V_0\right)}{100K}$$

$$\Rightarrow \qquad R_1 = \frac{100K\left[V_i + \frac{V_0}{A}\right]}{-\left[V_0 + \frac{V_0}{A}\right]} = \frac{100K\left[\frac{-V_0}{50} + \frac{V_0}{200}\right]}{-\left[V_0 + \frac{V_0}{200}\right]}$$

$$R_1 = 100K \times \frac{3}{201} = 1.49 \text{ k}\Omega$$

as given in question shunt resistor is R_a ,

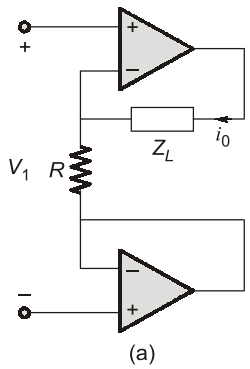
and $\qquad R_a \parallel 2\,\text{k}\Omega = 1.49\,\text{K}$

So, $\qquad \dfrac{R_a \times 2K}{R_a + 2K} = 1.49\,\text{K}$

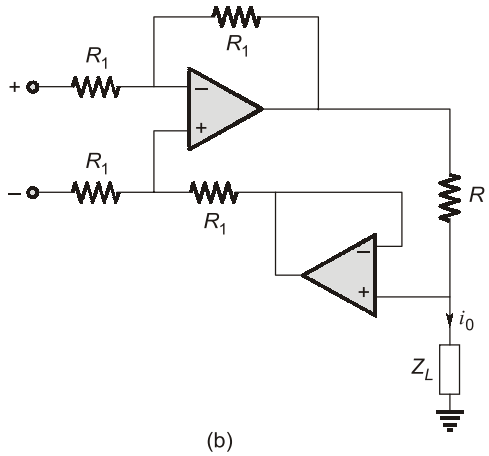
by solving above equation we will get

$$R_a = 5.84 \text{ k}\Omega$$

1.3 The two circuits in figures are intended to function as voltage to current converters, that is, they supply the load impedance Z_L with a current proportional to V_1 and independent of the value of Z_L. Show that this is indeed the case, and find for each circuit i_0 as a function of V_1. Comment on the differences between the two circuits.



(a)



(b)

(12 Marks)

Solution:

From figure (a):

Since input current for the Op-amp is zero hence V_i appears across the resistance R.

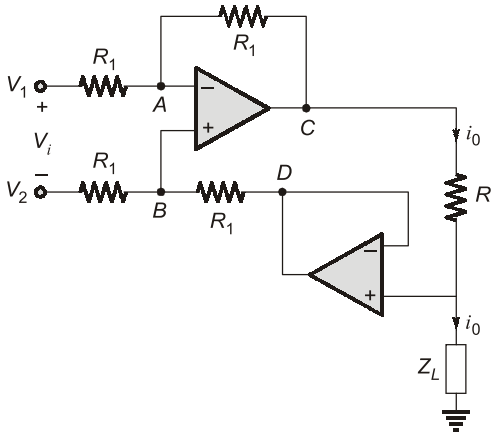
So, $$i_0 \approx \frac{V_i}{R}$$

From figure (b):

as $$V_P = Z_L i_0$$

Using superposition, $$V_I = V_1 - V_2$$

Considering V_1 only $$V_B = \frac{V_D}{2} = \frac{Z_L i_{01}}{2}$$



KCL at point,

$$\frac{V_1 - \frac{Z_L i_{01}}{2}}{R_1} = \frac{\frac{Z_L i_{01}}{2} - i_{01}(Z_L + R)}{R_1}$$

So, $$V_1 = i_{01} R \Rightarrow i_{01} = \frac{V_1}{R}$$

Considering $(-V_2)$ only

$$V_B = \frac{-V_2 + Z_L i_{02}}{2}$$ (by super position)

$$V_A = \frac{i_{02} \times (R + Z_L)}{2}$$

as $$V_A = V_B \text{ hence}$$

$$-V_2 + Z_L\, i_{02} = i_{02}\, R + i_{02}\, Z_L$$

$$-V_2 = i_{02}\, R$$

$\Rightarrow$ $$i_{02} = \frac{-V_2}{R}$$

Total current is :

$$i_0 = i_{01} + i_{02} = \frac{V_1}{R} - \frac{V_2}{R} = \frac{V_I}{R}$$

Circuit in figure (a) has infinite input while the circuit (b) has finite input resistance with one side of Z_L is grounded.

1.4 A differentiater utilizes an ideal op-amp, a 10 kΩ resistor and a 0.01 μF capacitor.

(a) What is the frequency f_0 (in Hz) at which its input and output sine-wave signals have equal magnitude?

(b) What is the output signals for a 1 volt peak to peak sine wave input with frequency equal to $10f_0$? **(10 Marks)**

Solution:

(a) We know that for a differentiator

$$\frac{V_0}{V_i}(s) = -SRC = -S \times 0.01 \times 10^{-6} \times 10 \times 10^3 = -10^{-4}\ \text{S}$$

$$\frac{V_0}{V_i}(j\omega) = -j\omega(10^{-4})$$

$$\left|\frac{V_0}{V_i}\right| = -10^{-4}\,\omega$$

When $\omega = 10^4$ rad/s

then $\left|\frac{V_0}{V_i}\right| = 1$

So, $2\pi f = 10^4$

So $f = 1.59$ kHz

(b) When frequency will be 10 times then the output will be 10 times as large as the input 10 volt peak to peak. $(-j)$ means the output lags the input by 90°

So $V_0(t) = -5\sin(10^5 t + 90°)$ Volts

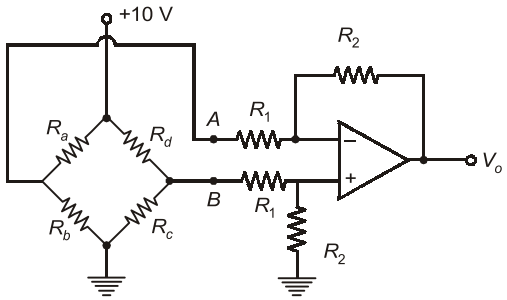
1.5 Consider the circuit shown in figure. The circuit uses an ideal operational amplifier. Assuming that the impedances at nodes A and B do not load the preceding bridge circuit, calculate the output voltage V_o.

(a) when $R_a = R_b = R_c = R_d = 10$ ohms.

(b) when $R_a = R_b = R_c = 10$ ohms and $R_d = 120$ ohms.

$R_2 = 12$ kΩ

$R_1 = 10$ kΩ



(5 Marks)

Solution:

(a)

$$V_A = 10\times\frac{R_b}{R_a+R_b} = 10\times\frac{100}{100+100} = 5\text{ V}$$

$$V_B = \frac{10R_C}{R_C+R_D} = 10\times\frac{100}{100+100} = 5\text{ V}$$

Given op-amp is a differential amplifier

So, $\boxed{V_o = \frac{R_2}{R_1}(V_B - V_A)} = \frac{12\text{k}}{10\text{k}}(5-5) = 0\text{ V}$

(b)

$$V_A = 10\times\frac{R_b}{R_d+R_b} = 10\times\frac{100}{100+100} = 5\text{ V}$$

$$V_B = 10\times\frac{R_c}{R_c+R_d} = 10\times\frac{100}{100+120} = 4.55\text{ V}$$

$$V_o = \frac{R_2}{R_1}(V_B - V_A) = \frac{12\text{k}}{10\text{k}}(4.55-5) = -0.55\text{ V}$$

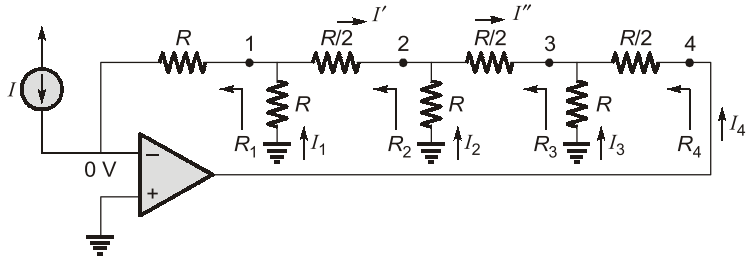
Level-2

1.6 In the circuit given in the figure,

(a) Find the resistances looking into node 1, R_1 : node 2, R_2 : node 3, R_3 : and node 4, R_4 :

(b) Find the current I_1, I_2, I_3 and I_4 in terms of the input current I.

(c) Find the voltages at nodes 1, 2, 3, 4 that is V_1, V_2, V_3 and V_4 in terms of (IR) (15 Marks)



Solution:

(a) From the figure:

$$R_1 = R$$

R_2 can be calculated as:

$$R_2 = (R \parallel R) + \frac{R}{2} = R$$

$$R_3 = (R_2 \parallel R) + \frac{R}{2} = R$$

$$R_4 = (R_3 \parallel R) + \frac{R}{2} = (R \parallel R) + \frac{R}{2} = R$$

(b) As, $V = IR$

So, $V_1 = I_1 R$

and $I_1 = I$

$I' = I + I = 2I$

By KVL at node-1

$$V_1 + 2I\left(\frac{R}{2}\right) = RI_2$$

$$I_R + I_R = RI_2$$

So, $I_2 = 2I$

$I'' = I_2 + I' = 4I$

By KVL at node-2

$$V_2 + 4I \times \frac{R}{2} = RI_3$$

$$R \times 2I + 4I \times \frac{R}{2} = RI_3$$

hence, $I_3 = 4I$

and $I_4 = -[4I + 4I] = -8I$

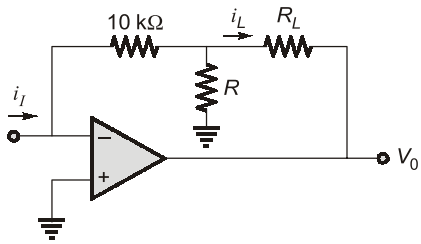
(c) $V_1 = -I_1 R = -IR$

$V_2 = -I_2 R = -2IR$

$V_3 = -I_3 R = -4IR$

$$V_4 = -I_3 R + I_4 \frac{R}{2} = -4IR - \frac{8IR}{2} = -8IR$$

1.7 Assuming the Op-amp to be ideal, it is required to design the circuit shown in figure, to implement a current amplifier with gain i_L/i_I = 20 A/A



(a) Find the required value of R.

(b) If R_L = 1 kΩ and the op-amp operates in an ideal manner so long as V_0 is in the range ±12 V. What range of i_I is possible?

(c) What is the input resistance of the current amplifier? If the amplifier is fed with a current source having a current of 1 mA and a source resistance of 10 kΩ find i_L.

(15 Marks)

Solution:

(a) Given that:

$$\frac{i_L}{i_I} = 20$$

$$\Rightarrow \quad i_L = 20 i_I$$

by KVL :

$$-10\ \text{k}\Omega \times i_I = R(i_I - i_L)$$

$$R = \frac{10K \times i_I}{20 i_I - i_I} = 0.53\ \text{k}\Omega$$

(b) Given R_L = 1 kΩ and range of V_0 is $-12 \le V_0 \le 12$ V

by KVL:

$$V_0 = R_L i_L + (10\text{K}) i_I$$

$$= i_z \left[R_L \frac{i_L}{i_Z} + 10K \right]$$

$$V_0 = i_Z [1k \times 20 + 10k]$$

$$V_0 = (30\, i_I) K$$

$$i_I = \frac{V_0}{30}$$

So, $$\frac{-12}{30} \le i_I \le \frac{12}{30}$$

$$\Rightarrow \quad -0.4\ \text{mA} \le i_I \le 0.4\ \text{mA}$$

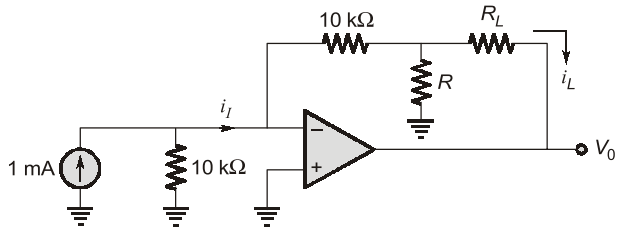
(c) Input resistance of given current amplifier

$$R_I = \frac{V_I}{i_I} = \frac{0}{i_I} = 0$$

as by diagram, $i_I = 1$ mA

and $i_L = 20\, i_I$

So, $i_L = 20$ mA



1.8 A designer wanting to achieve a stable gain of 100 V/V at 5 MHz, considers her choice of amplifier topologies. What unity-gain frequency would a single operational amplifier require to satisfy her need? Unfortunately, the best available amplifier has an f_T of 40 MHz.

(a) How many such amplifiers connected in a cascade of identical non inverting stages would she need to achieve her goal?

(b) What is the 3-dB frequency of each step she can use?

(c) What is the overall 3-dB frequency? (15 Marks)

Solution:

As we know that, $f_T = 100 \times 5 = 500$ MHz

If we use single Op-amp

But given in question that best Op-amp has $f_T = 40$ MHz, so the possible closed loop gain at 5 MHz is

$$(A) = \frac{40}{5} = 8 \text{ V/V}$$

as we need overall gain as 100 V/V, so at least three such amplifiers are cascaded,

Now if each of 3-stages has closed loop gain K, then its 3-dB frequency will be $\frac{40}{K}$MHz .

So for each stage the closed loop gain is

$$A = \frac{K}{\sqrt{1+\left(\frac{f}{f_{3d}}\right)^2}}$$

overall gain is 100 so, $$100 = \left|\frac{K}{\sqrt{1+\left(\frac{K}{8}\right)^2}}\right|^3$$

by solving $K = 5.7$

So for each cascading stage,

$$f_{3\,dB} = \frac{40}{5.7}$$

$$f_{3\,dB} = 7 \text{ MHz}$$

So for overall amplifier total f_T is

$$\left|\frac{5.7}{\sqrt{1+\left(\frac{f_T}{7}\right)^2}}\right|^3 = \frac{(5.7)^3}{\sqrt{2}}$$

$$f_T = 3.6 \text{ MHz}$$

1.9 A particular inverting amplifier with nominal gain of –100 V/V uses an imperfect Op-amp in conjunction with 100 kΩ and 10 MΩ resistors. The output voltage is found to be +9.31 V when measured with the input open and 9.09 V with the input grounded.

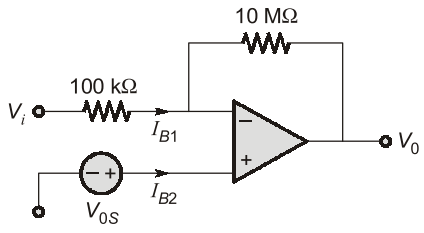
(a) What is the bias current of this amplifier? In what direction does it flow?

(b) Estimate the value of the input offset voltage.

(c) A 10 MΩ resistor is connected between the positive input terminal and ground with the input left floating (disconnected), the output dc voltage is measured to be –0.8 V, estimate the input offset current. (15 Marks)

Solution:

(a) ∵ $$I_B = \frac{(I_{B_1} + I_{B_2})}{2}$$



When input is open :

$$V_0 = V_{0s} + 100KI_{B_1}$$

$$9.31 = V_{0s} + 10000I_{B_1} \quad \ldots(i)$$

When input connected to ground:

$$V_0 = V_{0s} + R_2\left(I_{B_1} + \frac{V_{0s}}{R_1}\right)$$

$$V_0 = V_{0s}\left(1 + \frac{R_2}{R_1}\right) + R_2 I_{B_1}$$

$$9.09 = V_{0s}(101) + 10000 I_{B_1} \quad \text{...(ii)}$$

From (i) and (ii), [(1) – (2)]

$$100\ V_{0s} = -0.22$$

$$V_{0s} = -2.2 \text{ mV}$$

and $I_{B_1} = 930$ nA

So, $I_B \approx I_{B_1} = 930$ nA

(b) input offset voltage, $V_{0s} = -2.2$ mV

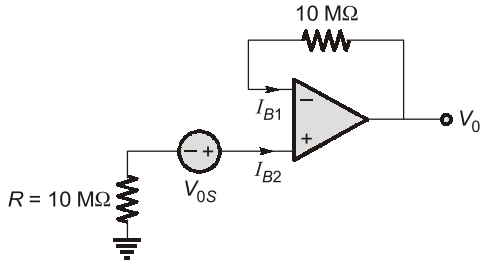
(c) Here V_{0s} can be neglected as magnitude of R is very large

$\because V_{0s} << RI_B$

$$V_0 = I_{0s} \times R_2$$

$$Z_{0s} = \frac{-0.8}{10M}$$

$$I_{0s} = -80 \text{ nA}$$



2. Diodes

Level-1

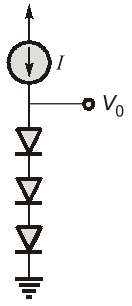
2.1 The circuit in the figure utilizes three identical diodes having $\eta = 1$ and $I_S = 10^{-14}$ A. Find the value of the current I required to obtain an output voltage $V_0 = 2$ V. If a current of 1 mA is drawn away from the output terminals by a load, what is the change is output voltage? (8 Marks)

Solution:

As each diode is identical. So the voltage across each diode is $\frac{V_0}{3}$.

and diode current, $I = I_S e^{\frac{V_0/3}{4V_T}} = 10^{-4} e^{\frac{2/3}{0.025}}$

$= 3.81$ mA

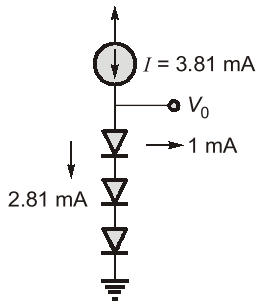


Now, let's say now the changed voltage across each diode is ΔV.

$$\frac{I_2}{I_1} = e^{\frac{(V_2 - V_1)/3}{0.025}}$$

$$\frac{2.81}{3.81} = e^{\frac{(V_2 - 2)/3}{0.025}}$$

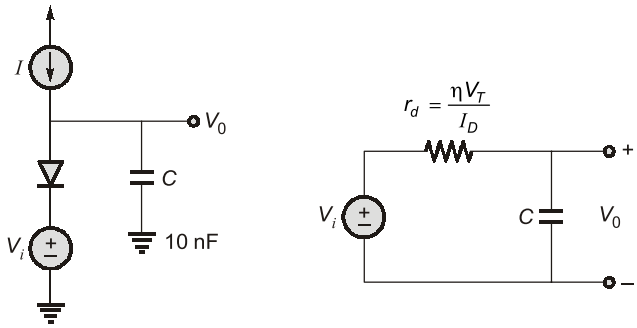
$$\Delta V = V_2 - 2 = -22.8 \text{ mV}$$



2.2 In the circuit shown in figure, I is a dc current and V_i is the sinusoidal signal with small amplitude (less than 10 mV) and a frequency of 100 kHz. Representing the diode by its small signal resistance r_d which is a function of I, sketch the circuit for determining the sinusoidal output voltage V_0 and thus find the phase shift between V_i and V_0. Find the value of I that will provide a phase shift of –45° and find the range of phase shift achieved as I is varied over the range of 0.1 to 10 times this value (η = 1). (10 Marks)

Solution:

To get small signal circuit we open the current source and then we draw the circuit as:



$$\frac{V_0}{V_i} = \frac{1/SC}{\frac{1}{SC} + r_d} = \frac{1}{1 + SCr_d}$$

$$\text{Phase shift} = -\tan^{-1}\left[\frac{\omega C r_d}{1}\right]$$

$$= -\tan^{-1}\left(2\pi \times 10^5 \times 10 \times 10^{-9} \times \frac{0.025}{I}\right)$$

as we know that the phase shift is –45°

So $$-45° = -\tan^{-1}\left(2\pi \times 10^5 \times 10 \times 10^{-9} \times \frac{0.025}{I}\right)$$

$$2\pi \times 10^3 \times \frac{0.025}{I} = 1$$

$$I = 157\ \mu\text{A}$$

Range of phase shift for I = 15.7 μA to 1570 μA is

For I = 15.7 μA

$$\Rightarrow \quad \phi_1 = -\tan^{-1}\left[2\pi \times 10^{-3} \times \frac{0.025}{15.7\ \mu\text{A}}\right] = -84.3°$$

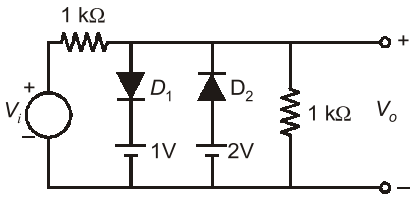
I = 1570 μA

$$\Rightarrow \qquad \phi_2 = -\tan^{-1}\left[2\pi \times 10^{-3} \times \frac{0.025}{15.7\ \mu A}\right] = -5.71$$

So range is –84.3° to –5.71°.

2.3 (i) Draw the transfer characteristics of the circuit of figure, assuming both D_1 and D_2 to be ideal

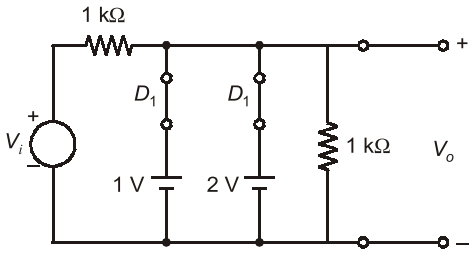
(ii) How would the characteristics change if D_2 is ideal, but D_1 is no-ideal and has a forward resistance of 10 Ω and a reverse of infinity.



(5 Marks)

Solution:

(i) Given that both the diodes are ideal, so when the diode is forward bias then it will act as short circuit and when the diode is reverse bias then it will act as open circuit.



When V_o is between 1 V to 2 V.

$$1\ V \le V_o \le 2\ V$$

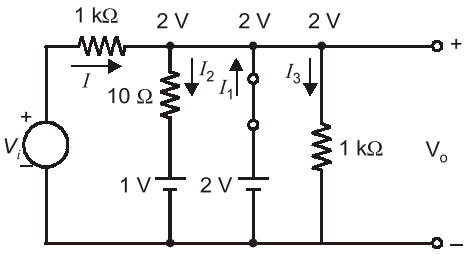
in this case both the diodes D_1 and D_2 are forward bias.

1 V and 2 V can not be in parallel and its violation of KVL.

So, this circuit does not exist.

(ii) $V_o \le 2$ V (D_2 F.B. and D_1 F.B)

Apply KCL



$$I + I_1 = I_2 + I_3$$

$$\frac{V_i - 2}{1k} + I_1 = \frac{2-1}{10} + \frac{2-0}{1k}$$

$$I_1 = \frac{104 - V_i}{1000}$$

$$I_1 \ge 0$$

$$\frac{104 - V_i}{1000} \ge 0$$

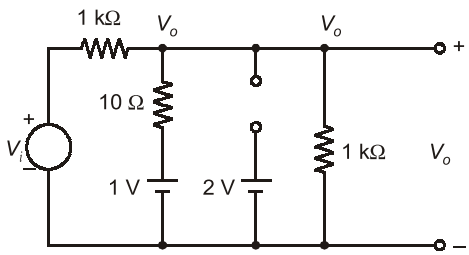
$$104 - V_i \ge 0$$

$$V_i \le 104\ V \quad \Rightarrow \quad V_o = 2\ V$$

Case 2: $V_i \ge 104$ V, So, $V_o \ge 2$ V

Diode D_1 is forward bias.

Diode D_2 is reverse bias.



Apply KCL

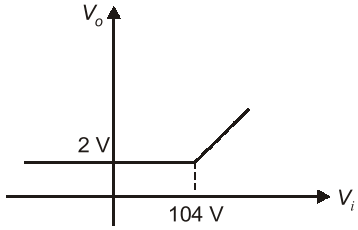
$$\frac{V_o - V_i}{1k} + \frac{V_o - 1}{10} + \frac{V_o - 0}{1k} = 0$$

$$\frac{V_o - V_i + 100\,V_o - 100 + V_o}{1\,k} = 0$$

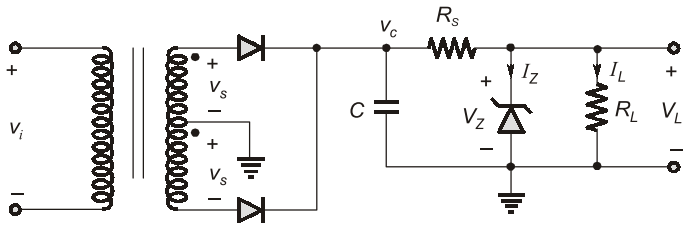
$$102\,V_o - V_i - 100 = 0$$

$$102\,V_o = V_i + 100$$

$$V_o = \frac{V_i + 100}{102}$$



2.4 Consider the circuit shown in the figure below:



The secondary voltage is given by $v_s = 24\sin\omega t$ V. The Zener diode has parameters $V_Z = 15$ V at $I_Z = 20$ mA and $r_z = 10\ \Omega$. Assume that all the diodes have a forward voltage drop of $V_\gamma = 0$. The value of capacitance C is designed in such a way that the peak-to-peak ripple voltage is no larger than 1 V. Determine the maximum value of R_S such that load current can vary over the range 20 mA ≤ I_L ≤ 180 mA with $I_{Z(min)} = 20$ mA. Also find the minimum value of C required when the line frequency is 50 Hz.

(12 Marks)

Solution:

It is given that the maximum peak-to-peak ripple voltage is 1 V.

So, $v_{c(min)} = 24 - 1 = 23$ V

$$R_S = \frac{v_{c(min)} - V_Z}{I_{Z(min)} + I_{L(max)}} = \frac{23 - 15}{20 + 180}\,k\Omega = 40\,\Omega$$

For a full wave rectifier with capacitive filter,

$$V_r = \frac{V_P}{2fRC} \le 1\,V$$

$$C \ge \frac{V_P}{2fR}$$

$V_P = 24$ V, $f = 50$ Hz and $R_{max} \approx R_{S(max)} + r_z = 50\ \Omega$.

So, $$C_{min} = \frac{24}{2 \times 50 \times 50}\,F = 4.8\,mF$$

Level-2

2.5 The circuit shown in figure is a model for a battery charger. Here V_I is a 10 V peak sine wave, D_1 and D_2 are ideal diodes, I is a 100 mA current source and B is a 4.5 V battery.

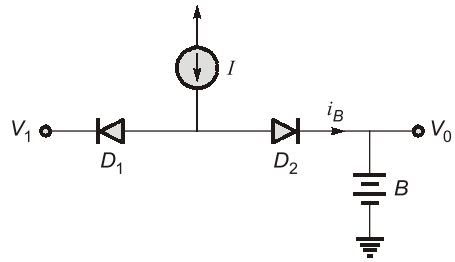
(a) Sketch and level the waveform of the battery current i_B.

(b) What is the peak value?

(c) What is its average value?

(d) If the peak value of V_I is reduced by 10%, what do the peak and average values of i_B become?

(20 Marks)



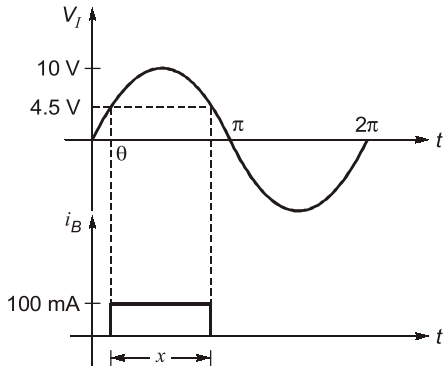
Solution:

(a) By the figure we can observe that when $V_I < 4.5$ volt, D_1 conducts and D_2 is cutoff so $i_B = 0$. For $V_I > 4.5$ volt, D_2 conducts and D_1 is cutoff and all the current flows through the battery.

$$\text{conduction angle} = \pi - 2\theta$$

$$\because \quad 10 \sin\theta = 4.5$$

$$\theta = \sin^{-1}\left(\frac{4.5}{10}\right)$$



(b) Fraction of cycle for that $i_B = 100$ mA is

$$x = \frac{\pi - 2\theta}{2\pi} = \frac{\pi - 2\sin^{-1}\left(\frac{4.5}{10}\right)}{2\pi}$$

$$= 0.351$$

(c) $$i_{B\,avg} = \frac{1}{T}\int_T i_B\, dt = \frac{1}{T}[100(0.35T)] = 35 \text{ mA}$$

(d) If V_I is reduced by 10% the peak value of the i_B remains same.

So $$i_{B\,peak} = 100 \text{ mA}$$

But the fraction of the cycle for conduction changes.

$$x = \frac{\pi - 20}{2\pi} = \frac{\pi - 2\sin^{-1}\left(\frac{4.5}{9}\right)}{2\pi} = \frac{1}{3}$$

Thus, $$i_{B\,avg} = \frac{1}{T}\left[100 \cdot \frac{T}{3}\right] = 33.3 \text{ mA}$$

2.6 In a particular circuit application, ten 20 mA diodes (*a* - 20 mA diode is a diode that provides a 0.7 V drop when the current through it is 20 mA) connected in parallel operate at a total current of 0.1 A. For the diodes closely matched, with $\eta = 1$.

(a) What current flows in each?

(b) What is the corresponding small signal resistance of each diode and of the combination?

(c) Compare this with the incremental resistance of a single diode ha a series resistance of 0.2Ω associated with the wire bonds to the junction.

(d) What is the equivalent resistance of the 10 parallel-connected diodes?

(e) What connection resistance would be single diode need in order to be totally equivalent?

(15 Marks)