1. Sketch and Explain high Zin capacitor coupled voltage follower with necessary design steps and show that the input impedance is very high as compared to capacitor coupled voltage follower.

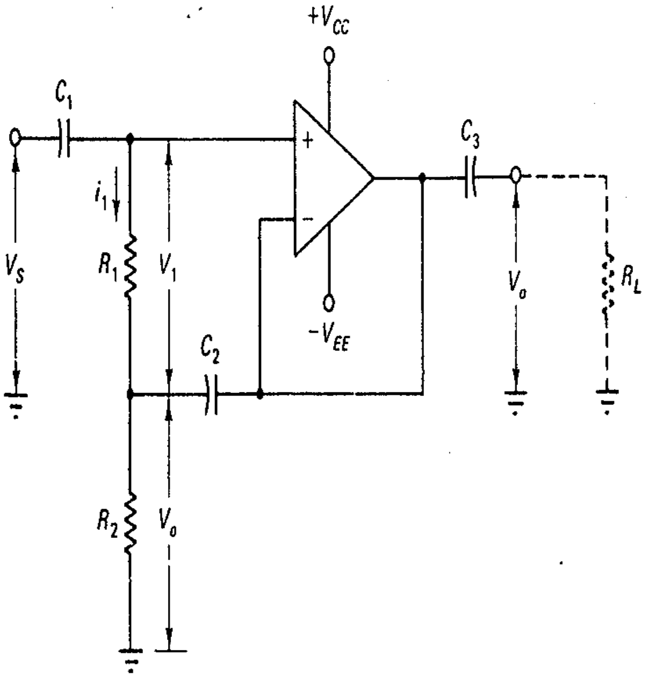


Figure High input impedance capacitor-coupled voltage follower. Feedback via C_2 to the junction of R_1 and R_2 gives an input impedance of $Z_{in} = (1 + M)R_1$.

- * The ~~*~~ I/p Impedance of the capacitor-coupled voltage follower is set by the value of resistor R_1. This gives a much smaller I/p Impedance than the direct coupled voltage follower.

- * Fig ① shows a method by which the I/p Impedance of the capacitor-coupled voltage follower can be substantially increased.

- * Capacitor C_2 couples the circuit o/p voltage to the junction of resistors R_1 & R_2.

  C_2 behaves as an ac short circuit. so that 'V_0' is developed across R_2.

- * Applying KNL from source, R_1 & R_2,

$$V_s - V_1 - V_0 = 0.$$

The voltage across R_1 is V_1 & is given by

$$\boxed{V_1 = V_s - V_0} \rightarrow ①$$

WKT open-loop gain is given by $M = \frac{V_0}{V_1}$

$$\boxed{V_0 = MV_1} \rightarrow ②$$

Sub eq ② in eq ①, we get

$$V_1 = V_s - MV_1$$

$$MV_1 + V_1 = V_s.$$

$$V_1(1+M) = V_s$$

$$\boxed{V_1 = \frac{V_s}{(1+M)}} \rightarrow ③$$

* The current i_1 is given by :

$$\boxed{i_1 = \frac{V_1}{R_1}} \rightarrow ④$$

sub eq ③ in eq ④, we get

$$\boxed{i_1 = \frac{V_s}{(1+M)R_1}} \rightarrow ⑤$$

* I/P resistance $$\boxed{Z_{in} = \frac{V_s}{i_1}} \rightarrow ⑥$$

sub eq ⑤ in eq ⑥, we get

$$Z_{in} = \frac{\cancel{V_s}}{\frac{\cancel{V_s}}{(1+M)R_1}}$$

$$\boxed{Z_{in} = (1+M)R_1} \rightarrow ⑦$$

Since open-loop gain 'M' is very high, this nodifies the ckt has very high I/p Impedance.

But if stray capacitance b/w the I/p & ground resent, then I/p Impedance reduces.

Design steps :-

$$R_{1(max)} = \frac{0.1 V_{BE}}{I_{B(max)}}$$

$R_{1(max)}$ is split into two equal resistors R_1 & R_2

$$\therefore R_1 = R_2 = \frac{R_{1(max)}}{2}$$

3> $\therefore \quad C_2 = \frac{1}{2\pi f_1 \left(\frac{R_2}{10}\right)}$

4> $\boxed{C_1 = C_2}$

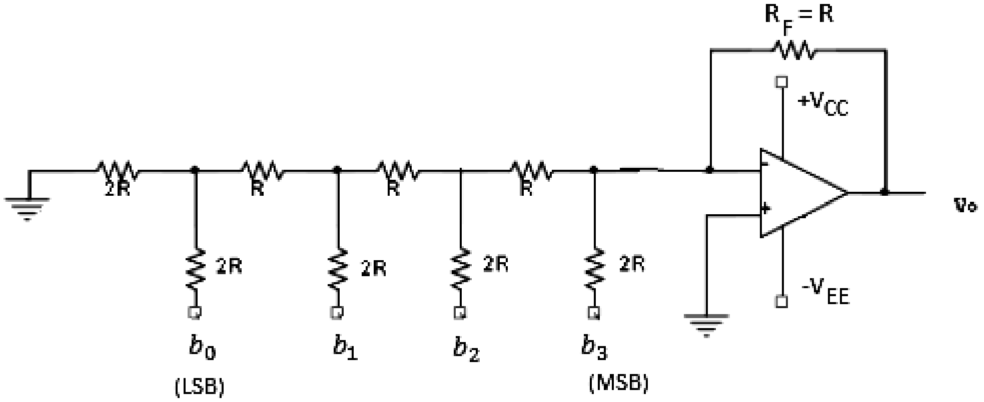
5> $C_3 = \frac{1}{2\pi f_1 R_L}$

6> $Z_{in} = (1+M)R_1$

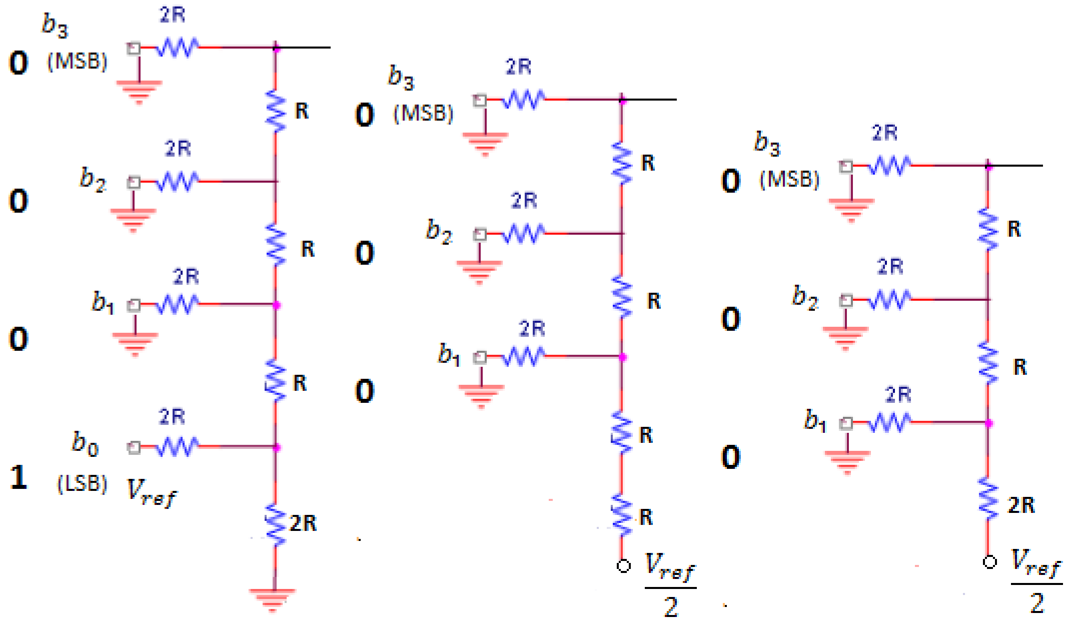
2) Explain the working of R-2R network DAC and derive expression for output voltage.

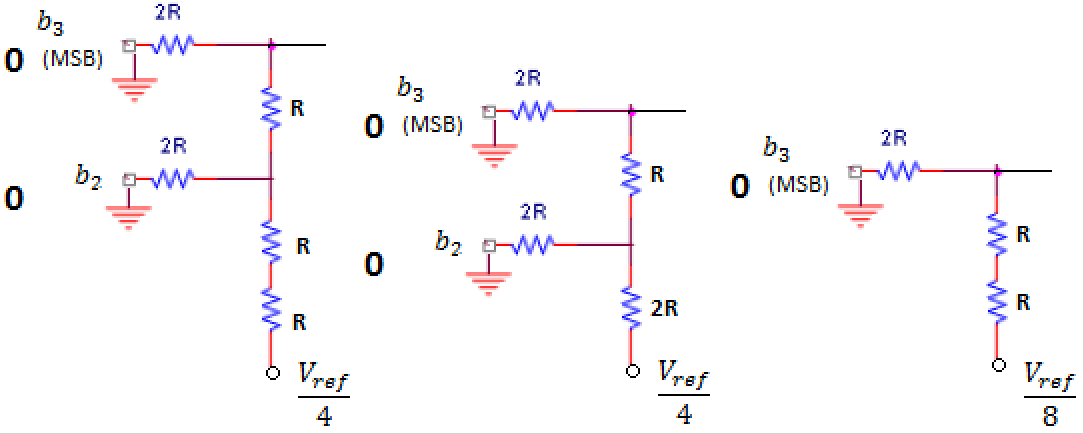
R-2R LADDER:

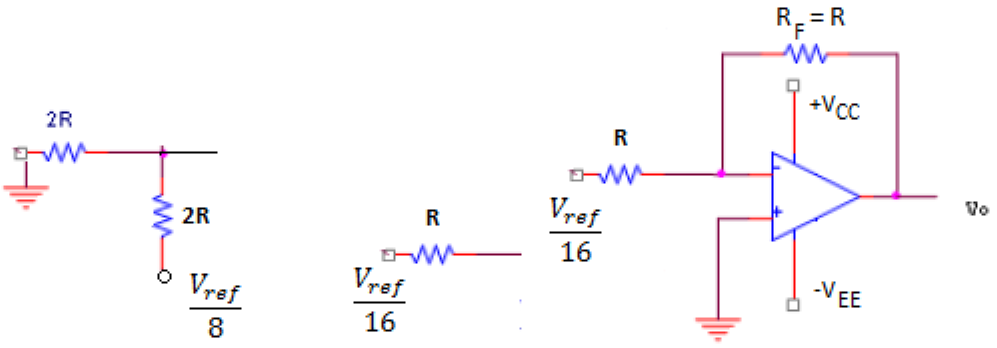
1. Wide ranges of resistors are required in binary weighted resistor type DAC. This can be avoided by using R-2R ladder type DAC, Here only two values of resistors are required. The typical value of 'R' range from 2.5KΩ to 10KΩ.
2. Consider a 4-bit DAC as shown in figure below, where b_3 , b_2 , b_1 , b_0 are the switches



3. When $b_3 b_2 b_1 b_0 = 0001$

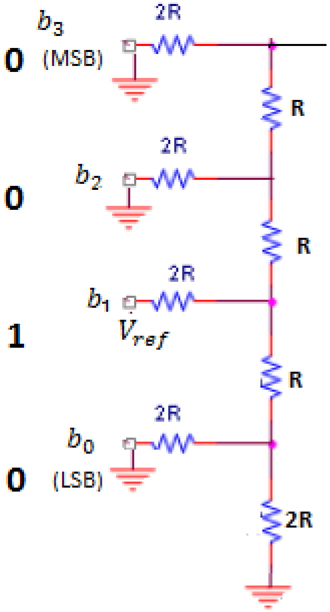


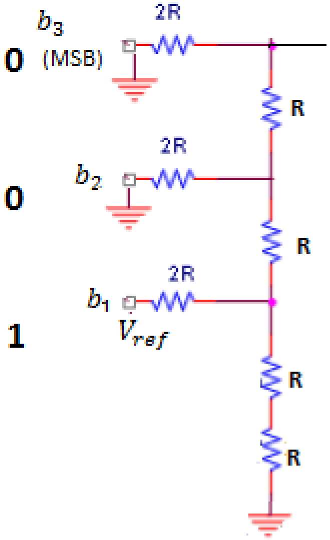


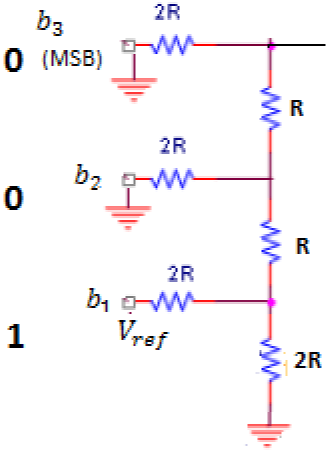


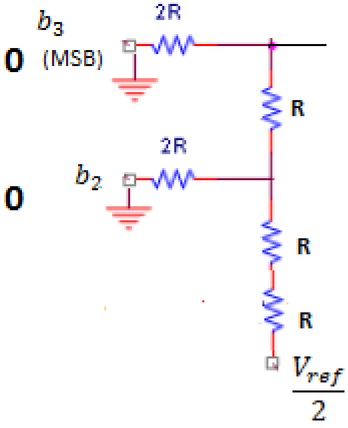
$$V_0 = -\frac{R_f}{R}\left(\frac{V_{ref}}{16}\right)$$

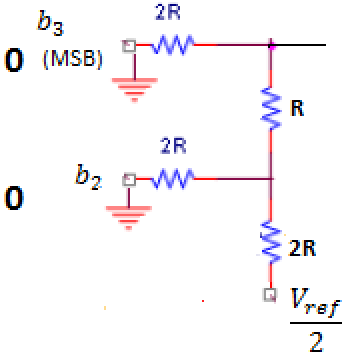
4. When $b_3 b_2 b_1 b_0 = 0010$

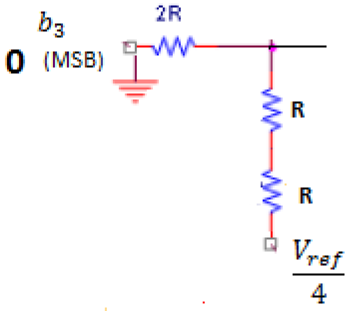


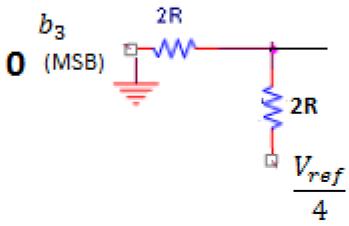


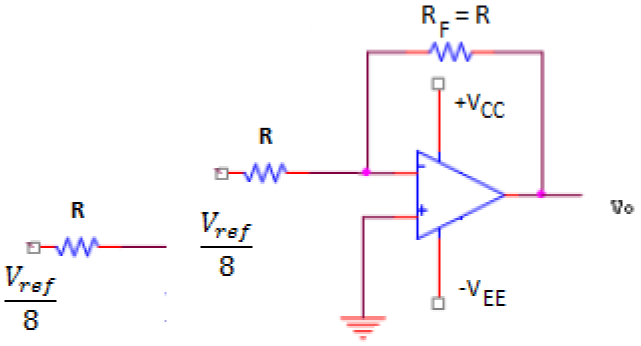






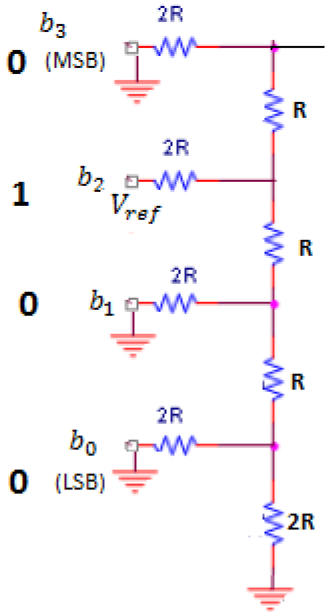


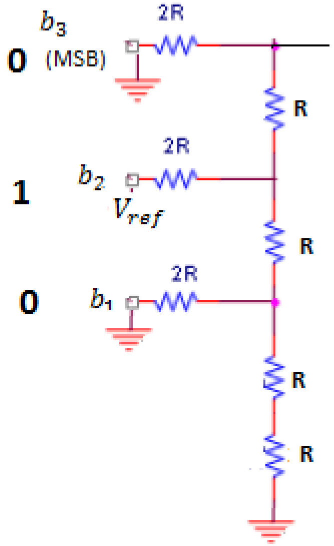


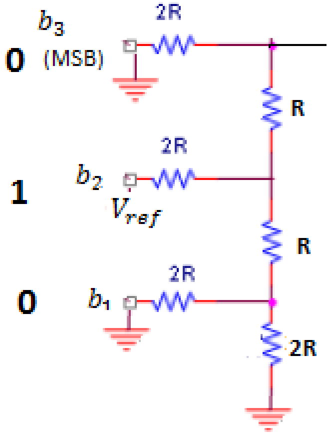


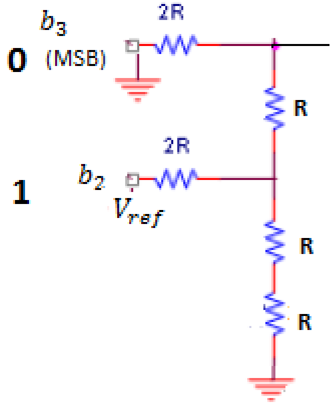
$$V_0 = -\frac{R_f}{R}\left(\frac{V_{ref}}{8}\right)$$

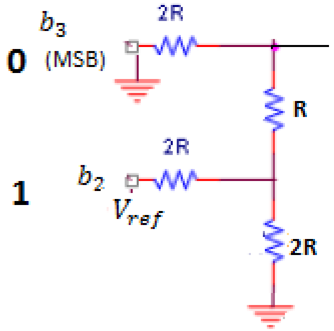
5. When $b_3 b_2 b_1 b_0 = 0100$

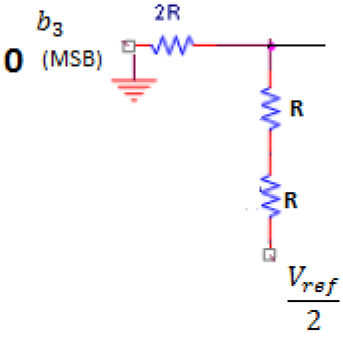


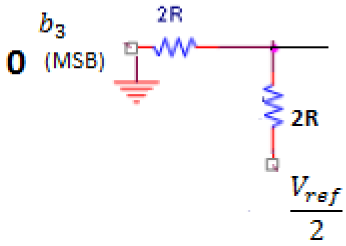


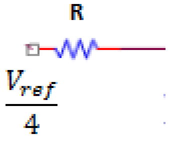


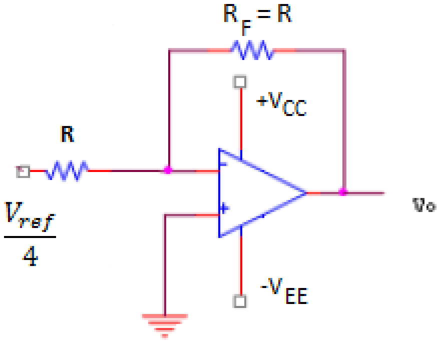






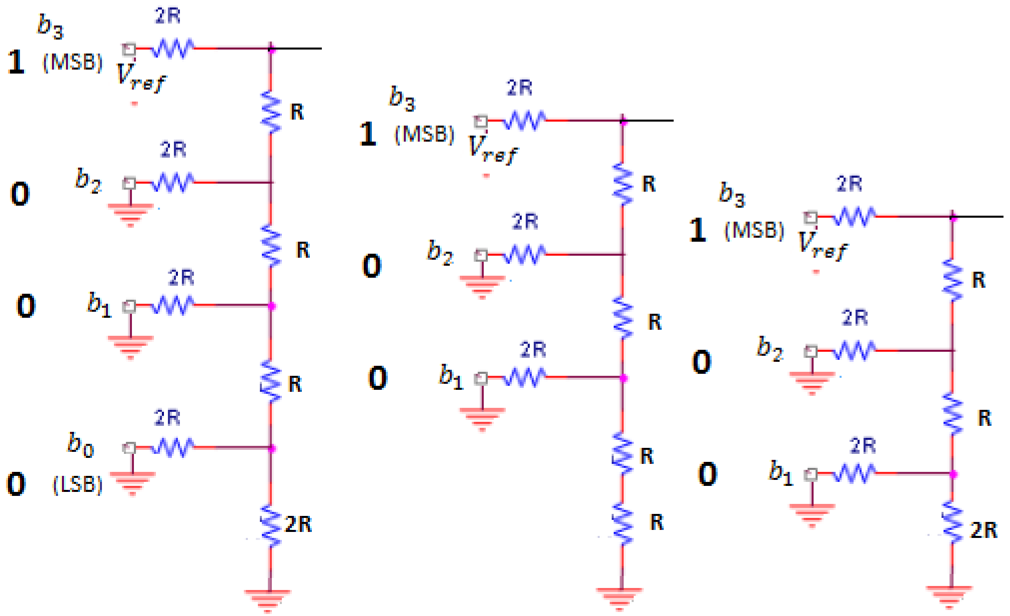


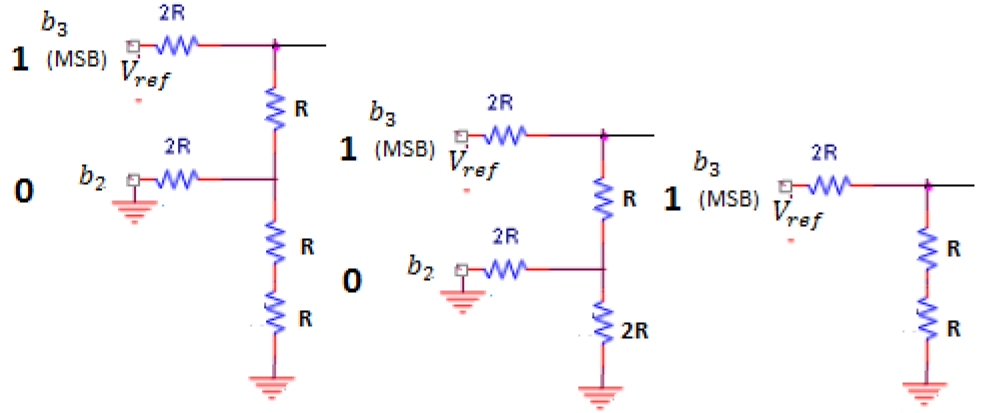


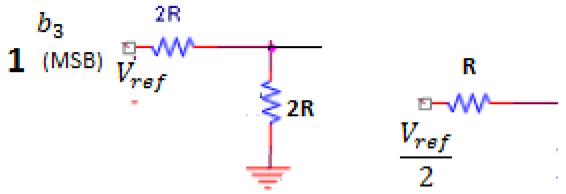


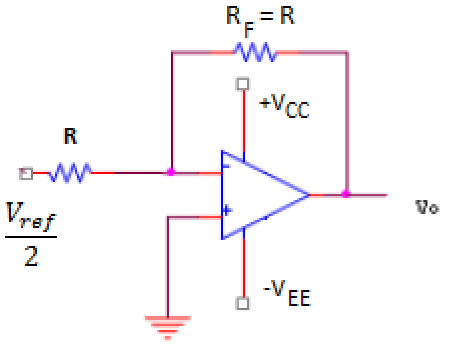
$V_0 = -\frac{R_f}{R}\left(\frac{V_{ref}}{4}\right)$

6. When $b_3 b_2 b_1 b_0 = 1000$









$$V_0 = -\frac{R_f}{R}\left(\frac{V_{ref}}{2}\right)$$

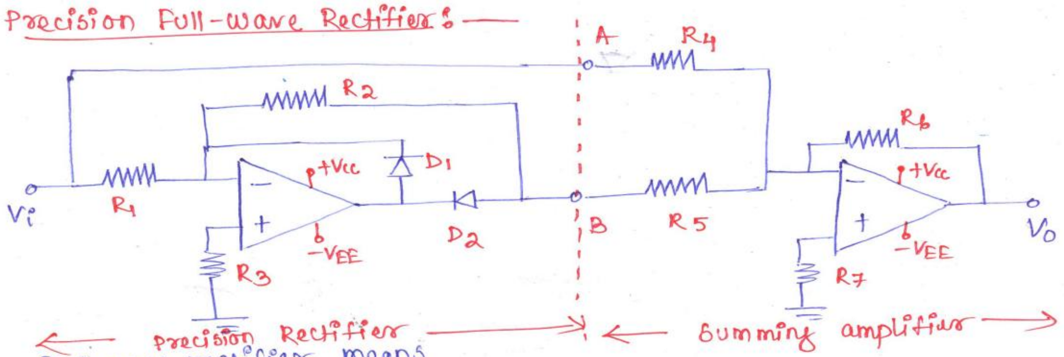
Hence the output can be represented as

$$V_0 = -\frac{R_f}{R}V_{ref}\left(\frac{b_3}{2}+\frac{b_2}{4}+\frac{b_1}{8}+\frac{b_0}{16}\right)$$

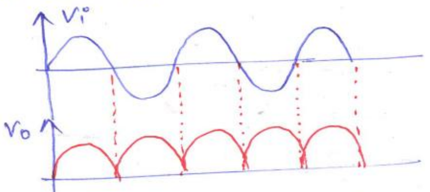
3) What are the advantages of precision rectifier over ordinary rectifier? Discuss the operation of full wave rectifier circuit using bipolar op-amp.

The advantages of precision rectifier are
(a) No diode voltage drop between input and output
(b) The ability to rectify very small voltages (less than 0.7V)
(c) Amplification, if required
(d) low output impedance

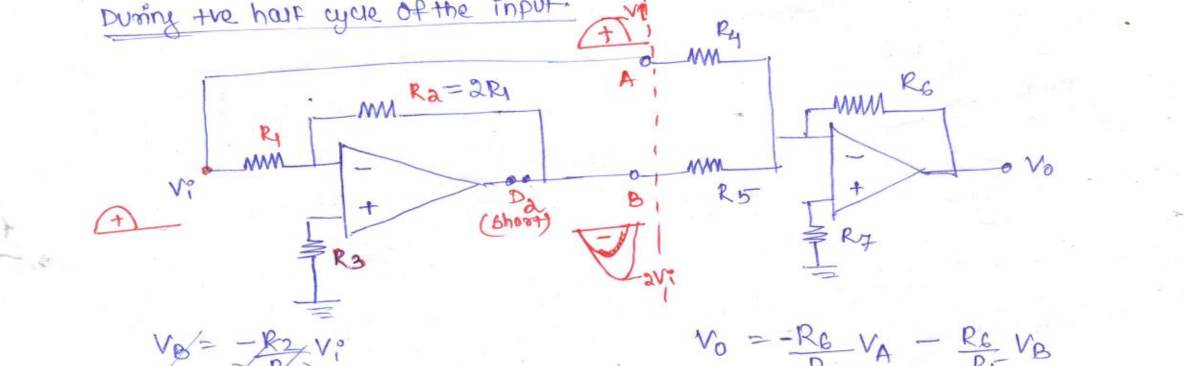
Precision Full-wave Rectifier :—



Full wave rectifier means



During +ve half cycle of the input.



~~$V_B = -\frac{R_2}{R_1} V_i$~~

~~IF $R_2 = R_1$, $V_B =$~~

$V_o = -\frac{R_6}{R_4} V_A - \frac{R_6}{R_5} V_B$

IF $R_4 = R_5$

$V_o = -\frac{R_6}{R_4} (V_A + V_B)$

IF $R_4 = R_6$, $V_o = -(V_A + V_B)$ −(

we need $V_0 = V_i$ — ②

But V_A is already same as V_i — ③

putting the eqⁿ ② and eqⁿ ③ in eqⁿ ① we got

$$V_i = -(V_i + V_B) \Rightarrow V_i + V_i = -V_B \Rightarrow \boxed{V_B = -2V_i} \quad — ④$$

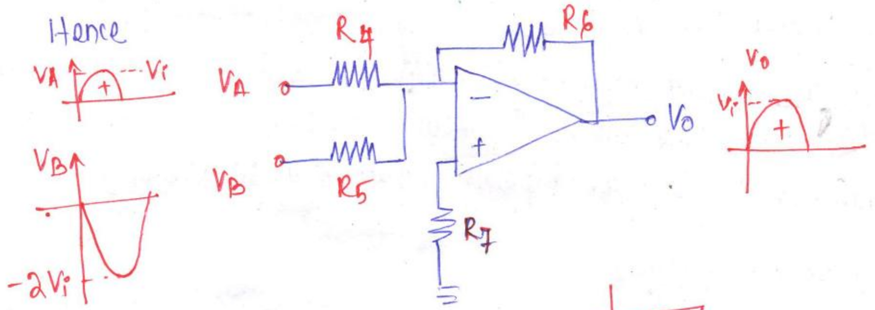
From the diagram it has been observed that

$$V_B = -\frac{R_2}{R_1} V_i \quad — ⑤$$

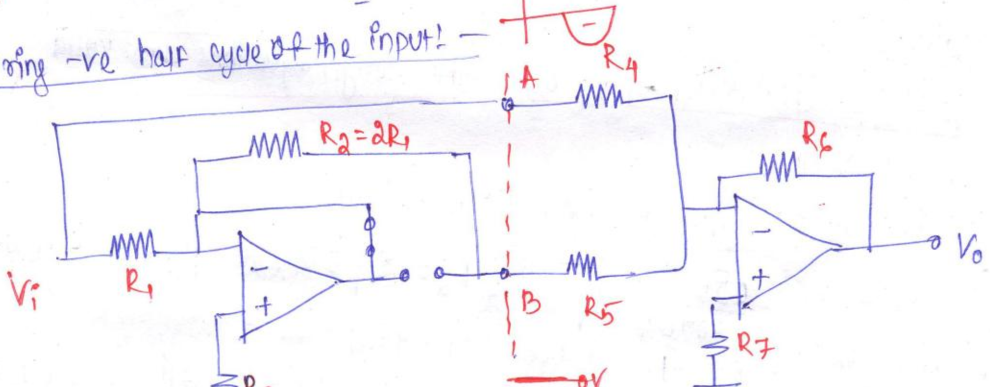
equating eqⁿ ⑤ with ④, we got

$$-2V_i = -\frac{R_2}{R_1} V_i \Rightarrow 2V_i = \frac{R_2}{R_1} V_i \Rightarrow \frac{R_2}{R_1} = 2 \Rightarrow \boxed{R_2 = 2R_1}$$

Hence

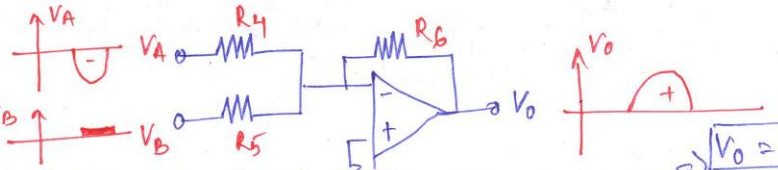


During -ve half cycle of the input! —



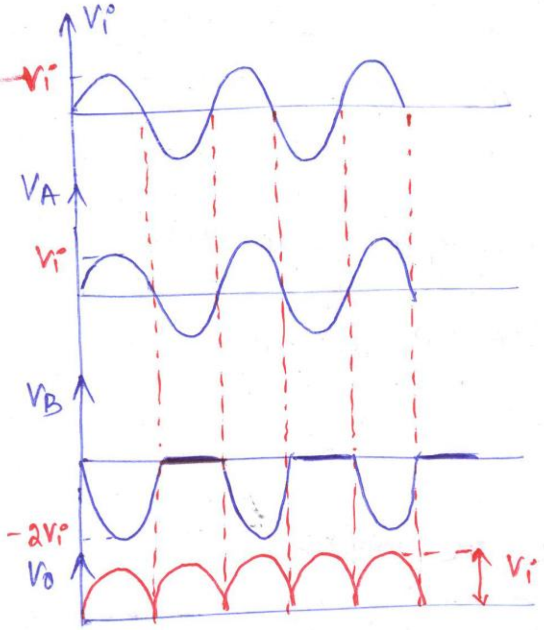
$\boxed{V_A = V_i}$

$V_B = 0V$



$V_0 = -\frac{R_6}{R_4}(V_A + V_B)$ If $R_6 = R_4$, $V_0 = -(V_A + V_B)$ $\Rightarrow V_0 = -(-V_i + 0) \Rightarrow \boxed{V_0 = V_i}$

Hence



As $V_0 = -\frac{R_6}{R_4}(V_A+V_B)$

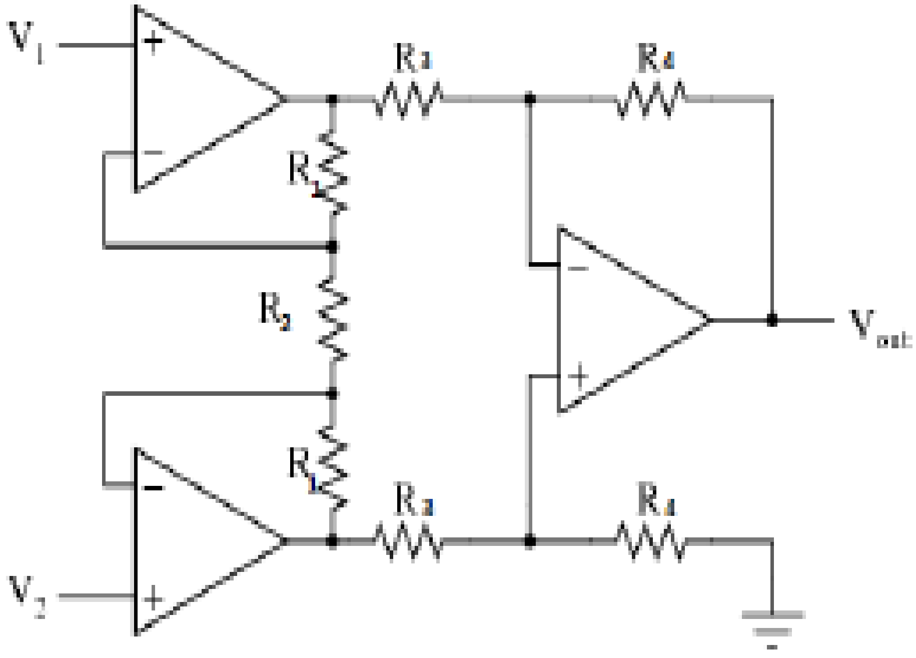
If $R_4 = R_6$

then $\boxed{V_0 = -(V_A+V_B)}$

4) Draw the circuit of instrumentation amplifier and explain its operation. Also show how voltage gain can be varied in instrumentation amplifier.

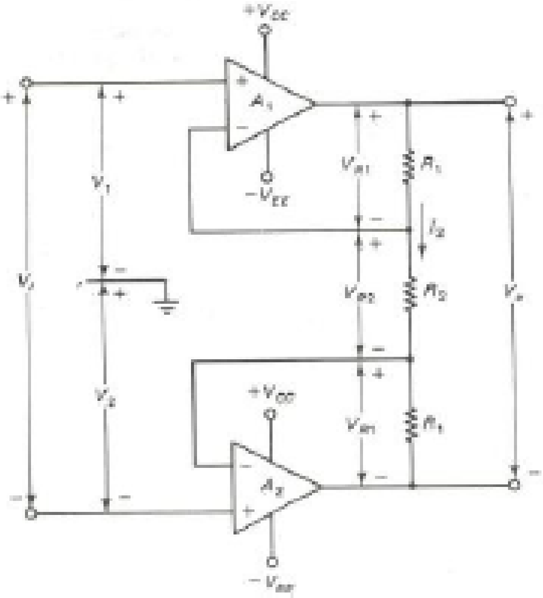
INSTRUMENTATION AMPLIFIER:

Instrumentation amplifier is the front end component of every measuring instrument which receives the signal from the input electrical signal from the transducer. It uses the fact the noise is common to the both output terminals of a transducer across which the output is measured and sent to measuring instrument.



Differential input differential Output Amplifier:

This circuit accepts a differential input voltage and produces a differential output. The voltage at the junction of R_1 *and* R_2 is equal to the input voltage. Also, the voltage at the junction of R_2 and R_3 equals input voltage V_2. The voltage across R_2 is



$V_{R_2} = V_1 - V_2 = V_i$

The circuit current through R_2 as $I_2 = \frac{V_i}{R_2}$

The differential output voltage is

$$V_o = V_{R_1} + V_{R_2} + V_{R_3} = I_2(R_1 + R_2 + R_3) = \frac{V_i}{R_2}(R_1 + R_2 + R_3)$$

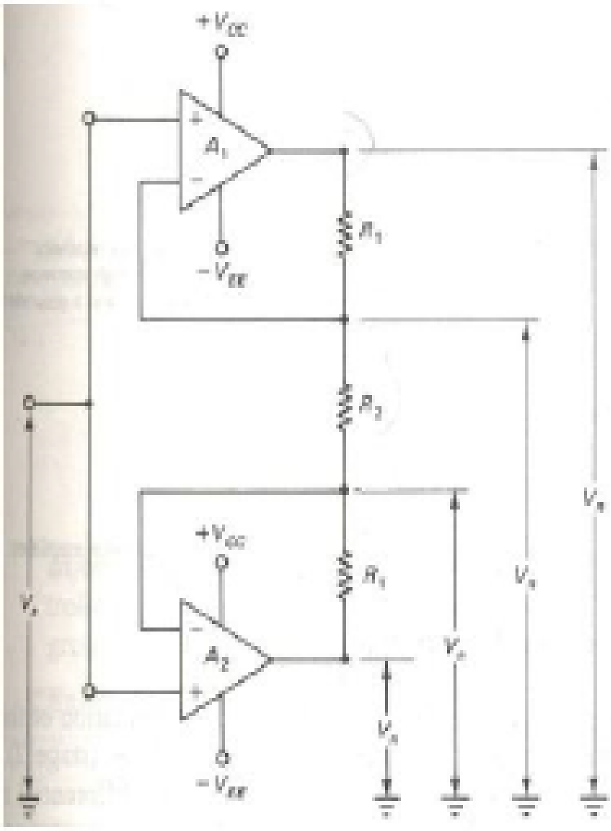
The circuit differential voltage gain is

$$A_V = \frac{V_o}{V_i} = \frac{R_1 + R_2 + R_3}{R_2} \quad normally \quad R_1 = R_3 \quad hence \quad A_V = \frac{2R_1 + R_2}{R_2}$$

(Voltage gain can be altered by adjusting a single resistor R_2)

Suppose 2 inputs are connected together and a common mode noise voltage V_n is applied to the two . The junction of R_1 *and* R_2 will be at the same voltage as the non-inverting input terminal of A_1 and the junction of R_2 *and* R_3 will be at the same potential as the non-inverting input of A_2. That is both resistor junctions will be at V_n. There will be no current flow through R_1 , R_2 *or* R_3 and the output of the amplifier will be V_n. This means the common mode gain is

$A_{V(cm)} = 1$



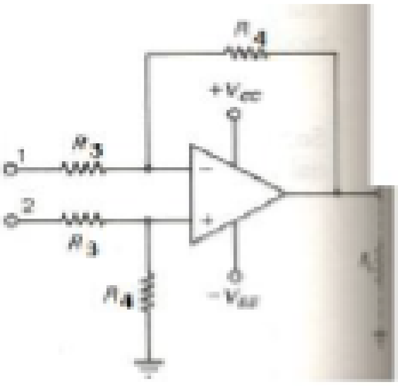
[A common mode voltage applied to a differential input and differntial output amplifier]

So common mode signals will be passed through but not amplified by the differential input differential output amplifier.

1. The differential input and differential output amplifier is used in conjunction with the difference amplifier. The input impedance of differential input differential output amplifier is extremely high because of the non-inverting amplifier configuration. The input impedance of the differential amplifier is $R_i = R_1$ at the inverting terminal and R_i=$(R_3 + R_4)$ at the non-inverting terminal.
2. The voltage gain of the differential input and differential output stage can be changed by adjusting only one resistor R_2. Changing the gain of the differential amplifier requires R_2 *and* R_4 to be adjusted together to maintain equal amplification of both inputs.
3. The common mode gain of the differential input/output amplifier is 1, compared to common mode gain of zero for the difference amplifier.
4. The differential input/output amplifier operates with a floating load, while the difference amplifier uses a grounded load.

Differential Amplifier:

The instrumentation amplifier is a combination of differential input/output amplifier (stage 1) and difference amplifier (stage 2). The voltage gain of the complete circuit is



$A_V = A_{V_1} . A_{V_2}$

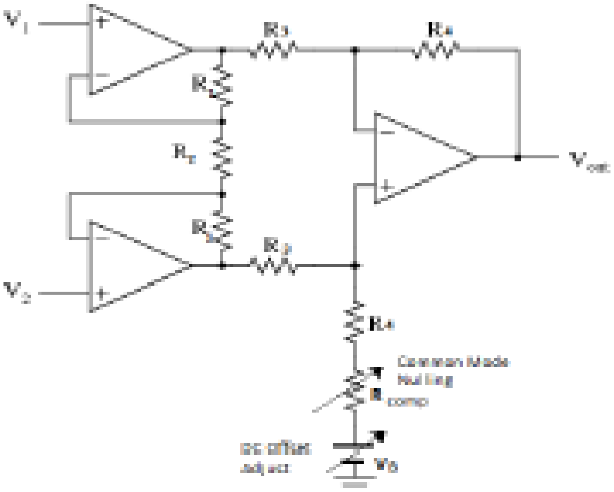
Wehere $A_{V_1} = \left(1+\frac{2R_1}{R_2}\right)$ and $A_{V_2} = \frac{R_4}{R_3}$

$$A_V = \left(1+\frac{2R_1}{R_2}\right)\left(\frac{R_4}{R_3}\right)$$

Instrumentation amplifier is a combination of the differential input/output amplifier (Stage 1) and difference amplifier (stage 2)

$A_V = \left(1+\frac{2R_1}{R_2}\right)\left(\frac{R_4}{R_3}\right)$ The overall gain can be controlled by adjustment of R_2

Like difference amplifier the instrumentation amplifier can also use R_{Comp} resistor (adjustable) in series with R_4 and the DC output voltage level shifting can be controlled by connecting a bias voltage to the R_{Comp} resistor instead of being directly connected to ground.



5) A capacitor coupled Non-inverting amplifier is to have a gain, Av=100 and output voltage, Vo=5V with a load resistor, RL =10k and frequency, F=100Hz. Design a suitable circuit using 741 op-amp.

Given :- $A_V = 100$, $V_0 = 5V$, $R_L = 10\,K\Omega$, $f_1 = 100Hz$.

For 741 op-amp : $I_B(max) = 500nA$.

sol :-

* $$R_1(max) = \frac{0.1\,V_{BE}}{I_B(max)} = \frac{0.1 \times 0.7V}{500\,nA} = \underline{\underline{140K\Omega}}$$

choose. $\boxed{R_1 = 120K\Omega}$

* $$C_1 = \frac{1}{2\pi f_1 \left(\frac{R_1}{10}\right)} = \frac{1}{2\pi(100Hz) \times \left(\frac{120K\Omega}{10}\right)} = 0.132\,\mu F$$

choose. $\boxed{C_1 = 0.15\,\mu F}$

* $$C_2 = \frac{1}{2\pi f_1 R_L} = \frac{1}{2\pi \times 100 \times 10K\Omega} = 0.159\,\mu F$$

choose $\boxed{C_2 = 0.15\,\mu F}$

* $$I_2 = 100 \times I_B(max) = 100 \times 500\,nA = \underline{\underline{50\,\mu A}}$$

* $$R_3 = \frac{V_i}{I_2}.$$

WKT $$A_V = \frac{V_o}{V_i}$$

$$V_i = \frac{V_o}{A_V} = \frac{5V}{100} = \underline{\underline{50mV}}$$

$$* \quad R_3 = \frac{50mV}{50\mu A} = \underline{\underline{1K\Omega}}$$

$$* \quad R_2 = \left(\frac{V_0}{I_2} - R_3\right) = \left(\frac{5V}{50\mu A} - 1k\Omega\right)$$

$$\boxed{R_2 = 99K\Omega}$$

OR

$$A_V = 1 + \frac{R_2}{R_3}$$

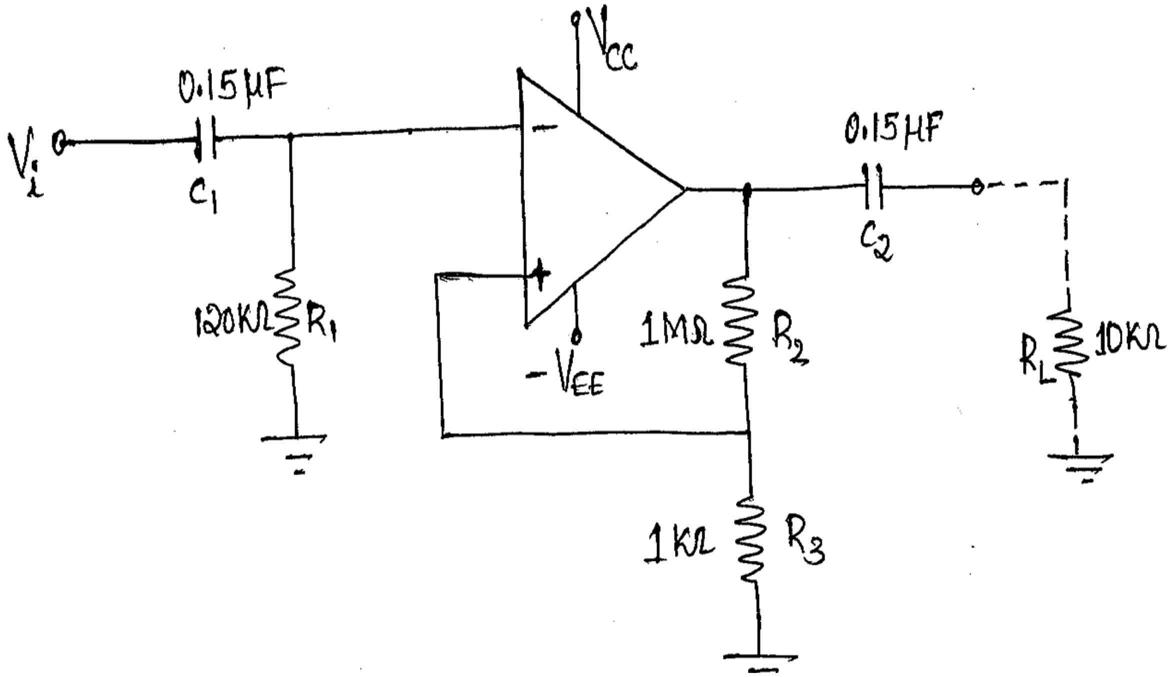
$$\frac{R_2}{R_3} = (A_V - 1)$$

$$R_2 = R_3(A_V - 1)$$

$$= 1k\Omega(100 - 1)$$

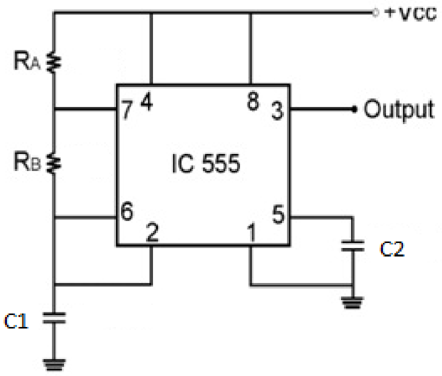
$$\boxed{R_2 = 99k\Omega}$$

Choose · $\boxed{R_2 = 1M\Omega}$

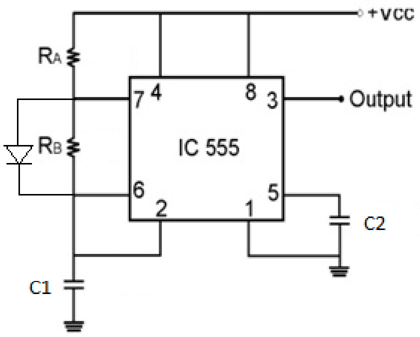


6) Explain the operation of Astable multivibrator using 555 timer with relevant functional diagram, waveforms and derive the expression for duty cycle.

ASTABLE MULTIVIBRATOR:

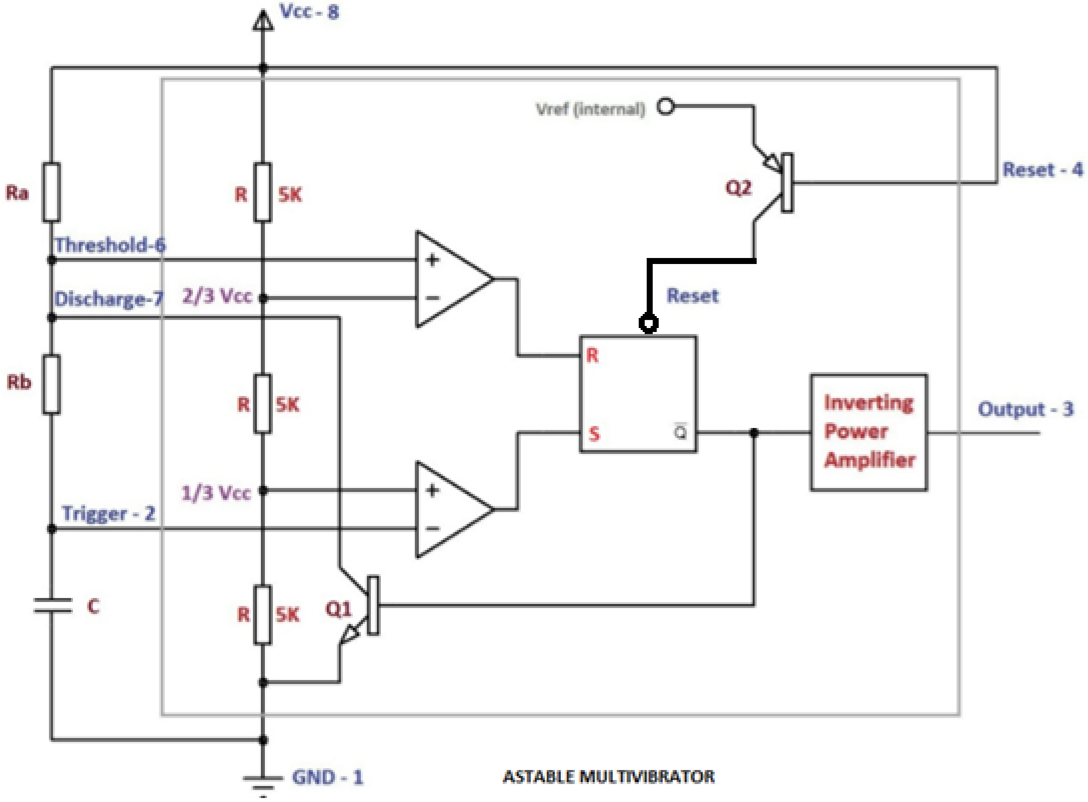


Asymmetric



Symmetric

1. When the power supply V_{CC} is connected, the external timing capacitor C charges towards V_{CC} with a time constant $(R_A + R_B)C$. During this time the upper comparator produces the output as LOW and the lower comparator produces the output as HIGH. Hence the output of the S-R flip-flop is HIGH. i.e. $Q = 1\ (HIGH)\ and\ \bar{Q} = 0\ (LOW)$. At the same time transistor Q_1 is OFF.
2. When the capacitor voltage is just greater than $\frac{2}{3}V_{CC}$, the upper comparator produces HIGH output and the lower comparator output is LOW. Hence the output of the S-R flip –flop is LOW. i.e. $Q = 0\ (LOW)\ and\ \bar{Q} = 1\ (HIGH)$. So the transistor $Q_1$is ON and the capacitor starts discharging towards ground through R_B.
3. During the discharge of the capacitor C, as it reaches just less than $\frac{1}{3}V_{CC}$, the lower comparator produces the output HIGH and the upper comparator produces the output as LOW. Hence the output of the S-R flip-flop is HIGH. . i.e. $Q = 1\ (HIGH)\ and\ \bar{Q} = 0\ (LOW)$. At the same time transistor Q_1 is OFF, so the capacitor starts charging.
4. The capacitor is thus periodically charged and discharged between $\frac{2}{3}V_{CC}\ and\ \ \frac{1}{3}V_{CC}$ respectively.



ASTABLE MULTIVIBRATOR

Capacitor voltage at any instant of time can be calculated as

$$V_C(t) = V_{C(final)} + \left[V_{C(initial)} - V_{C(final)}\right]e^{-\frac{t}{\tau}}$$

$$V_C(t) = V_{CC} + \left[\frac{1}{3}V_{CC} - V_{CC}\right]e^{-\frac{t}{(R_A+R_B)C}} \quad as \ \ \tau = (R_A + R_B)C$$

$$V_C(t) = V_{CC} + \left[-\frac{2}{3}V_{CC}\right]e^{-\frac{t}{(R_A+R_B)C}}$$

$$at\ t = T_{ON} \ \ , V_C(t) = \frac{2}{3}V_{CC}$$

$$\frac{2}{3}V_{CC} = V_{CC} - \frac{2}{3}V_{CC}e^{-\frac{T_{ON}}{(R_A+R_B)C}} => \frac{2}{3}V_{CC} - V_{CC} = -\frac{2}{3}V_{CC}e^{-\frac{T_{ON}}{(R_A+R_B)C}}$$

$$=> -\frac{1}{3}V_{CC} = -\frac{2}{3}V_{CC}e^{-\frac{T_{ON}}{(R_A+R_B)C}} => 1 = 2e^{-\frac{T_{ON}}{(R_A+R_B)C}} => \frac{1}{2} = e^{-\frac{T_{ON}}{(R_A+R_B)C}}$$

$$=> \ln\left(\frac{1}{2}\right) = -\frac{T_{ON}}{(R_A + R_B)C} => -0.693 = -\frac{T_{ON}}{(R_A + R_B)C} => T_{ON} = 0.693(R_A + R_B)C$$

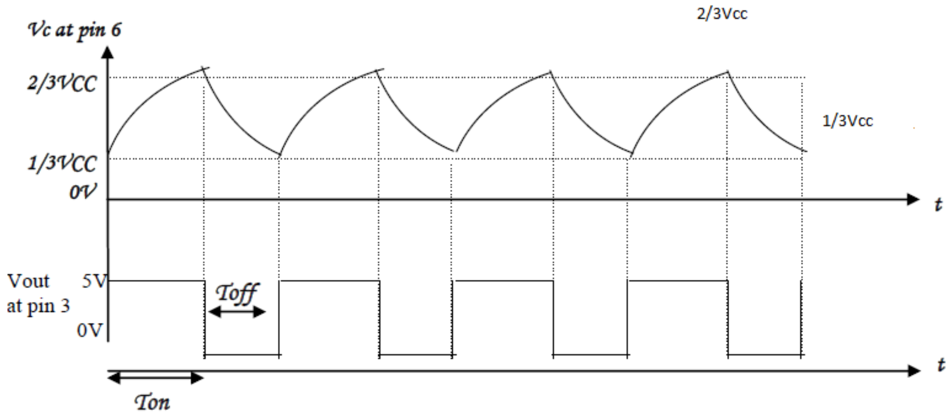
Similarly T_{OFF} can be derived as $T_{OFF} = 0.693R_BC$

$$Duty\ Cycle, \quad D = \frac{T_{ON}}{T}$$

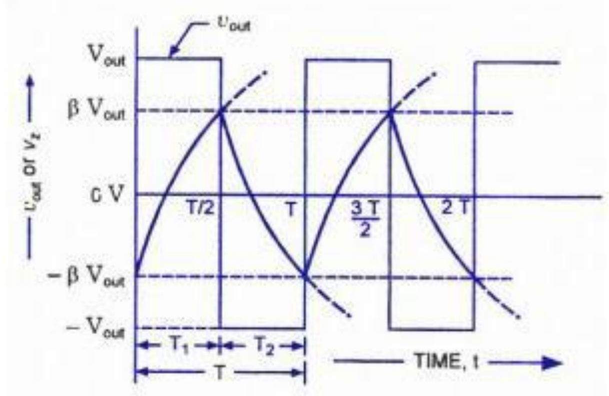
$$T = T_{ON} + T_{OFF}$$

$$Duty\ Cycle \quad D = \frac{T_{ON}}{T_{ON} + T_{OFF}} = \frac{0.693(R_A + R_B)C}{0.693(R_A + 2R_B)C} = \frac{R_A + R_B}{R_A + 2R_B}$$

ASYMMETRIC CIRCUIT



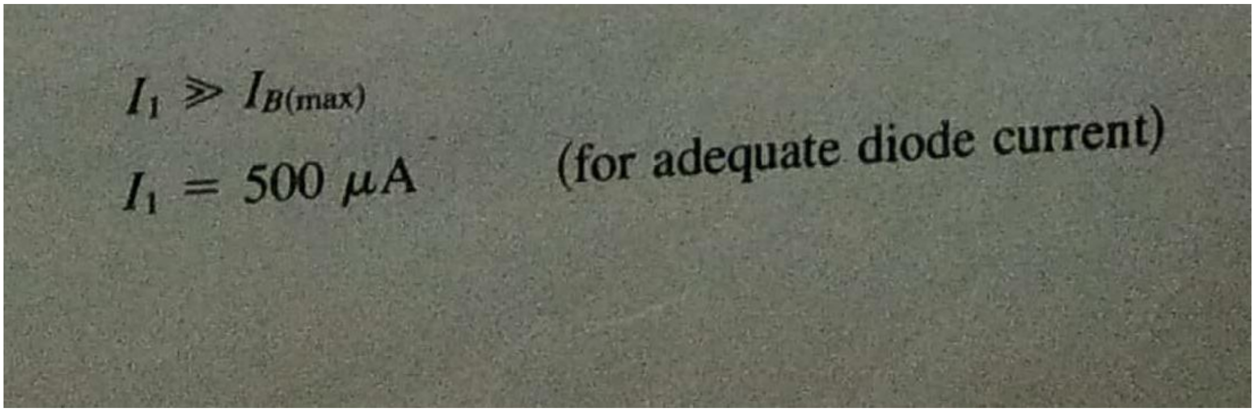
SYMMETRIC CIRCUIT



APPLICATION OF ASTABLE MULTIVIBRATOR:

1. FSK Generator
2. Pulse Position Modulator

7) Design a non-saturation precision half-wave rectifier to produce a 2V peak output from a sine wave input with a peak value of 0.5V and frequency of 1 MHz. Use bipolar op-amp with supply voltage of 15V.



$I_1 \gg I_{B(max)}$

$I_1 = 500\ \mu A$ (for adequate diode current)

$$R_1 = \frac{V_i}{I_1} = \frac{0.5\ \text{V}}{500\ \mu\text{A}}$$

$$= 1\ \text{k}\Omega \qquad \text{(standard value)}$$

$$R_2 = \frac{V_o}{I_1} = \frac{2\ \text{V}}{500\ \mu\text{A}}$$

$$= 4\ \text{k}\Omega \qquad \text{(use 3.9 k}\Omega\text{ standard value)}$$

$$R_3 = R_1 \parallel R_2 = 1\ \text{k}\Omega \parallel 3.9\ \text{k}\Omega$$

$$= 796\ \Omega \qquad \text{(use 820 }\Omega\text{ standard value)}$$

For diodes D_1 and D_2, $$V_R > [V_{CC} - (-V_{EE})] > [15\ \text{V} - (-15\ \text{V})]$$

$$> 30\ \text{V}$$

$$t_{rr} \ll T$$

let $$t_{rr(\max)} = \frac{T}{10} = \frac{1}{10 \times f}$$

$$= \frac{1}{10 \times 1\ \text{MHz}} = 0.1\ \mu\text{s}$$

Compensate the op-amp as a voltage follower.

wo-Output Precision Rectifier