...ication

it - 1 - IC and op-Amp applications
- chip size and ckt complexity
- Ideal & practical OP-Amp, OP-Amp charac (dc, ac, slew rate, freq. resp) 741 OP-Amp modes of operation; Inverting, non inverting and differential, OP-Amp application
- Basic app of OP-Amp - Instrumentation Amp ac amp, V to I & I to V convertors, Sample and hold circuits, differentiator and integrator Comparators, Schmitt trigger, multivibrators and 723 voltage regulator.

- Amp & linear integrated ckts by Ramakant K. Gaykvad.

linear circuits by Roy choudary.

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Unit-1 - IC Application and OP-Amp application

★ Integrated ckt :- If all the components of a ckt are fabricated on the silicon chip it is called integrated circuit (IC). They are used in computer industry, automobile, home appliances, communication and control system

IC's offer a no. of advantages over the discrete ckts they are.

-> The size is reduced and hence increased component density
-> Cost reduction
-> Increased system reliability due to elimination of soldering
-> Increased operating speeds
-> Reduction in power consumption

★ Pin diagram :- The function of an IC can be explained using the pin diagram

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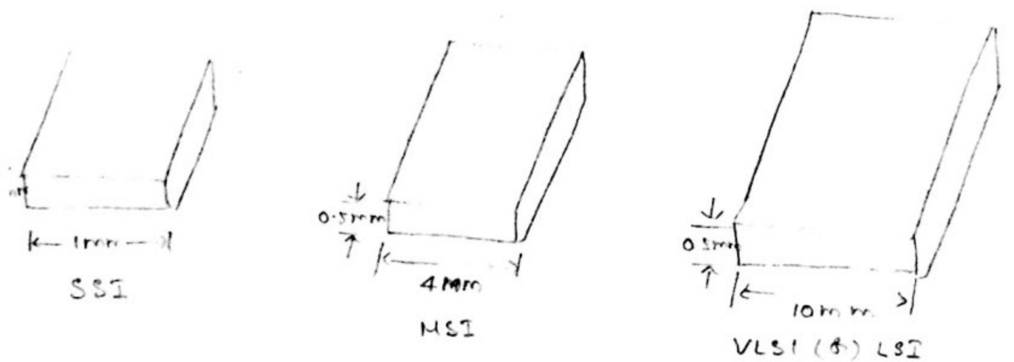
★ classification of IC's :-

(i) Based on the no. of components & gates on the IC the IC's are classified as.

(i)

Type of IC	No. of Components	Examples
[Sm]all scale IC's (SSI)	<10	logic gates, flipflops
[M]edium Scale IC's (MSI)	<100	Mux, demux, decoder, encoder etc
[La]rge Scale IC's (LSI)	100 to 1000	RAM, ROM, PLA etc.
[Ve]ry large Scale IC's (VLSI)	>1000	8 bit microprocessor 16 bit micro Controller
[Ult]ra large Scale IC's (ULSI)	10^6 to 10^7	Special processor like DSP, ARM, AVR, virtual reality machine.
[G]aint scale IC's (GLSI)	$>10^8$	SOC (System on chip)



[ii] Based on the mode of operation, IC's are classified as 1) digital IC
2) Linear & Analog IC

[D]igital IC :- Digital IC's are Complete functioning [l]ogic n/ws They are used to form ckts as gates, [c]ounters, mux, demux etc.

Digital IC's have only 2 levels of voltages i.e., [hi]gh & low

Linear & Analoge IC :- Linear IC's are equivalent of discrete transistor n/ws such as amplifiers, filt[ers] oscillators etc which requires additional compon[ents]

Ex:- IC741, 555 timer, 723 voltage regulator.

(iii) Based on the active devices used IC's can be classified as 1) unipolar IC
2) Bipolar IC.

The active device to design any logic ckt is a transistor & BJT then it is known as Bipolar IC.

Bipolar IC's are further classified as
-> Dielectric isolation
-> Pn junction isolation

If the active device in an IC is a MOSF[ET] & JFET then the IC is known as unipolar IC

(iv) Based on the fabrication method IC's are classified as -> Monolithic IC
-> Hybrid IC

In the monolithic IC's, all the components active and passive are formed simultaneously by a diffusion process.

The monolithic IC's exhibit good therm[al] stability.

In the Hybrid IC's passive component su[ch] as resistor and capacitor and the interconnecti[ons]

...ween them are formed on an isolating subs. Active components such as transistor, diode as well as monolithic IC's are then connected to form a complete circuit.

Based on application, IC's are classified as general purpose & special purpose.

Ex:- For general purpose are OP-Amps, logic gates

Ex:- For special purpose are voltage regulator, audio power IC's etc.

Temperature ranges of IC's :-

All the IC's manufactured are classified one of the 3 basic ranges

Military temp range (-55°c to 125°c) (1)

Industrial temp range (-20°c to +85°c) (2)

Commercial temp range (0°c to 70°c) (3)

IC Package types :- There are 3 types of packages

Dual inline package (DIP)

Flat pack

Metal can (or) Transistor pack

Manufacturer designation for IC's

Each manufacturer uses a specific code and assigns a specific no. to the IC's it produces

Some of the wellknown manufacturers for IC's a

Fair child : μA, μAF

National semiconductor : LM, LH, LF, TBA

Motorola : MC, MFC

Texas instruments : SN

Signetics : L, N/s, NE/SE, SU

Ex:-

μA	741	mini DIP T	C - temp
MC	3400	P	0° to 70°C
L	741	P → DIP	1 - temp

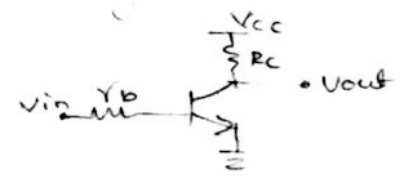
Note :- The national semiconductor manufacturer represents nos like 1, 2, 3 for the temp. range. Here 1 - military, 2 - Industrial, 3 - commercial range.

★ Amplifier :-

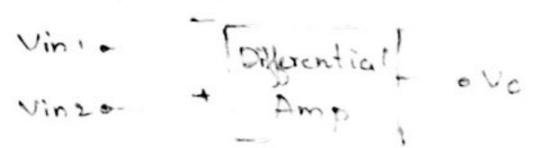
An amplifier is an electronic device which accepts an input signal and produces an o/p signal proportional to the i/p signal

i.e., $V_o \propto V_{in}$

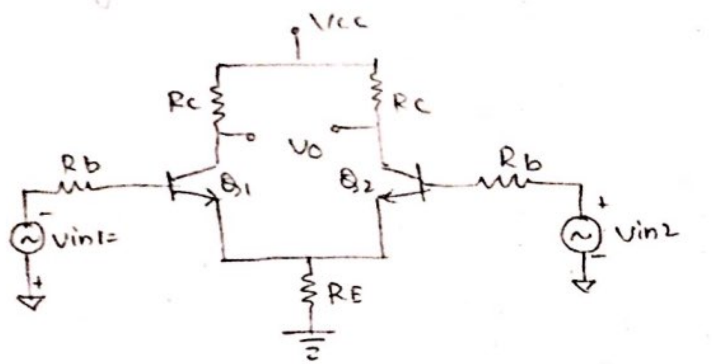
$V_o = A V_{in}$ (A → gain)



★ Differential amplifier :-



Circuit diagram:-



let $V_{in2} = 0$ — By using superposition theorem

$V_{o1} \propto -V_{in1}$ — ①

$V_{o1} = -AV_{in1}$

$V_{in1} = 0 \Rightarrow V_{o2} \propto V_{in2}$.

$V_{o2} = AV_{in2}$ — ②.

$V_o = V_{o1} + V_{o2}$

$= -AV_{in1} + AV_{in2}$.

$V_o = A(V_{in2} - V_{in1})$.

$= A \cdot V_{id}$.

An amplifier which amplifies the diff b/w two i/p signals is called differential amp. It is the basic building block of OP-Amp.

The diff amp has certain adv like

- excellent stability.
- Immune to interface signal. etc

If $V_{in2} > V_{in1} \Rightarrow V_{id}$ is +ve $\Rightarrow$ non inverting amp.

If $V_{in1} > V_{in2} \Rightarrow V_{id}$ is -ve $\Rightarrow$ inverting amp.

★ **Differential gain:-**

We define diff amp as $V_o \propto (V_{in2} - V_{in1})$

i.e., $V_o \propto V_{id}$. where $V_{id} = V_{in2} - V_{in1}$

$\therefore V_o = A_d \cdot V_{id}$.

A_d → diff gain.

$\therefore A_d = \dfrac{V_o}{V_{id}}$. — (1)

★ **Common mode gain:- (A_c)**

If we apply 2 i/p voltages which are equal in amp to diff amplifier i.e., $V_{in1} = V_{in2}$ then we get

$V_o = 0$

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→ The o/p voltage of practical differential amp depends not only diff voltage but also on avg common level of the 2 i/p voltages which is called common mode signal voltage (V_c) where

$V_c = \dfrac{V_{in1} + V_{in2}}{2}$.

So the o/p voltage of the diff amp due to common mode signal V_c is $V_o \propto V_c$.

$\therefore V_o = A_c V_c$.

Where A_c is called common mode gain.

So the total o/p of any diff amp is expressed as $V_o = A_d \cdot V_d + A_c \cdot V_c$

Note:- For an ideal diff amp the diff gain Ad must be ∞ and common mode gain Ac must be zero.

Common mode rejection ratio:- (CMRR)

It is defined as ratio of diff voltage gain to common mode voltage gain.

$$\rho = CMRR = \left|\frac{A_d}{A_c}\right|.$$

For ideal case $\rho = \infty$

$\because A_c = 0$

The o/p voltage of the diff amp V_o can be expressed in terms of CMRR as

$$V_o = A_d V_d\left[1 + \frac{A_c V_c}{A_d V_d}\right]$$

$$= A_d V_d\left[1 + \frac{1}{CMRR} \times \frac{V_c}{V_d}\right]$$

1) If CMRR = 10^5 and $A_d = 5000$ calculate A_c

$$CMRR = \left|\frac{A_d}{A_c}\right|.$$

$$10^5 = \frac{5000}{A_c}.$$

$$A_c = \frac{5000}{1000 \times 10^2}$$

$$A_c = 0.05$$

$$A_c(dB) = 20\log_{10} 0.05$$

$$A_c = -26.02\ dB$$

② If $V_1 = 300\mu V$ & $V_2 = 240\mu V$ $A_d = 5000$, CMRR=100. Find the o/p voltage of the diff amp.

$V_d = V_1 - V_2 = 60\mu V$

$V_c = \frac{V_1+V_2}{2} = 270\mu V$

$$V_o = A_d V_d\left[1 + \frac{1}{CMRR} \times \frac{V_c}{V_d}\right]$$

$$= 5000(60)\left[1 + \frac{1}{100} \times \frac{270}{60}\right]$$

$$V_o = 0.313\ V$$

③ The o/p voltage $V_o = 500mV$, $V_d = 200mV$, $V_c = 180mV$, $A_d = 4500$ Find CMRR.

$$A_c = \frac{V_o}{V_c} = \frac{500}{180} = 2.77$$

$$CMRR = \frac{A_d}{A_c} = \frac{4500}{2.77} = 1624.548$$

$$V_o = A_d V_d\left[1 + \frac{1}{CMRR} \times \frac{V_c}{V_d}\right]$$

$$500 = 4500(200)\left[1 + \frac{1}{CMRR} + \frac{180}{200}\right]$$

$$CMRR = 0.9$$

★ **Features of diff Amplifier:-**

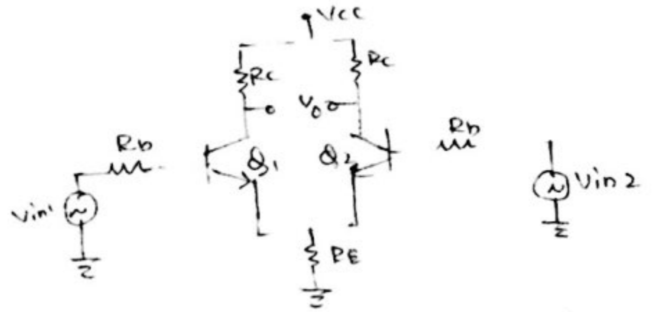
→ High diff voltage gain.
→ Low common mode gain.
→ High CMRR.
→ High i/p impedance
→ low o/p impedance
→ Large B.W. → Low offset voltages & currents

/6/17 **Differential Amp Configuration:-**

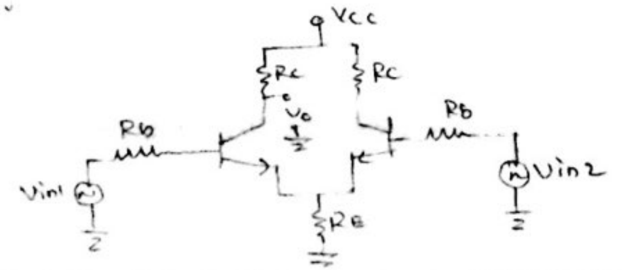
Depending upon how i/p signals are applied and o/p taken the diff amp are classified into 4 types

- Dual i/p balanced o/p
- Dual i/p unbalanced o/p
- Single i/p balanced o/p
- Single i/p unbalanced o/p

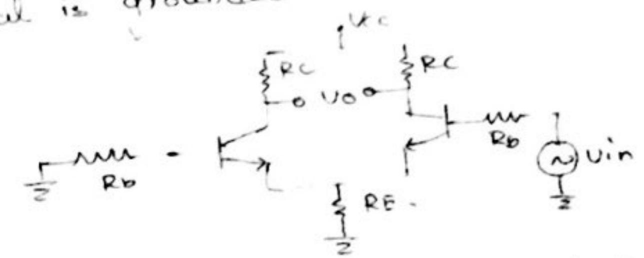
(i) If the i/p is given to two terminals it is called dual i/p and output is taken between 2 collectors it is called dual i/p balanced o/p



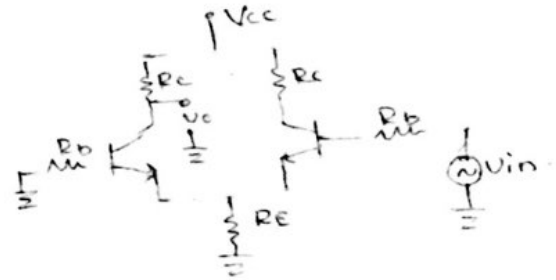
(ii) If in this configuration signal is given to both the i/p terminals and the o/p is taken b/w one collector wrt ground Hence the name dual i/p unbalance o/p



(iii) In this configuration ip is given to only one terminal and the but the i/p is given to only one terminal is grounded.



(iv) In this configuration the o/p is take b/w 1 collector wrt ground and the i/p is given to only one terminal other terminal is grounded



★ **Modes of operation of differential amplifier—**

There are 2 modes of operation for diff amp

(i) Differential mode
(ii) Common mode

In the diff mode 2 unequal i/p signals are applied and their diff is amplified

In the common mode of operation either 2 equal signals are applied & a common signal applied to i/p terminals

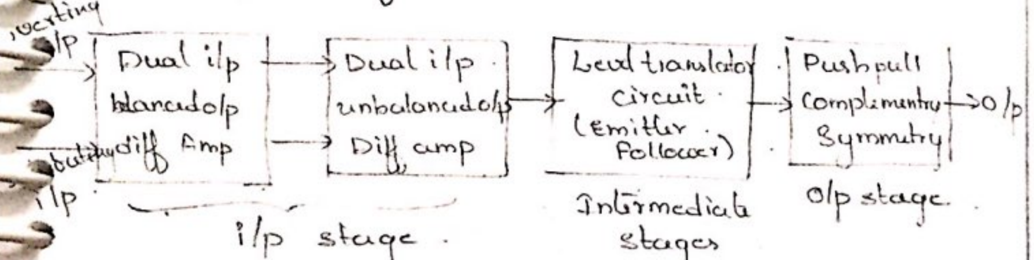
Operational Amplifier:-

The operational amp is a direct coupled high gain amp consisting of one & more diff amp followed by a level translator and an o/p stage.

The operational amp is also called as OP-Amp is a versatile device that can be used to amplify dc as well as AC i/p signals.

∵ The OP-amp is designed for computing mathematical operations like addition, sub, integration, differentiation and for designing log OP-amp and antilog OP-amp.

Block diagram of OP-Amp:-

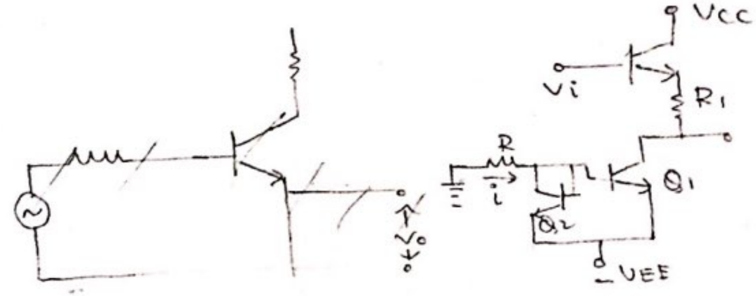


The first two stages are cascaded diff amp. are designed to provide high gain and high i/p resistance. 1st & 2nd stage:- Fig & explanation (before page)

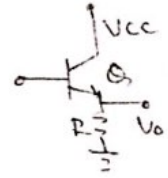
3rd stage:- It acts as a buffer as well as level shifter. the buffer is an emitter follower ckt whose i/p impedance is very high so that is prevents loading of high gain stages the level shifter adjusts the dc voltages wrt ground as the first to stages are direct coupled.

∵ The capacitors occupy large space during IC fabrication we avoid coupling capacitors.

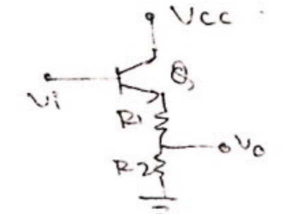
a)



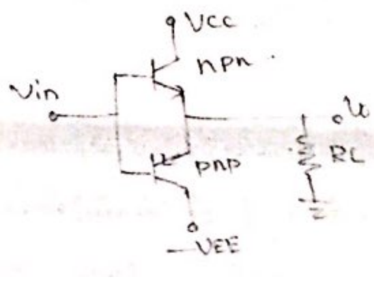
b)



c)

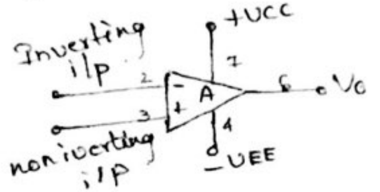


4th stage:- Finally stage is usually a push pull symmetry amp & push pull comp symmetry amp. The o/p stage increases the o/p voltage swing and raise the current supplying capability of op-amp. It also provides low o/p impedance.

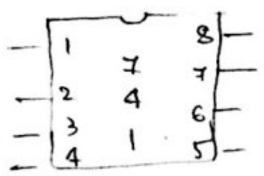


* Symbol of OP-Amp:-

eg:



* Pin diagram of OP-Amp using IC 741:-



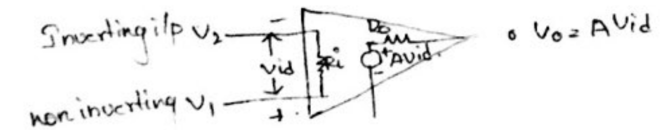
It is an 8 pin DIP

1 -> offset null.
2 -> inverting i/p.
3 -> non inverting i/p.
4 -> -VEE

5 -> offset null
6 -> o/p
7 -> + Vcc
8 -> no connecting

The power supply for OP-Amp 741 are ±15V

1/1/1* OP-Amp Equivalent circuit:-

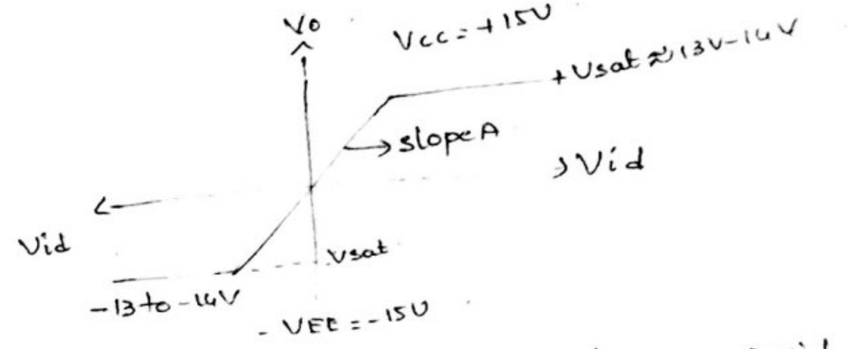


The o/p voltage for op-Amp is $V_o = AVid$

$\Rightarrow A(V_1 - V_2)$

Where A - large signal voltage gain

* OP-Amp ideal Transfer



The graphical representation of $V_o = AVid$ is called voltage transfer curve. Here the o/p voltage Vo is plotted against the i/p diff voltage Vid keeping gain A constant

The o/p voltage cannot exceed +ve and -ve sat voltages.

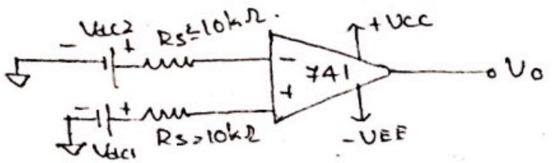
The saturation voltages are specified by volt swing for the given supply voltages this means the o/p voltage is directly proportional to i/p untill it reaches the saturation voltage and there after the o/p voltage remains constant the curve is called ideal voltage transfer curve because the o/p offset voltage of op-Amp is assumed to be zero.

DC & AC characteristics of OP-Amp :-

The DC characteristics of OP-Amp are i/p offset voltage

Input offset voltage :-

The input offset voltage is the voltage that must be applied b/w two i/p terminals of an OP-Amp to null the o/p



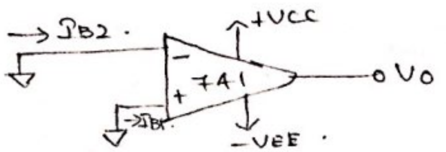
The input offset voltage is represented as V_{io}

$$V_{io} = V_{dc1} - V_{dc2}.$$

For 741 IC The max. value of V_{io} is 6mV.

Input offset current :-

The diff b/w currents into the inverting and non inverting terminals is referred to as.



$$I_{io} = | I_{B1} - I_{B2} |$$

For 741 IC the I_{io} value is 200nA.

Input bias current :- (I_B)

The input bias current is the avg of the currents that flow into the inverting and non inverting terminals of OP-Amp

$$I_B = \frac{I_{B1} + I_{B2}}{2}.$$

Thermal Drift :-

Bias current, offset current and offset voltage changes with the temp. this is called thermal drift and the offset current drift is expressed as nA/°c and offset voltage drift is expressed as mV/°c.

★ AC characteristics :-

Gain band width product :-

It is the B.W of OP Amp when voltage gain is 1. For 741 IC it is 1MHz

Large signal voltage gain :-

The voltage gain of OP-Amp is given by

$A = \frac{V_o}{V_i}$. If $R_L > 2k\Omega$ and $V_o = \pm 10V$ then

$A = 2$ lakhs.

Slew rate :-

It is defined as max. rate of change of o/p voltage per unit of time.

It is expressed in volts/µsec.

$$SR = \frac{dV_o}{dt} \quad V/\mu s$$

For 741 IC SR is 0.5 V/µs.

Supply voltage rejection ratio:-

The change in OP-Amp's i/p offset voltage V_{io} by the variations in supply voltage is called Supply voltage rejection ratio (SURR).

$$SURR = \frac{\Delta V_{io}}{\Delta V}$$

where ΔV - change in supply voltage.

For 741 IC SURR 150 µV/V

Differential input resistance (Ri):-

It is the equivalent resistance that can be measured at either the inverting & non inverting i/p terminal with the other terminal grounded.

For 741 IC Ri is 2MΩ.

Input capacitance:- (Ci)

Equiv. Capacitance that can be measured either at inverting & non inverting terminal with other terminal grounded.

For 741 IC Ci is 1.4 PF

Transient Response:-

The transient response is based on rise time and over shoot.

For 741 IC the rise time is 0.3µs and over shoot is 5%.

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Output Resistance (Ro):- It is the equivalent resistance that can be measured b/w o/p terminal of OP-Amp and ground.

For 741 IC it is 75 Ω

Supply current:- Current drawn by the OP-Amp from power supply (Is).

For 741 IC it is 2.8 mA

Power Consumption:- (Pc) It is the quiescent power (Vin = 0V) that must be consumed by OP-Amp to operate properly.

For 741 IC it is 85mW.

Char	Value For 741	Char	Value for 741
Input offset voltage (Vio)	6mV	Slew rate	SR = 0.5V/µs
Input offset current (Iio)	200nA	Supply voltage rejection ratio	SURR = 150µV
Input bias current	IB = Avg	Diff i/p resistance	Ri = 2MΩ
Thermal Drift	in mV/°C & mA	I/p capacitance	Ci = 1.4PF
Gain Bandwidth product	1MHz.	Transient resp	0.3µs, 5%
Large signal V-gain	A = 2 lakhs.	O/p resistance	75Ω
		Supply current	2.8mA
		Power consumption	[illegible]

Ideal OP-Amp Characteristics :-

The ideal OP-Amp has the following characteristics

- Infinite gain
- Infinite i/p resistance (R_i) so that any signal source can drive it and there is no loading of preceding state.
- Zero o/p resistance.
- Zero o/p voltage when i/p voltage is zero.
- Infinite B.W.
- Infinite CMRR.
- Infinite slew rate.

(1) A non inverting Amp with a gain of 100 is null at 25°C. What will happen to the o/p voltage if temp rises to 50°C for an offset voltage drift of 0.15mV/°C

A = 100 at 25°C o/p = 0

voltage drift = 0.15mV/°C. at ~~25°~~

for 25°C rise

25°C
Per 1°C — Vio — 0.15 mV/°C.
50°C — Vio — (50−20)°C × 0.15 mV/°C

= 3.75mV

$V_{os} = A\,V_{io}$

= 100 × 3.75mV

= 375 mV

(2) The o/p of an OP-amp voltage follower is a Δlar waveform with p-p amp of 6V and T = 0.5 μs for an i/p of square wave with 8V(p-p) amp and 2MHz freq. What is the slew rate of the OP-Amp.

half cycle $SR = \frac{dV_o}{dt} = \frac{6}{0.25\times10^{-6}} = 24V/\mu s$.

here $t = \frac{T}{2}$

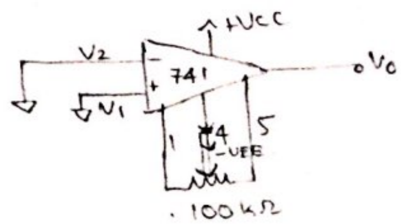
(3) A sq. wave of p-p amp 500mV is to be amplified to a p-p amp of 3V with a rise time of 4μs or less. Can 741 IC be used for amplification.

$SR = \frac{3}{4\mu s} = 0.75V/\mu s$.

∴ For 741 IC. SR max is 0.5 V/μs.

∴ It cannot be used.

*Offset voltage Adjustment Range :-



For 741 IC the pins 1 & 5 are used to null the offset voltage a potentiometer is placed b/w 1 & 5 and wiper of potentiometer is connected to −VEE. As the wiper of potentiometer is changed the o/p offset

voltage can be reduced to 0V

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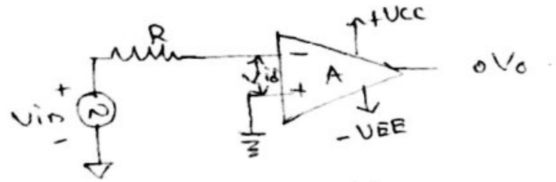
★ Open loop OP-Amp Configurations:-

The OP-Amp is having 3 open loop Config.

i) Inverting Amp
ii) Non-inverting amp
iii) Differential amp

★ Inverting Amp:-



$V_o = AV_{id}$

$= A(V_1 - V_2)$

From above ckt $V_1 = 0, V_2 = V_{in}$

$\Rightarrow \boxed{V_o = -AV_{in}}$

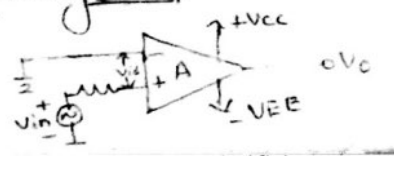
Assume $A = 1$.

$V_o = -V_{in}$

In inverting amps the o/p voltage is 180° out of phase with the i/p voltage.

$\therefore$ Open loop gain $A = -\frac{V_o}{V_{in}}$

★ Non inverting Amp:-



$V_o = AV_{id} = A(V_1 - V_2)$.

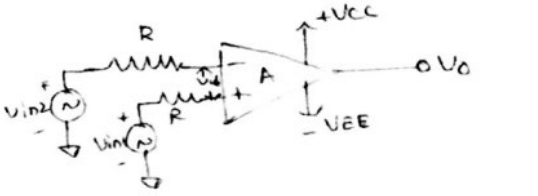
Here $V_1 = V_{in}$, $V_2 = 0$

$\therefore V_o = AV_{in}$

$A = \frac{V_o}{V_{in}}$

For non inverting amp the o/p voltage is in phase with i/p voltage.

★ Differential Amplifier:-



$V_o = AV_{id}$

$= A(V_1 - V_2)$

$V_o = A(V_{in1} - V_{in2})$

$= A \cdot V_d$

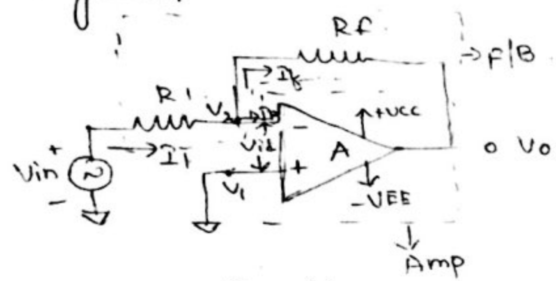
$A = \frac{V_o}{V_d}$

★ Closed loop Configurations:-

In the closed loop configuration a feedback ckt is used along with the OP-Amp. For Amplifier a -ve feedback is used. There are 3 types

(i) Inverting amp with feedback
(ii) Non inverting amp with feedback
(iii) Differential amp with feedback

Inverting Amp:-



$A = \frac{V_o}{V_{id}}$

$A_F = \frac{V_o}{V_{in}}$

By using KCL at node $I_1 = I_B + I_f$ — (1)

∵ OP-Amp is having very high i/p resistance $I_B = 0$ — (2)

$\therefore I_1 = I_f$ — (3)

$\frac{V_{in} - V_2}{R_1} = \frac{V_2 - V_o}{R_F}$ — (4)

Virtual ground:-

$A = \frac{V_o}{V_{id}}$

$A = \infty$ for ideal OP-Amp

$\Rightarrow V_{id} = 0$

$V_1 - V_2 = 0$

$\Rightarrow \boxed{V_1 = V_2}$

But $V_1 = 0$

$\therefore V_2 = 0$ (virtulal ground)

By using virtual ground sub $V_2 = 0$ in (4)

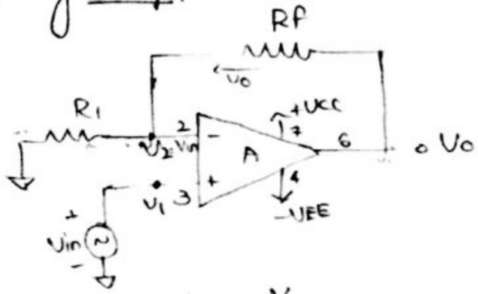
(4) $\Rightarrow \frac{V_{in}}{R_1} = \frac{-V_o}{R_f}$

$$\boxed{A_F = \frac{V_o}{V_{in}} = -\frac{R_f}{R_1}}$$

Virtual ground:- For an ideal OP-Amp gain in ∞ which means the diff of two voltages $V_{id} = 0 \Rightarrow V_1 = V_2$

In inverting amp since $V_1 = 0$ then the node V_2 voltage should also be equal to zero which makes V_2 to act as a ground even though it is not ground. Hence we call it as virtual ground

★ Non inverting Amp:-



$A_F = \frac{V_o}{V_{in}}$

By using voltage divider rule.

$V_{in} = \frac{R_1}{R_1 + R_f} \times V_o$

$A_F = \frac{V_o}{V_{in}} \quad \frac{R_1 + R_f}{R_1}$

$$\boxed{A_F = 1 + \frac{R_F}{R_1}}$$

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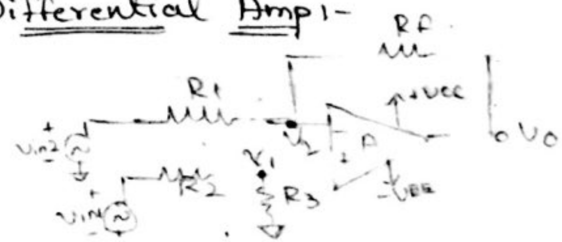
★ Differential Amp:-



$R_1 = R_2 = R_3 = R_f = R$.

By using superposition theorem

$V_o = V_{o1} + V_{o2}$.

If $V_{in2} = 0V$ ~~V_{o1}~~

$V_1 = V_{in1} \times \frac{R_3}{R_2+R_3}$ —(1) (Voltage division rule)

But A_F for non inverting amp is

$1 + \frac{R_F}{R_1}$

$V_{o1} = A_F V_1$

$\therefore V_{o1} = \left(1+\frac{R_F}{R_1}\right) \times \frac{R_3}{R_2+R_3} \times V_{in1}$ —(2)

If $V_{in1} = 0$

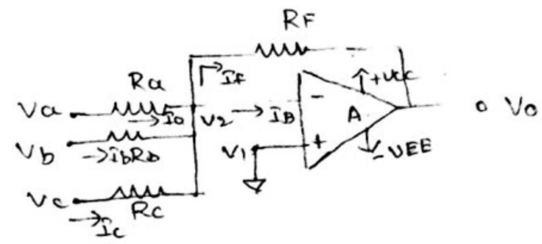
$V_{o2} = \underbrace{-\frac{R_F}{R_1}}_{A_F \text{ for inverting amp}} \times V_{in2}$ —(3)

$V_o = (1+1)\frac{1}{1+1} \times V_{in1} - 1 \times V_{in2}$.

$\boxed{V_o = V_{in1} - V_{in2}}$.

Note:- If all the resistor values $R_1 = R_2 = R_3 = R_F = R$ are same then the diff amp with feed back confi. works as a Subtractor.

Summing, scaling and averaging amp in Inverting configuration:-



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Apply KCL at node V_2

$I_a + I_b + I_c = I_F + I_B$ —(1)

$I_B = 0$ —(2)

We get $I_a + I_b + I_c = I_F$.

$\frac{V_a - V_2}{R_a} + \frac{V_b - V_2}{R_b} + \frac{V_c - V_2}{R_c} = \frac{V_2 - V_o}{R_F}$ —(3)

From virtual ground concept $\because V_1 = 0$

$\Rightarrow V_2 = 0$

(3) $\Rightarrow \frac{V_a}{R_a} + \frac{V_b}{R_b} + \frac{V_c}{R_c} = \frac{-V_o}{R_F}$.

$V_o = -R_F\left(\frac{V_a}{R_a} + \frac{V_b}{R_b} + \frac{V_c}{R_c}\right)$ —(4)

Case(i):- If $R_a = R_b = R_c = R_F = R$.

(4) $\Rightarrow V_o = -(V_a + V_b + V_c) \rightarrow$ Summing amp / Adder

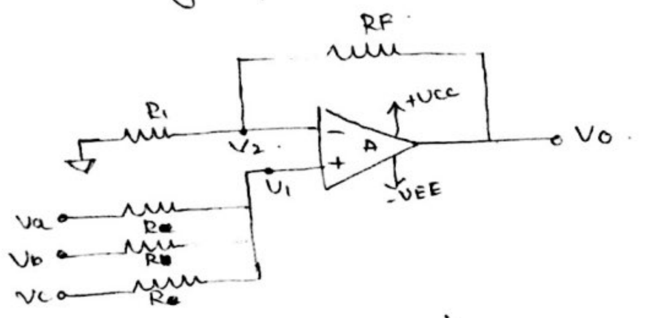
Case(ii):- If all resistances are diff

(4) $\Rightarrow V_o = -\left(\frac{R_F}{R_a}V_a + \frac{R_F}{R_b}V_b + \frac{R_F}{R_c}V_c\right) \rightarrow$ Scaling / weighing amp

Case (iii) :- If $R_a = R_b = R_c = \frac{n R_F}{}$ $\rightarrow n = 3$

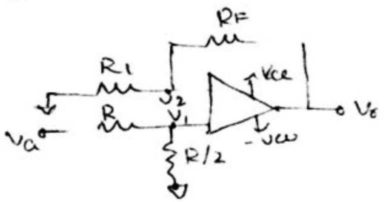
(i) $\Rightarrow V_o = -\left(\frac{V_a + V_b + V_c}{3}\right)$ - averaging amp

Summing, Scaling and averaging amp using non-inverting amp :-



$\Rightarrow V_o = \left(1 + \frac{R_F}{R_1}\right) V_1$

$V_{a1} = V_a \times \frac{R/2}{R + R/2}$



||ly for V_{b1} & V_{c1}.

By using superposition theorem

$$V_1 = V_a \times \frac{R/2}{R + R/2} + V_b \times \frac{R/2}{R + R/2} + V_c \times \frac{R/2}{R + R/2} \quad \text{— (1)}$$

For non inverting configuration $V_o = \left(1 + \frac{R_F}{R_1}\right) V_1$

$$\Rightarrow V_o = \left(1 + \frac{R_F}{R_1}\right) \left(\frac{R/2}{R + R/2}\right) (V_a + V_b + V_c) \quad \text{— (a)}$$

$$V_o = \frac{1}{3}\left(1 + \frac{R_F}{R_1}\right)(V_a + V_b + V_c) \quad \text{— (2)}$$

Case (i) :- If $R_F = 2R_1$ then

$V_o = V_a + V_b + V_c$ $\rightarrow$ Adder

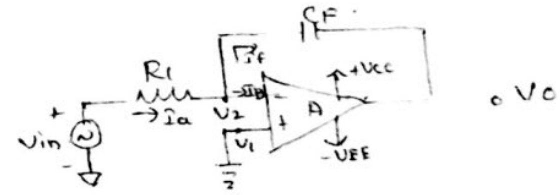
Case (ii) :- If $R_F = R_1$ then

$V_o = \frac{2}{3}(V_a + V_b + V_c)$ $\rightarrow$ scaling

Case (iii) :- If gain is unity of non inverting amp

$V_o = \frac{V_a + V_b + V_c}{3}$ $\rightarrow$ Averaging amp.

★ Integrator :-



Apply KCL at node V_2

$\Rightarrow I_a = I_F + I_B$ $\qquad I_B = 0$

$\Rightarrow \frac{V_{in} - V_2}{R_1} = \frac{d(V_2 - V_o)}{dt} C_F$

From virtual ground $V_2 = 0$

$$\frac{V_{in}}{R_1} = -C_F \frac{dV_o}{dt}$$

$$\boxed{V_o = -\frac{1}{R_1 C_F} \int V_{in}\, dt} \quad \text{— (1)}$$

It is used as a wave shaping ckt, waveform generator and in ADC

$$f = \frac{1}{2\pi R_1 C_F}$$

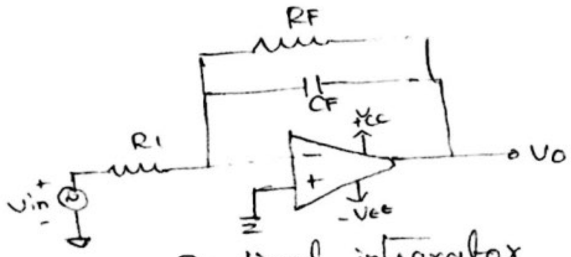
3/7/17 The For (1) Apply L.T

$$V_o(s) = \frac{-1}{R_1 C_F} \cdot \frac{V_{in}(s)}{s}$$

$$\text{gain} = \frac{V_o(s)}{V_{in}(s)} = \frac{-1}{R_1 C_F j\omega} = \frac{-1}{R_1 C_F j 2\pi f}$$

$$A = \frac{-1}{2\pi j f R_1 C_F}$$

At low frequencies the integrator ckt acts as a open loop ckt hence gain becomes ∞ which decreases the stability. Hence in practical a resistor R_F is placed capacitor C_F.



Practical integrator

1) If the i/p voltage for the integrator is a step voltage with $V_i = 1V$; $0 \le t \le 0.3ms$ then find the o/p voltage. $R_1 = 10k\Omega$, $R_F = 100k\Omega$, $C_F = 10nF$

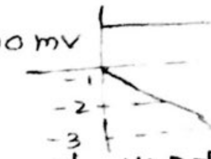
X_F 100 kgion

$$V_o = \frac{-1}{10\times10^3 \times 10\times10^{-9}} \int_0^{0.1} 1\, dt$$

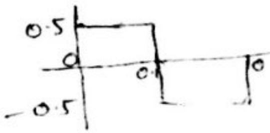
$$V_o = -1000\, mV = -1V$$

$$V_o = \frac{-1}{100\times10^{-6}} \int_0^{0.2} 1\, dt = -2000\, mV = -2V$$

$$V_o = \frac{-1}{100\times10^{-6}} \int_0^{0.3} 1\, dt = -3000\, mV = -3V$$



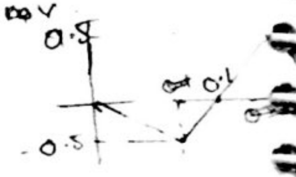
(2) For the above prob i/p is a sq. wave of 1V p-p freq of 5kHz. $t = 0.2ms$



$$V_o = \frac{-1}{10^{-4}} \int_0^{0.05} 1\, dt$$

$$= -\frac{0.05}{10^{-4}} = -10^3 mV = -1V$$

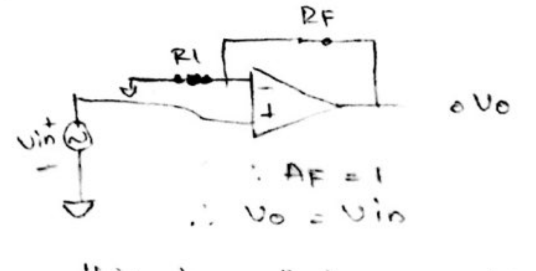
$$V_o = -\left(\frac{-1}{10^{-4}} \int_{0.1}^{0.2} 1\, dt\right) = +1V$$



(3) For a non inverting amp. the gain should be unity design a ckt for this consideration.

$$A_F = 1 + \frac{R_F}{R_1}$$

R_F - shorted , R_1 - open.



$\therefore A_F = 1$

$\therefore V_o = V_{in}$

this is called as voltage follower.

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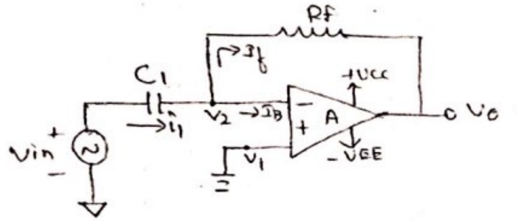
Differentiator:-



Applying KCL at node V_2.

$$i_1 = I_B + I_f \qquad I_B = 0$$

$$C_1 \frac{d(V_{in} - V_2)}{dt} = \frac{V_2 - V_0}{R_F}$$

From virtual ground concept $V_2 = 0$.

$$C_1 \frac{d(V_{in})}{dt} = \frac{-V_0}{R_F}$$

$$\boxed{V_0 = -C_1 R_F \frac{dV_{in}}{dt}} \quad -(1)$$

Applying L.T for (1).

$$V_0(s) = -C_1 R_F [V_{in}(s)] s$$

$$= -C_1 R_F j\omega [V_{in}(s)]$$

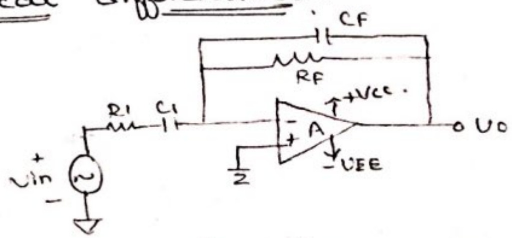
$$V_0(s) = -C_1 R_F j 2\pi f \, V_{in}(s)$$

$$A = \frac{V_0(s)}{V_{in}(s)} = -C_1 R_F 2\pi j f$$

As freq ↑ gain ↑ so it is called as highpass filter.

As the frequency increases the gain increases as 20 dB / decade which causes instability of the ckt and also the impedance of the capacitor decreases with increase in frequency. Hence for a practical diff a resistor R_1 is added across i/p and capacitor C_F is placed in the feed back ckt.

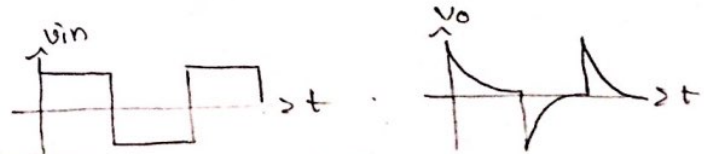
Practical differentiator:-



$$f = \frac{1}{2\pi C_1 R_F}$$

If the i/p for diff is sine wave the o/p is Cosine

If i/p for diff is a square waveform then at $RC \neq t$ we get spikes as an o/p.



① Find the o/p for a differentiator with $f = 100Hz$, $C_1 = 0.1\mu F$ for a sine wave of 1V peak

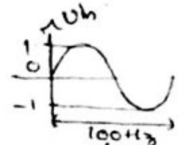
$$f = \frac{1}{2\pi C_1 R_F}$$

$$R_F = \frac{1}{2\pi \, 0.1\times10^{-6}\times 100} = 15.9\,k\Omega$$

$\sin 2\pi f t$

$\sin 200\pi t$

$$V_o = -C_1 R_F \frac{dV_{in}}{dt}$$

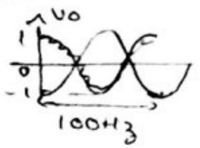


$$= -0.1\times10^{-6}\times 15.9\times10^{3} \frac{d}{dt}\sin 200\pi t$$

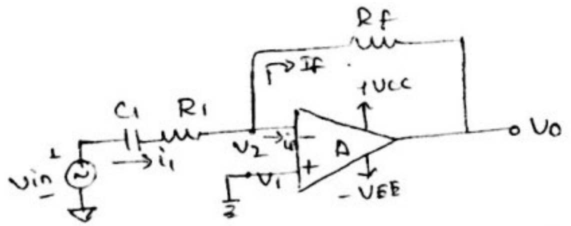
$$= -0.0016 \times 200\pi \cos 200\pi t$$

$$= -0.99 \cos 200\pi t$$

$$\simeq -1 \cos 200\pi t$$



★ AC Amplifier:-



Inverting AC amplifier

Apply KCL at node V_2

$$i_1 = i_B + i_F \qquad i_B = 0$$

$$C_1 \frac{d(V_{in}-V_2)}{dt} + \frac{(V_{in}-V_2)}{R_1} = \frac{V_2 - V_o}{R_F}$$

$$V_2 = 0$$

$$C_1 \frac{dV_{in}}{dt} + \frac{V_{in}}{R_1} = \frac{-V_o}{R_F}$$

Apply L.T

$$C_1 s V_{in}(s) + \frac{V_{in}(s)}{R_1} = \frac{-V_o(s)}{R_F}$$

$$\left(C_1 j\omega + \frac{1}{R_1}\right)V_{in}(s) = \frac{-V_o(s)}{R_F}$$

$$\frac{V_o(s)}{V_{in}(s)} = -\left(C_1 s + \frac{1}{R_1}\right)R_F$$

$$= \frac{-R_F}{R_1}\left[1 + sC_1R_1\right]$$

$$\left(R + \frac{1}{sC_1}\right) I_1 = I_F \Rightarrow \frac{V_{in} - V_2}{\left(R + \frac{1}{sC_1}\right)} = \frac{V_2 - V_o}{R_F}$$

$$\frac{V_{in}}{R + \frac{1}{sC_1}} = \frac{-V_o}{R_F}$$

$$\Rightarrow V_o = -R_F V_{in} \Big/ \left(R + \frac{1}{sC_1}\right)$$

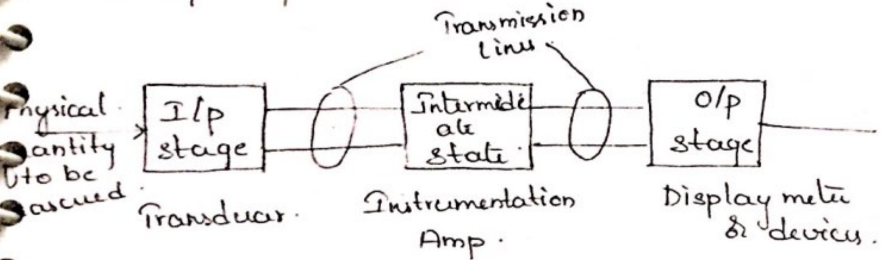
$$A = -R_F \Big/ \left(R + \frac{1}{sC_1}\right)$$

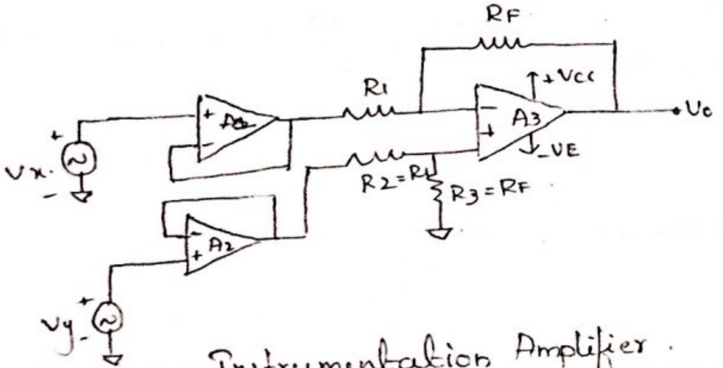
$$\boxed{A = \frac{-R_F}{R} \times \frac{1}{1 + \frac{1}{sC_1R}}}$$

10/7/17 **Instrumentation Amplifier:-**

In a no. of industrial and consumer applica- there is need to measure and control physical q- -ties, such as control of temp, measuring of l- intensity, water flow etc. These physical quantities are measured with the help of transducer. Transducer is a device that converts one form of energy into another. The o/p of the transducer has to be amplified so that it can drive the indicator & display system. This function is performed by an instrumentation amp. The features of instrumentation amp. are.

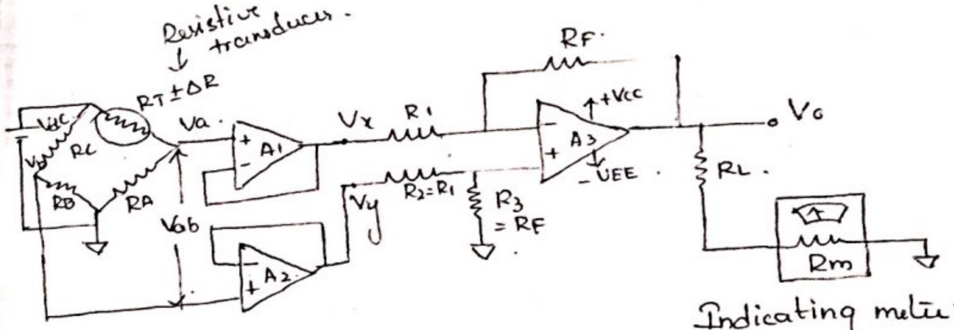
- high gain accuracy.
- high CMRR.
- high gain stability with low temp coeff
- Low dc offset voltage.
- Low o/p impedance.





Instrumentation Amplifier.

* Instrumentation Amp using transducer bridge:-



Indicating meter.

In the above ckt a resistive transducer i.e., the resistance changes as a function changes of some physical energy is connected in one arm of the bridge with a small circle around it.

Where R_T is resistance of transducer and ΔR is change in resistance.

For a balance bridge i.e, no change in R_T value then

$$V_a = V_b.$$

$$\Rightarrow V_{dc} \cdot \frac{R_A}{R_A + R_T} = V_{dc} \cdot \frac{R_B}{R_B + R_C}$$

$$\Rightarrow \boxed{\frac{R_A}{R_T} = \frac{R_B}{R_C}}$$

if Va & Vb voltages are given to OP-Amp A3 then $V_o = -\frac{R_F}{R_1} V_{ab}$ — (1)

has to be amplified so that it can drive the indicator & display system. This function is performed by an instrumentation amp. The features of instrumentation amp. are.

- → high gain accuracy.
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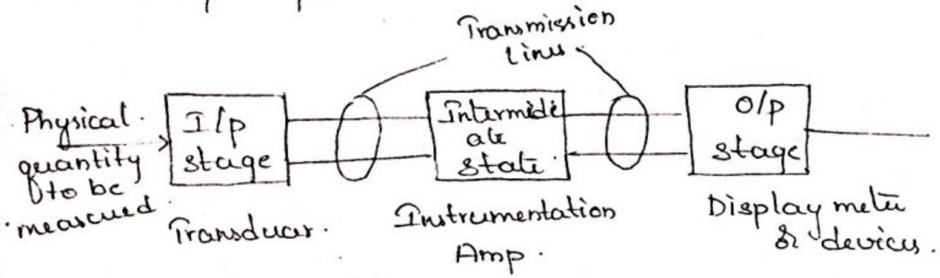
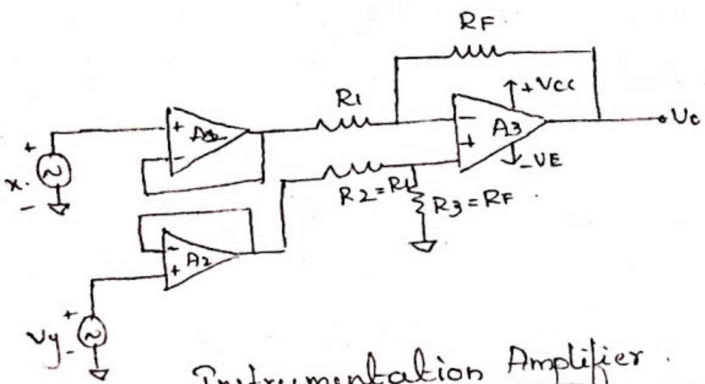
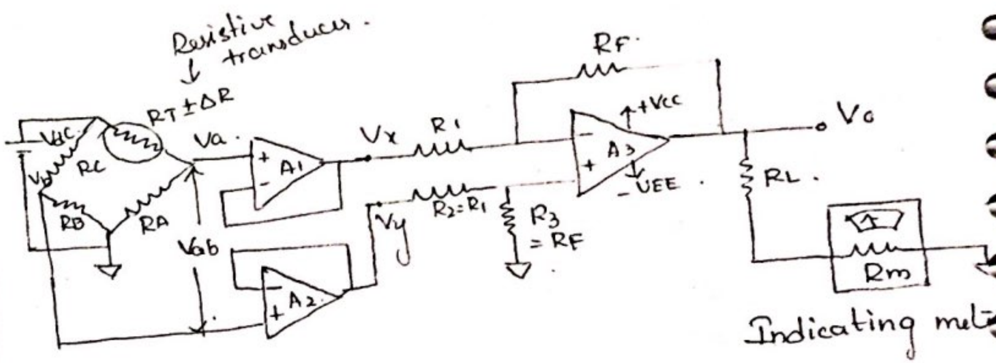




Instrumentation Amplifier.

* Instrumentation Amp using transducer bridge:-



In the above ckt a resistive transducer i.e, the resistance changes as a function change of some physical energy is connected in one arm of the bridge with a small circle around it.

When R_T is resistance of transducer and ΔR is change in resistance.

For a balance bridge i.e, no change in R_T value then

$$V_a = V_b.$$

$$\Rightarrow V_{dc} \cdot \frac{R_A}{R_A + R_T} = V_{dc} \cdot \frac{R_B}{R_B + R_C}$$

$$\Rightarrow \boxed{\frac{R_A}{R_T} = \frac{R_B}{R_C}}$$

if Va & Vb voltages are given to OP-Amp A_3 then $V_o = -\frac{R_F}{R_1} V_{ab}$ — (1)

If there is a change in resistance due to some then $V_{ab} = V_a - V_b$.

$$V_a = \frac{R_A}{R_A+R_T \pm \Delta R} V_{dc} \qquad V_b = \frac{R_B}{R_B+R_C} \times V_{dc}$$

$$V_{ab} = \left(\frac{R_A}{R_A+R_T \pm \Delta R} - \frac{R_B}{R_B+R_C}\right) V_{dc}$$

If $R_A = R_B = R_C = R_T = R$. then.

$$V_{ab} = \left(\frac{R}{2R \pm \Delta R} - \frac{R}{2R}\right) V_{dc}$$

$$= \frac{\cancel{2}R^2 - (\cancel{2}R^2 \pm \Delta R \cdot R)}{2R(2R \pm \Delta R)} V_{dc}$$

$$= \frac{\mp \Delta R \cdot R}{4R^2 \pm \Delta R} V_{dc}$$

$$V_{ab} = \frac{\mp \Delta R}{2(2R \pm \Delta R)} \times V_{dc}$$

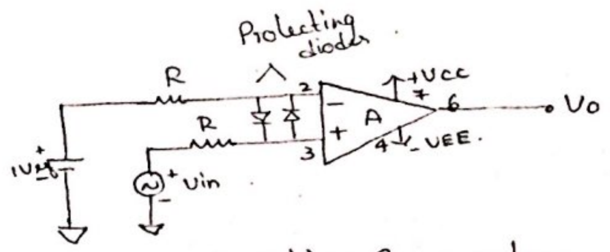
$$V_o = \frac{-R_F}{R_1} \times V_{ab}$$

$$V_o = \frac{R_F}{R_1} \times \frac{\pm \Delta R}{2(2R \pm \Delta R)} V_{dc}$$

Change in resistance value of transducer is very small i.e., $2R \pm \Delta R \approx 2R$.

$$\therefore \boxed{V_o = \frac{R_F}{R_1} \frac{\pm \Delta R}{2(2R)} V_{dc}}$$ this eq. indicates V_o is $\propto \Delta R$ of the transducer $\because \Delta R$ is caused by a change in physical energy the meter connected at the o/p can be callibrated

20/7/17 Comparator :-

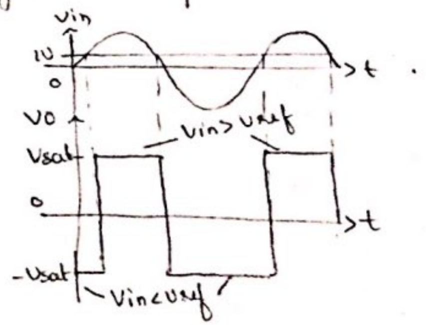


non-inverting Comparator.

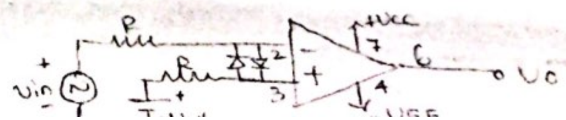
A comparator as its name implies compares a signal voltage on one i/p of an op-Amp with any known voltage Vref on another i/p

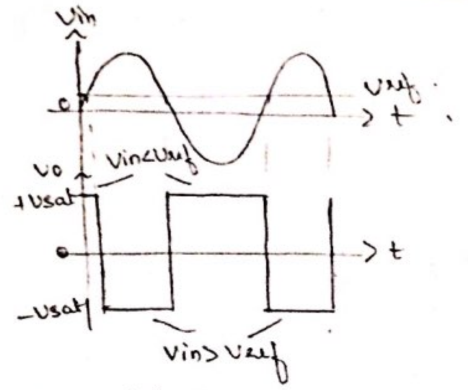
It operates in open loop configuration. Hence the o/p will be +Vsat & -Vsat.

Comparator ckts are used in digital interphasing, Schmitt trigger, voltage level detector etc..



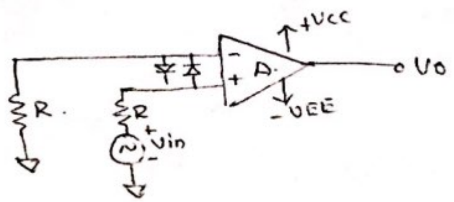
★ Inverting Comparator :-

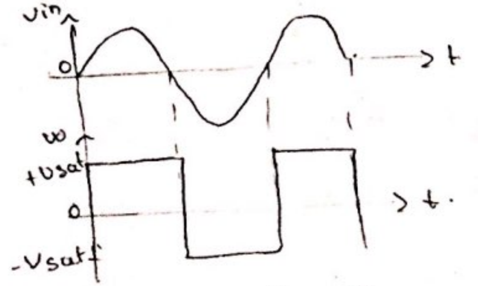




* Zero crossing detector :-

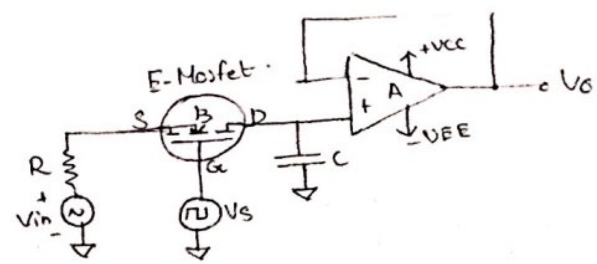
An application of comparator is zero crossing detector & sine wave to square wave converter.

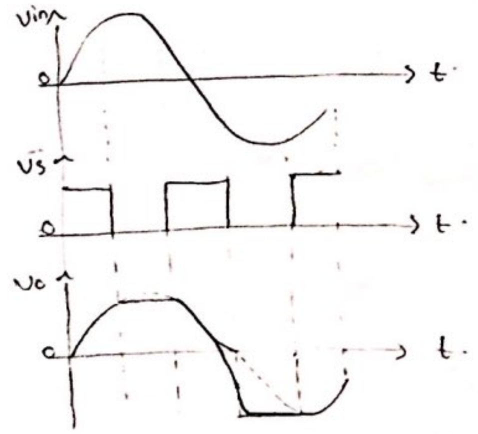




* Sample and Hold circuit

The sample & hold ckt as its name implies samples an i/p signal and holds on its last sampled value untill the i/p is sampled again. In this ckt the E-MOSFET works as a switch controled by Vs.

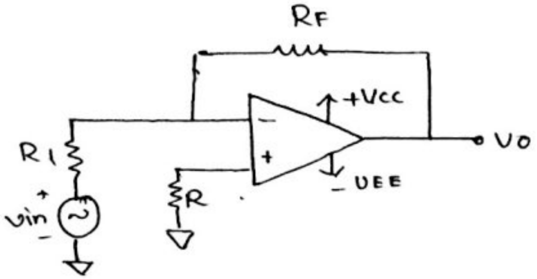




And the capacitor C as a storage element. The i/p voltage Vin is applied to Source and Vs is applied to gate of the MOSFET. During the +ve part of Vs the E-MOSFET conducts and acts as a switch which allows 'c' to be charged and the o/p appear same as the i/p since the OP-Amp is in voltage follower mode. When Vs = 0 MOSFET is off and acts as an open switch the only discharge path for C is OP-Amp but the i/p resistance of the OP-Amp is very high hence voltage across 'c' is retained. When Vs = 0 ...

Then MOSFET is ON, o/p voltage can be obtained. The time period T_S during which the voltage across 'C' are equal to i/p voltage are called sample period. The time period T_H during which the voltage across 'C' is constant is called hold period.

I to V Convertor :-

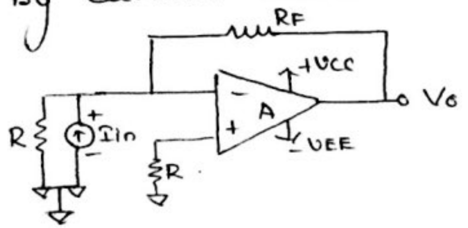


$$V_o = \frac{-R_F}{R_1} \times V_{in}$$

$$= -R_F \times \left(\frac{V_{in}}{R_1}\right)$$

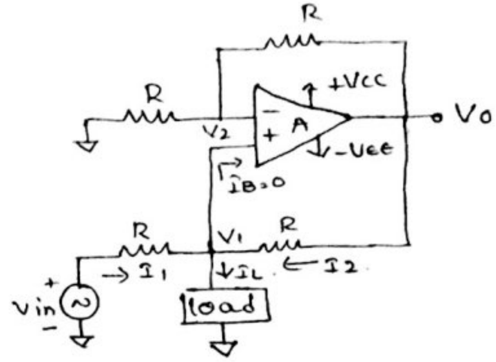
$$= -R_F \times I_{in}$$

Wkt, for inverting amp. If the voltage $\frac{V_{in}}{R_1}$ is replaced by current source then $V_o \propto I_{in}$.



Hence, it is called as current to voltage convertor.

★ V to I Convertor :-



Apply KCL at node 1

$\Rightarrow I_1 + I_2 = I_L$

$\Rightarrow \frac{V_{in} - V_1}{R} + \frac{V_o - V_1}{R} = I_L$

$$\boxed{V_o = 1 + \frac{R_F}{R_1} \times V_1}$$

$\Rightarrow V_{in} + V_o - 2V_1 = I_L R$

$\Rightarrow V_1 = \frac{-I_L R + V_{in} + V_o}{2}$

$$V_o = \left(1 + \frac{R_F}{R_1}\right) \times \frac{V_{in} + V_o - I_L R}{2}$$

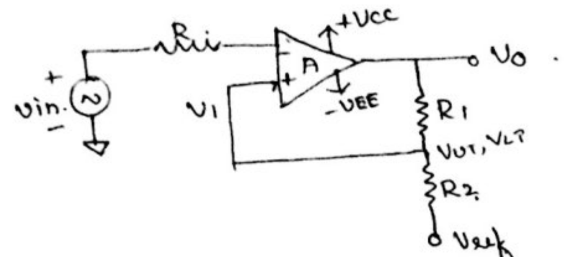
$$V_o = \left(1 + \frac{R}{R}\right)\left(\frac{V_{in} + V_o - I_L R}{2}\right)$$

$$\boxed{I_L = \frac{V_{in}}{R}}$$

$V_{in} - V_1 + V_o = 0$

$V_1 =$

14/4/17 ## Schmitt trigger:-



A schmitt trigger is also known as regenerative comparator. And it converts any irregular shape wave into square wave. For the schmitt trigger the loop gain $A\beta$ is considered > 1

The i/p voltage Vin triggers (changes the state) the o/p Vo every time it exceeds certain voltages called upper threshold & lower threshold. These threshold voltages are obtained by voltage divider ckt R1 & R2. If $V_o = +V_{sat}$ the voltage across R1 is called upper threshold voltage.

$$V_{UT} = V_{sat} \cdot \frac{R_2}{R_1+R_2} + V_{ref} \frac{R_1}{R_1+R_2} \quad (1)$$

When the i/p voltage vin becomes more than V_{UT} the o/p triggers from $+V_{sat}$ to $-V_{sat}$ then the voltage across R_1 is called lower threshold voltage when Vin becomes more -ve than V_{LT} then the o/p triggers from $-V_{sat}$ to $+V_{sat}$

$$V_{LT} = V_{ref} \frac{R_1}{R_1+R_2} - V_{sat} \frac{R_2}{R_1+R_2} \quad (2)$$

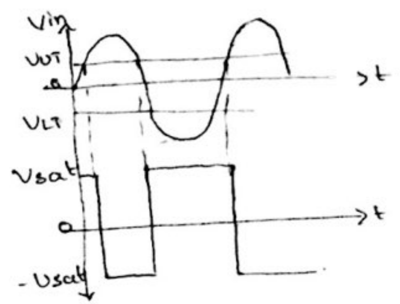
Because of the +ve feedback the ckt will switch faster from $+V_{sat}$ to $-V_{sat}$ and viceversa.

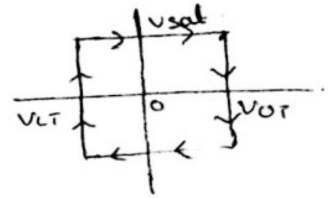
The hysteresis voltage is diff b/w V_{UT} & V_{LT}

$$\therefore V_H = V_{UT} - V_{LT}$$

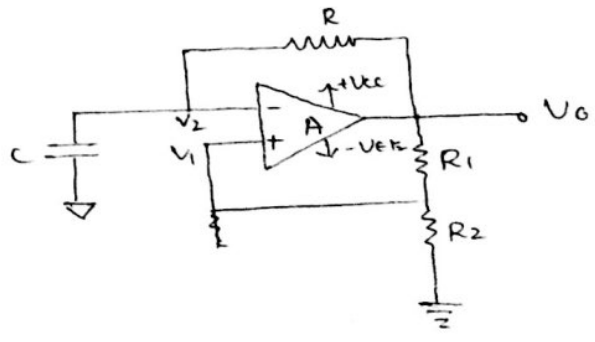
From (1) & (2)

$$V_H = \frac{2 V_{sat} R_2}{R_1 + R_2}$$





* ## Astable Multivibrator:-



The astable multivibrator is also known as free running (or) square wave generator. The square wave o/p are generated when the OP-Amp is forced to operate in saturation region.

The o/p of OP-Amp in this ckt will be +Vsat or -Vsat depending on d/f voltage Vid.

Initially because of offset voltage at non inverting terminal let $v_0 = +V_{sat}$ then voltage at $v_1 = \frac{R_2 V_0}{R_1+R_2}$

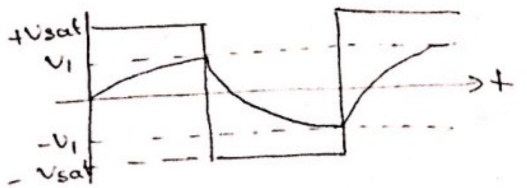
let $\frac{R_2}{R_1+R_2} = \beta$, $V_0 = V_{sat}$.

$$V_1 = \beta V_0$$

then through the resistor R the capacitor starts charging the voltage across the c appears at V_2. When the capacitor charges more than V_1 i.e., $V_2 > V_1$ then the o/p changes from +Vsat to -Vsat then the voltage at $V_1 = V_0\beta$. then the voltage across C starts discharging when the voltage becomes more -ve than V_1 then the o/p changes from -Vsat to +Vsat.

The time period of wave form that is generated from the ckt is obtained by using voltage across the capacitor wrt time period.

4/7/18



The voltage across capacitor

$$V_c = V_f + (V_i - V_f)\, e^{-t/RC} \quad \text{—} ①$$

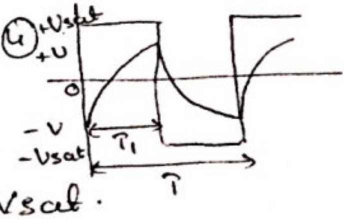
$V_f = +V_{sat}$, $V_{in} = -\beta V_{sat}$ — ②

Sub ② in ①

$$V_c = V_{sat} + (-\beta V_{sat} - V_{sat})\, e^{-t/RC}$$

$$= V_{sat} - (1+\beta) V_{sat}\, e^{-t/RC}$$

$$\boxed{V_c = V_{sat} - (1+\beta) V_{sat}\, e^{-t/RC}} \quad \text{—} ③$$



At $t = T_1$ $V_c(t) = +\beta V_{sat}$ — ④

Sub ④ in ③.

$\Rightarrow \beta V_{sat} = -(1+\beta) V_{sat}\, e^{-T_1/RC} + V_{sat}$.

$\Rightarrow$ $\frac{1-\beta}{1+\beta} = e^{-T_1/RC}$.

$\Rightarrow$ $T_1 = RC \ln\left(\frac{1+\beta}{1-\beta}\right)$.

$\Rightarrow$ $T = 2T_1$

$\Rightarrow$ $T = 2RC \ln\left(\frac{1+\beta}{1-\beta}\right)$ — ⑤

Wkt $\beta = \frac{R_2}{R_1+R_2}$. — ⑥

Sub ⑥ in ⑤

$\Rightarrow$ $T = 2RC \ln\left(1 + \frac{2R_2}{R_1}\right)$.

$\frac{R_1+2R_2}{R_1}$

$1 + \frac{2R_2}{R_1}$

1.16R

if $R_2 = R_1$

$\Rightarrow$ $T = 2RC \ln(3)$.

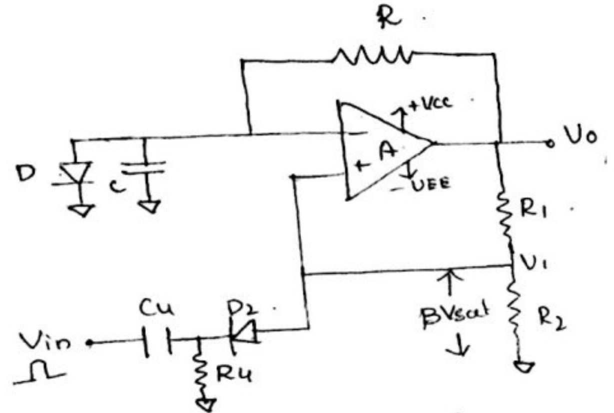
$$\boxed{T = 2.197\, RC}$$

If $R_1 = 1.16 R_2$ then

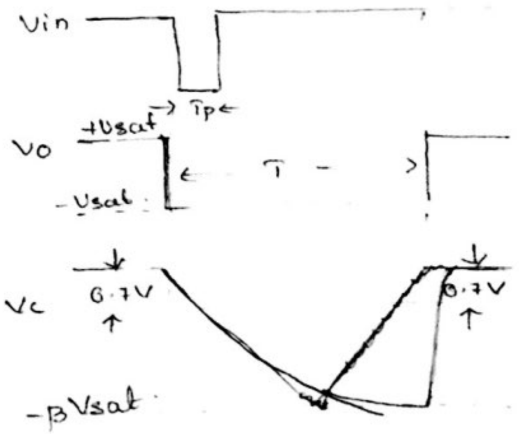
$$\boxed{T = 2RC}$$

$$\Rightarrow f = \frac{1}{2RC}$$

* Monostable Multivibrator :-



26/7/14 Monostable multivibrator has 1 stable state and the other is quasi stable state. The ckt is useful for generating single o/p pulse of adjustable time duration in response to a triggering signal. The width of the o/p pulse depends only on the external components connected to OP-Amp. The ckt of M.S.M. is a modified form of ASM. So this ckt consists of a diode D_1 clamped across the capacitor and for triggering the differentiator the diode D_2 produces a -ve going triggering impulse. Initially assume that ckt is at stable state i.e., $V_o = +V_{sat}$ then voltage at $V_1 = +\beta V_{sat}$ where $\beta = R_2/R_1+R_2$. The capacitor starts charging to +0.7V as the diode is in F.B as this voltage is less than the voltage at V_1 the ckt will be in the same state. A triggering pulse is applied such that the voltage at the terminal is less than 0.7V then the o/p switches from +Vsat to -Vsat and D_1 gets R.B. Hence the capacitor C starts charging exponentially upto $-\beta V_{sat}$ as the capacitor voltage becomes more -ve than $-\beta V_{sat}$ then V_{id} is +ve hence the o/p switches back to +Vsat. Now the capacitor voltage is clamped at 0.7V and stays in the state until trigger pulse applied again.



The voltage across the capacitor

$$V_c(t) = V_f + (V_i - V_f)\, e^{-t/RC} \quad \text{--- (1)}$$

$V_f = -\beta V_{sat}$, $V_i = V_D$

$V_C(t) = -\beta V_{sat} + (V_D + \beta V_{sat}) e^{-t/RC}$.

$= \beta V_{sat}(e^{-t/RC} - 1) + V_D e^{-t/RC}$ — (3)

at $t = T$, $V_C(t) = -\beta V_{sat}$ — (4)

sub (4) in (3)

$\Rightarrow -\beta V_{sat} = \beta V_{sat}(e^{-t/RC} - 1) + V_D e^{-t/RC}$

$\Rightarrow \cancel{V} = \cancel{V} e^{-t/RC} - V_D e^{-t/RC}$

$\Rightarrow \cancel{(1 + V_D)} = \cancel{e^{-RC/t}}$

$\Rightarrow -\beta V_{sat} = V_{sat}(e^{-t/RC} - 1) + V_D e^{-t/RC}$.

$\Rightarrow -\beta V_{sat} + V_{sat} = V_{sat} e^{-t/RC} + V_D e^{-t/RC}$

$\Rightarrow V_{sat}(1-\beta) = e^{-t/RC}(V_{sat} + V_D)$

$\Rightarrow \dfrac{V_{sat}(1-\beta)}{V_{sat} + V_D} = e^{-t/RC}$.

$\Rightarrow \dfrac{1-\beta}{1 + \frac{V_D}{V_{sat}}} = e^{-t/RC}$.

$\Rightarrow \dfrac{1 + \frac{V_D}{V_{sat}}}{1-\beta} = e^{t/RC}$.

$\Rightarrow \dfrac{t}{RC} = \ln\left(\dfrac{1 + \frac{V_D}{V_{sat}}}{1-\beta}\right)$

$\Rightarrow \boxed{t = RC \ln\left(\dfrac{1 + \frac{V_D}{V_{sat}}}{1-\beta}\right)}$ — (5)

wkt $\beta = \dfrac{R_2}{R_1 + R_2}$

let $R_1 = R_2$ & $V_D << V_{sat}$

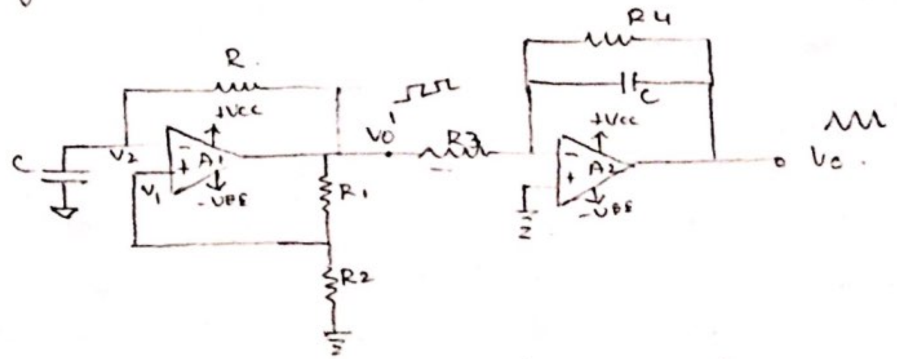
$\Rightarrow t = RC \ln\left(\dfrac{1}{1 - \frac{1}{2}}\right)$

$\boxed{t = 0.69\, RC}$

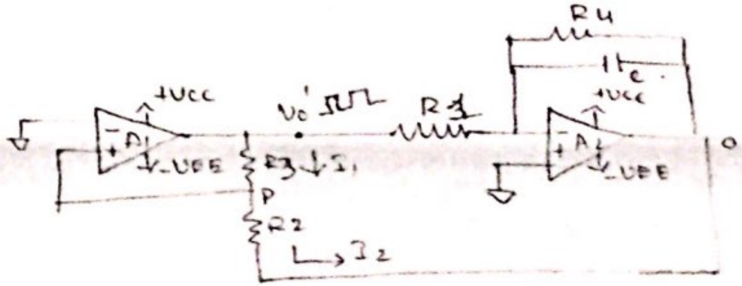
$\dfrac{-V_{sat}}{V_{sat}}$.

* Triangular wave generator :-

The triangular wave can be obtained by using astable multivibrator & integrator.



A triangular wave generator can also be designe using comparator and an integrator. Comparator is used as it is simple and less no. of components compared to astable multivibrator.

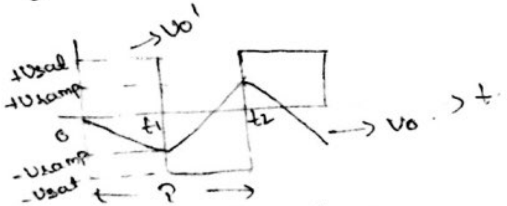


Scanned by CamScanner

7/7/17 The ckt consists of comparator A_1 and an integrator A_2. The comparator A_1 compares the voltage V at P continously with inverting i/p 0V. When the voltage at P goes slightly above & below 0V the o/p of A_1 is at -ve & +ve saturation level resp.

Initially let o/p of A_1 is +Vsat which is given as i/p to A_2. Then o/p of A_2 is -ve going ramp. The voltage divider ckt R_1 & R_2 has +Vsat of A_1 at one end and -Vramp of A_2 at another end and at certain value of -Vramp point P becomes slightly below 0V. Hence o/p of A_1 will switch from +Vsat to -Vsat then o/p of A_2 is +ve going ramp + Vramp then at certain value at +Vramp the point P becomes slightly above 0V. Hence the o/p of A_1 switches from -Vsat to +Vsat the sequence repeats.

The frequency of square wave & Δlar wave are same. The amp of sq. wave is constant but the amp of Δlar wave decreases as freq increases



Apply KCL at node P

$$I_1 = I_2$$

$$A_1 = V_{sat}, \quad A_2 = -V_{ramp}$$

at P = 0, $\frac{+V_{sat}}{R_3} = \frac{-V_{ramp}}{R_2}$

$$-V_{ramp} = -\frac{R_2}{R_3} V_{sat} \quad \text{—} (1)$$

11^{ly} when $A_1 = -V_{sat}$, $A_2 = +V_{ramp}$

$$I_1 = I_2$$

$$\frac{V_{o1}}{R_3} = \frac{V_o}{R_2}$$

$$-\frac{V_{sat}}{R_3} = \frac{V_{ramp}}{R_2}$$

$$V_{ramp} = -\frac{R_2}{R_3} V_{sat} \quad \text{—} (2)$$

$$V_o(PP) = +V_{ramp} - (-V_{ramp})$$

$$= -\frac{R_2}{R_3} V_{sat} - \frac{R_2}{R_3} V_{sat}$$

$$V_o(PP) = \frac{2R_2}{R_3} V_{sat} \quad \text{—} (3)$$

The time the o/p waveform swings from -Vramp to +Vramp is equal to half the time period T i.e., $\frac{T}{2}$ this time period can be calculated from integrator o/p eq. i.e., when $V_i = -V_{sat}$, $V_o = V_o(P\text{-}P)$

Hence $V_o(P\text{-}P) = \frac{-1}{R_1C_1}\int_0^{T/2} -V_{sat}\, dt$

$$= \frac{+1}{R_{f1}} \frac{V_{sat}}{1} \frac{T}{2} \quad \text{—} (4)$$

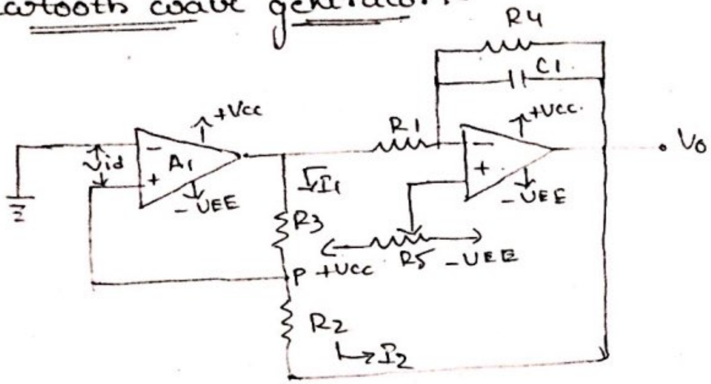
Sub eq (3) in (4)

$$\Rightarrow \frac{2R_2}{R_3} V_{sat} = \frac{V_{sat}}{R_{f1}} \frac{T}{2}$$

$$T = \frac{4R_1R_2C_1}{R_3}$$

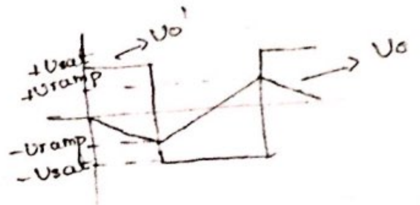
$$f = \frac{1}{T} = \frac{R_3}{4R_1R_2C_1}$$

Sawtooth wave generator:-



For a triangular wave the rise time and fall time are equal i.e., the time taken to swing from +Vramp to -Vramp is equal to that of +Vramp to -Vramp to Vramp. The sawtooth wave has unequal rise & fall times.

A Δle wave generator can be converted to sawtooth wave generator by injecting a DC value of non inverting terminal of A2. A potentiometer is connected to +Vcc & -VEE. Hence duty cycle of square wave depends on this dc value. If the wiper is moved towards -VEE the rise time of sawtooth wave form becomes longer than fall time and vice versa.



28/7/17

* Voltage Regulators:-

A voltage regulator is a ckt that supplies constant voltage. They can be designed using OP-Amps but it is easier and quick to use IC voltage regulators. IC voltage regulators are versatile, inexpensive and available with features as programmable o/p, current/voltage boosting, internal short ckt current limiting etc.

4 types of voltage regulators — +ve, -ve.

- → Fixed voltage regulators — +ve, -ve.
- → Variable " " — adjustable Variable
- → Switching " "
- → Special purpose " " .

For the fixed o/p voltage regulators, variable and special purpose regulators are called series voltage regul. ∵ a transistor is placed in series with error amp. These voltage reg. are also called linear reg. In switching reg. a power amp is used as a switch which is turned on & off at a rate such that the regulator delivers desired avg current.

as pulses to the load.

voltage reg. are used for power supplies for laboratories in pulse width modulation, push pull bridge etc.

Parameters of voltage regulators:-

line/i/p regulation:- It is defined as change in o/p voltage for a change in i/p voltage

load regulation:- change in o/p current for a change in load current.

Temperature stability / Avg. temp. coeff. :- It is change in o/p voltage per unit change in temp.

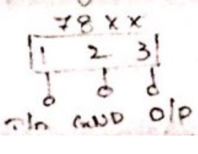
Ripple rejection:- It is a measure of regulator's ability to reject ripple voltages. It is measured in decibles

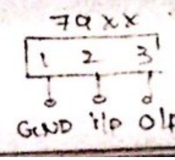
The 78xx series IC are used as fixed +ve voltage regulator. where xx represents max o/p voltages

Ex:- 7805, 7809, 7812

IC 79XX series are used as fixed -ve voltage regulators Ex:- 79012, 7915

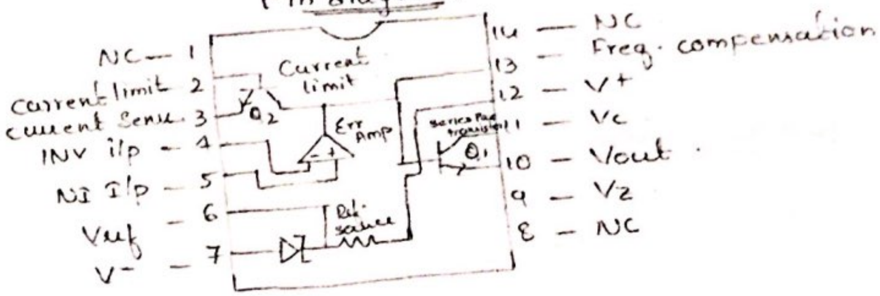
IC 723 1723 & 7840 are used as switching voltage regulators





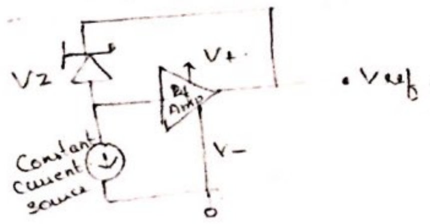
IC 723 is general purpose voltage regulator

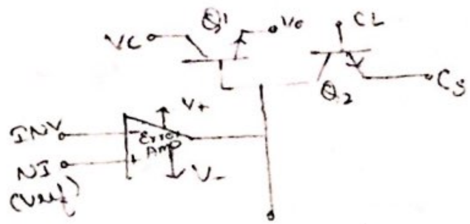
Pin diagram



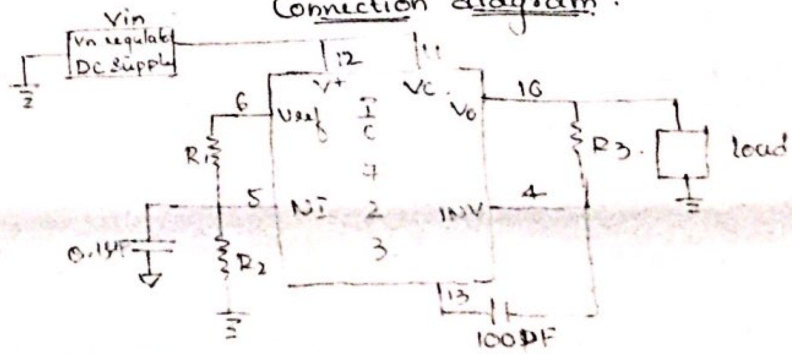
IC 723.

Internal blocks of 723.





Connection diagram.



IC 723 is a general purpose regulator which can be adjusted over wide range of +ve & -ve regulated voltage. It has 2 seperate section. 1st section consists of zener diode with const current source and ref. amp to produce Vref.

The const. current source forces the zener to operate at fixed pt. The other section consists of error amp, series pass transistor Q_1, current limiting amp Q_2. The error amp compares sample of o/p voltage applied at inv i/p terminal to the Vref applied NI i/p terminal. The error signal controls conductions of Q_1. This 2 sections are not internally connected.

The o/p of the error amp drives Q_1 so as to minimise the diff b/w NI & INV i/ps of error amp. If o/p Vo is low then INV is low. Hence error amp. o/p is +ve, then by driving Q_1 into saturation this reduces voltage across Q_1 and drives more current into the load which causes voltage across the load to increase. If the reverse is condition (i.e., erro amp is -ve the transistor Q_1 is cutoff so the current across load decreases and hence reduce Vo). This process continues until error amp o/p is zero.

2/8/17

Unit-2 Active filters, oscillators, timers and phaselocked loops

-> First order & 2nd order LP, HP, BP, BR and AP

-> Principle of operation & types of oscillators: RC, Wein bridge

-> Waveform generators: Δ'ar, sawtooth, and square wave

-> 555 timer; functional diag, Monostable and Astable operation & app, schmitt trigger, VCO

-> Functional diag of 566

-> PLL: Block diag, princles & discription of individual blocks of 565

* Filters :-

Filters are the ckts that allow a particular range of freq. and all the remaining freq are attenua

depending on type of signals filters are clasified into 2 types (i) Analoge filter (ii) Digital filter

Ex:- LP, HP, BP Ex:- FIR, IIR (finit impulse response)

Depending on type of material used filters are clasified as passive filter and active filter

Depending on material filters are clasified as audio freq/low freq, High freq. filter/radio freq

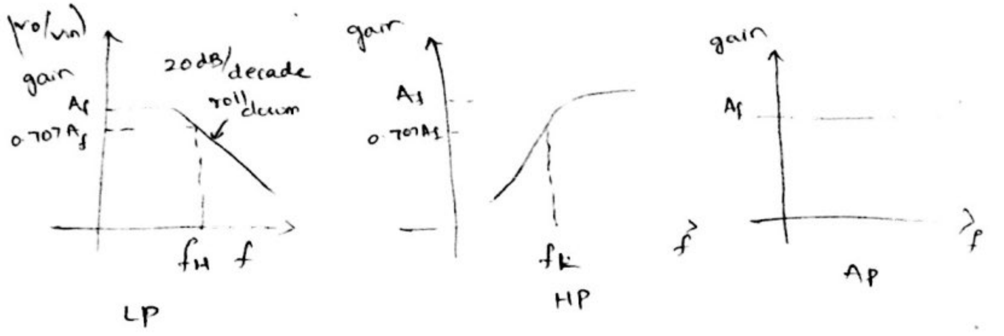
The advantages of active filters over passive filters are -> gain & frequency,

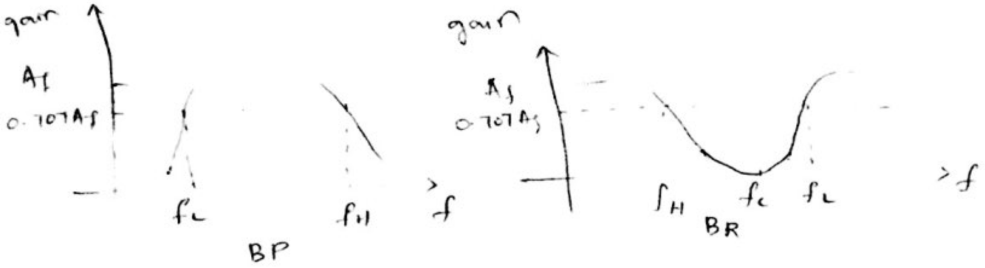
-> adjustment flexibility

2) No loading problem

3) Active filters are cheaper than passive filter

The commonly used filters as LP, HP, BP, BR and AP





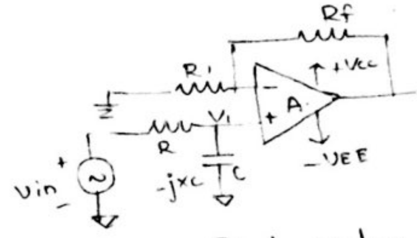
There are 3 types of practical filters

1) Butterworth 2) Chebyshev 3) Cauer

* ~~Che~~Butterworth filter has flat pass band flat stop band. Hence, it is sometimes called flat-flat filter

Chebyshev filter has ripple pass band flat SB while Cauer filter has ripple PB & SB. The cauer filter gives best SB response

First order low pass Butterworth filter:-



First order LPF

$$V_1 = \frac{-jX_C}{R - jX_C} \times V_{in} \quad -(1) \Rightarrow \quad -jX_C = \frac{1}{j\omega C} = \frac{1}{2\pi f C j} \quad -(2)$$

$$V_1 = \frac{\frac{1}{2\pi f C j}}{R + \frac{1}{2\pi f C j}} \times V_{in} = \frac{V_{in}}{j2\pi f CR + 1} \quad -(3)$$

$$V_o = \left(1 + \frac{R_F}{R_1}\right)V_1 \quad -(4)$$

Sub (3) in (4),

let $1 + \frac{R_F}{R_1} = A_F$

$$V_o = A_F \frac{V_{in}}{1 + 2\pi j f CR} \quad -(5)$$

For a LP filter the cutoff freq $f_H = \frac{1}{2\pi RC}$ $-(6)$

Sub (6) in (5)

$$\frac{V_o}{V_{in}} = \frac{A_F}{1 + j\left(\frac{f}{f_H}\right)}$$

$$\left|\frac{V_o}{V_{in}}\right| = \frac{A_F}{\sqrt{1 + \left(\frac{f}{f_H}\right)^2}} \qquad \phi = -\tan^{-1}\left(\frac{f}{f_H}\right)$$

i) $f << f_H$.

$\left|\frac{V_o}{V_{in}}\right| = A_F$.

ii) $f = f_H$

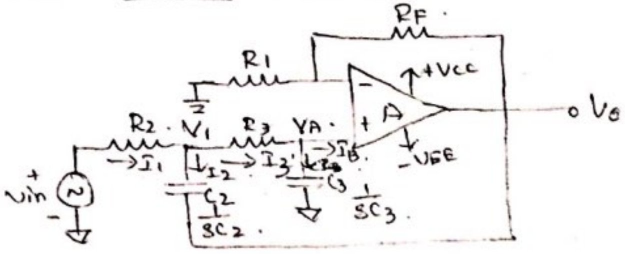
$Gain = \frac{A_F}{\sqrt{2}} = 0.707 A_F$.

iii) $f >> f_H$.

$Gain < A_F$

2/8/17.

2nd Order lowpass filter -



Apply KCL at node V_1

$$\frac{V_{in}-V_1}{R_2} = \frac{1}{C_2}\frac{d(V_1-V_0)}{dt} + \frac{V_1-V_A}{R_3}.$$

$$\frac{V_{in}-V_1}{R_2} = \frac{V_1-V_0}{\frac{1}{sC_2}} + \frac{V_1-V_A}{R_3} \quad -(1)$$

By Voltage dividing rule.

$$V_A = V_1 \times \frac{\frac{1}{sC_3}}{\frac{1}{sC_3}+R_3}$$

$$V_A = \frac{V_1}{1+R_3 s C_3}.$$

$$V_1 = V_A(1+sR_3C_3) \quad -(2)$$

Sub (2) in (1)

$$\Rightarrow \frac{V_{in} - V_A(1+sR_3C_3)}{R_2} = \frac{V_A(1+sR_3C_3)-V_0}{1/sC_2} + \frac{V_A(1+sR_3C_3)-V_A}{R_3}.$$

$$\Rightarrow \frac{V_{in}}{R_2} + V_0 sC_2 + \cancel{V_A} = V_A\left[(1+sR_3C_3)sC_2 + \frac{1+sR_3C_3}{R_3} - \frac{1}{R_3} + \frac{1+sR_3C_3}{R_2}\right]$$

$$\Rightarrow \frac{V_{in}}{R_2} + V_0 sC_2 = V_A\left[\frac{(1+sR_3C_3)(sC_2R_3) + 1 + sR_3C_3 - 1}{R_3} \cdots \frac{1+sR_3C_3}{R_2}\right]$$

$$\Rightarrow V_A = \frac{R_3V_{in} + V_0sC_2R_2R_3}{\left[(1+sR_3C_3)(sC_2R_3R_2+R_2+R_3)-R_2\right]} \quad -(3)$$

$\because$ The OP Amp is in the non inverting configuration

$$V_0 = \left(1+\frac{R_F}{R_1}\right)V_A$$

$$A_F = 1+\frac{R_F}{R_1}$$

$$\therefore V_0 = A_F\left[\frac{R_3V_{in}+V_0sC_2R_2R_3}{(1+sR_3C_3)(sC_2R_3R_2+R_2+R_3)-R_2}\right]$$

$$\cancel{\frac{V_0}{V_{in}}}\ V_0\left[\frac{1-A_FsC_2R_2R_3}{---}\right] = \left[\frac{A_F\ R_3V_{in}}{---}\right]$$

$$\cancel{\frac{V_0}{V_{in}} = \frac{A_F\ R_3}{1-sC_2}}$$

$$V_0 - \frac{V_0A_FsC_2R_2R_3}{(1+sR_3C_3)(sC_2R_3R_2+R_2+R_3)-R_2)} = \frac{A_F\ R_3V_{in}}{(1+sR_3C_3)(sC_2R_3R_2+R_2+R_3)-R_2}$$

$$V_0\left[1 - A_FsC_2R_2R_3\right] = A_F\ R_3V_{in}$$

$$\Rightarrow \frac{V_0}{V_{in}} = \frac{A_F R_3}{(1+sR_3C_3)(sC_2R_3R_2+R_2+R_3)-R_2-A_FsC_2R_2R_3}.$$

$$\frac{V_o}{V_{in}} = \frac{A_F R_3}{sC_2R_3R_2+R_2+R_3+s^2C_2C_3R_3^2R_2+sR_2C_3R_2+sR_3^2C_3-R_2-sC_2R_2R_3}$$

$$= \frac{A_F}{s^2+s\left[\frac{C_3R_2+C_2R_2-A_FR_3C_2+R_3C_3}{C_2C_3R_2R_3}\right]+\frac{1}{R_2R_3C_2C_3}} \quad -(4)$$

The standard form of transfer function of any 2^{nd} order system is $\frac{V_o(s)}{V_{in}(s)} = \frac{A}{s^2+2\xi\omega_n s+\omega_n^2}$ $-(5)$

Where A is overall gain

ξ is damping of system

ω_n is freq of oscillation

By comparing (4) & (5) $\omega_n^2 = \frac{1}{R_2R_3C_2C_3}$

So for 2nd order low pass filter $\omega_n = \omega_H$

But $\omega_H = 2\pi f_H$

$$f_H = \frac{1}{2\pi\sqrt{R_2R_3C_2C_3}}$$

Let $R_2 = R_3 = R$ & $C_2 = C_3 = C$.

then $f_H = \frac{1}{2\pi RC}$

For 2^{nd} order

$$\left|\frac{V_o}{V_{in}}\right| = \frac{A_F}{\sqrt{1+\left(\frac{f}{f_H}\right)^4}}$$

Frequency Scaling:- The procedure to convert original cut off freq f_H to a new cut off freq f_H' is called freq scaling. The scaling factor $= \frac{f_H}{f_H'}$ then multiply the scaling factor to resistors to obtain new resistor value then the filter is designed with new cut off freq resistor value

Filter designing:-

→ Choose a value of high cut off freq f_H.

→ Select a value of C ($\leq 1\mu F$)

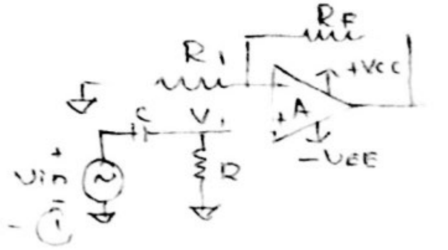
→ Calculate the value of R using $R = \frac{1}{2\pi f_H C}$.

→ Select values of R_1 & R_F calculate the gain A_F

Note:- For the 2^{nd} order low pass filter $A_F = 1.586$

4/8/17 **First order high pass filter:-**

$$V_1 = \frac{R}{R-jX_C} \times V_{in}$$



$$= \frac{R}{R+\frac{1}{j\omega C}} \times V_{in}$$

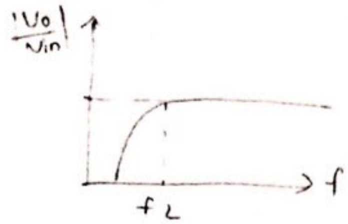
$$= \frac{j\omega RC}{1+j\omega RC} \times V_{in} \quad -(1)$$

$$V_o = A_F \cdot V_1 = A_F\left(\frac{j\omega RC}{1+j\omega RC}\right) \times V_{in} \Rightarrow \frac{V_o}{V_{in}} = A_F\left(\frac{j\omega RC}{1+j\omega RC}\right)$$

For the high pass filter, cut off freq is $f_L = \frac{1}{2\pi RC}$ and substitute $\omega = 2\pi f$

$$\frac{V_o}{V_{in}} = \frac{A_F}{1 - j\left(\frac{f_L}{f}\right)} \qquad \phi = \tan^{-1}\left(\frac{f_L}{f}\right)$$

$$\left|\frac{V_o}{V_{in}}\right| = \frac{A_F}{\sqrt{1+\left(\frac{f_L}{f}\right)^2}}$$



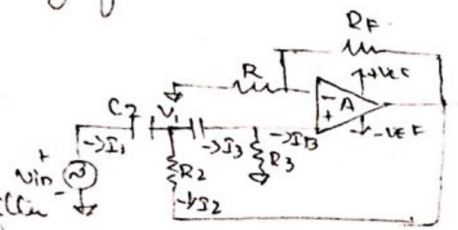
★ **Second order high pass filter:-**

The voltage gain mag of 2nd order HPF is,

$$\left|\frac{V_o}{V_{in}}\right| = \frac{A_F}{\sqrt{1+\left(\frac{f_L}{f}\right)^4}}$$

where $A_F = 1.586$.

PB gain for second filter



★ **Bandpass filter:-**

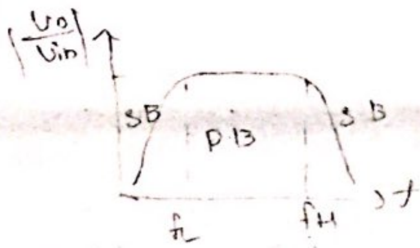
(1) Wide band pass filter (2) Narrow band pass filter

Note:- There is no dividing line b/w the two types of filter is.

$Q < 10$ it is considered as wide BPF

$Q \geq 10$ then Narrow BPF.

Frequency response of a BPF:-



Wide BPF:-

A wide BPF can be formed by cascading high pass & low pass filter

$$\left|\frac{V_o}{V_{in}}\right| = \frac{A_F}{\sqrt{1+\left(\frac{f}{f_H}\right)^2}} \times \frac{A_F}{\sqrt{1+\left(\frac{f_L}{f}\right)^2}} = \frac{A_{FT}}{\sqrt{1+\left(\frac{f}{f_H}\right)^2} \times \sqrt{1+\left(\frac{f_L}{f}\right)^2}}$$

A_{FT} - Total BP gain.

(1) Design a wide BPF having $f_L = 400\,Hz$ and $f_H = 2\,kHz$ and BP gain is 4.

Quality factor for BPF is $Q = \frac{f_c}{BW}$ where $f_c = \sqrt{f_H \times f_L}$

$BW = f_H - f_L$

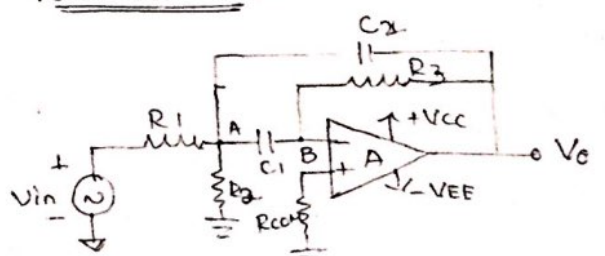
$f_c = \sqrt{400 \times 2 \times 10^3} = 100 \times 2\sqrt{20} = 894.42$

$BW = 1600$

$Q = \frac{894.42}{1600} = 0.55 \Rightarrow Q = 0.55$

7/8/17

Narrow BPF:-



The narrow BPF has only one op-Amp and it has the following features

→ It has 2 feed back paths

→ The op-amp is in the inverting config

→ Due to the 2 feed back paths it is called multiple feed back filter

→ The resistor which is connected to non inverting terminal is called offset compensating resistor.

→ For simplifications consider $C_1 = C_2 = C$ then

$$R_1 = \frac{Q}{2\pi f_c C A_F}, \quad R_2 = \frac{Q}{2\pi f_c C(2Q^2 - A_F)} \quad R_3 = \frac{Q}{\pi f_c C}$$

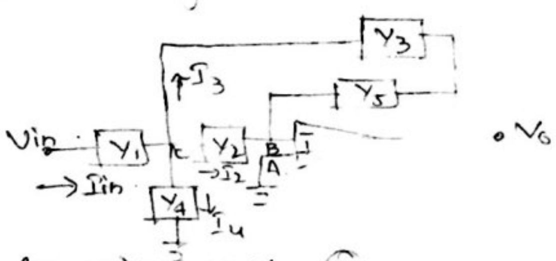
$$A_F = \frac{R_3}{2R_1}, \text{ gain at } f_c.$$

Another adv. of multiple feedback filter is the center freq f_c can be changed to new center freq f_c' without changing gain & BW by changing resistance R_2.

The new resistance $R_2' = R_2 \times \left(\frac{f_c}{f_c'}\right)^2$

Note:- The above ckt is called IGMF ckt (infinite gain multiple feedback config)

KCL at node C



$$I_{in} = I_2 + I_3 + I_4.$$

$$\Rightarrow (V_{in} - V_c)Y_1 = (V_c - V_B)Y_2 + (V_c - V_o)Y_3 + V_c Y_4 \quad -(1)$$

$$V_{in}Y_1 + V_oY_3 = V_c[Y_1 + Y_2 + Y_3 + Y_4]$$

OP-amp current = 0

$$\Rightarrow V_c Y_2 = -V_o Y_5$$

$$V_c = -V_o\left[\frac{Y_5}{Y_2}\right] \quad -(2)$$

Sub (2) in (1),

$$V_{in} Y_1 + V_o Y_3 = -V_o \frac{Y_5}{Y_2}[Y_1 + Y_2 + Y_3 + Y_4]$$

$$\therefore V_{in}Y_1 = -V_o\left[\frac{Y_5 Y_1}{Y_2} + Y_5 + \frac{Y_5 Y_3}{Y_2} + \frac{Y_5 Y_4}{Y_2}\right]$$

$$\therefore \frac{V_{in}}{V_o} = \frac{-Y_1 Y_2}{Y_5 Y_1 + Y_5 Y_2 + Y_3 Y_5 + Y_5 Y_4 + Y_2 Y_3}.$$

∴ This is the general expr of voltage gain IGFM config

For this ckt, to be a band pass ckt substitute

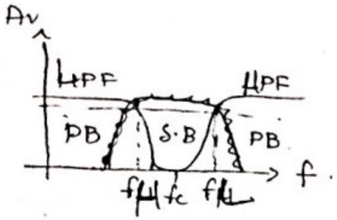
$Y_1 = 1/R_1$, $Y_2 = SC_2$, $Y_3 = SC_3$, $Y_4 = 1/R_4$, $Y_5 = 1/R_5$

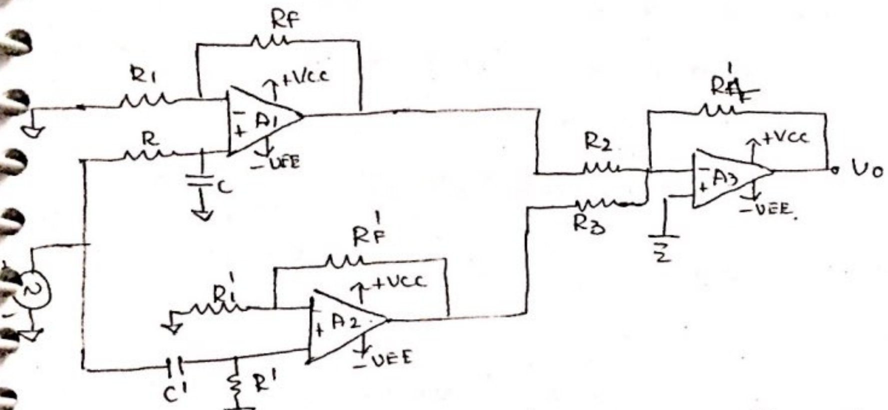
9/8/17 **Band Reject Filter:-**

9/8/17 **Band Reject Filter :-** It is also known as Band elimination / Band attenuation filter. Band on Q value BRF is classified into 2 types.
(i) Wide BRF (ii) Narrow BRF.

★ **Wide Band reject filter :-**

The wide band reject filter is a combination of LPF & HPF and an adder.





To have proper operation of this filter it should satisfy following 2 conditions

→ The low cutt of HPF must be greater than high cutoff freq of LPF

→ The PB gain of HP & LP must be equal.

→ The gain of summing amp. must be set to 1 i.e,

$R_2 = R_3 = R_4 = R$.

→ The center freq $f_c = \sqrt{f_H f_L}$.

(1) Design a wide BRF having $f_H = 400$ Hz $f_L = 2$kHz with a PB gain of 2. And calculate f_c

Assume $C = 0.1\mu F$

$f_H = \frac{1}{2\pi RC}$ =>

$f_L = \frac{1}{2\pi RC}$ =>

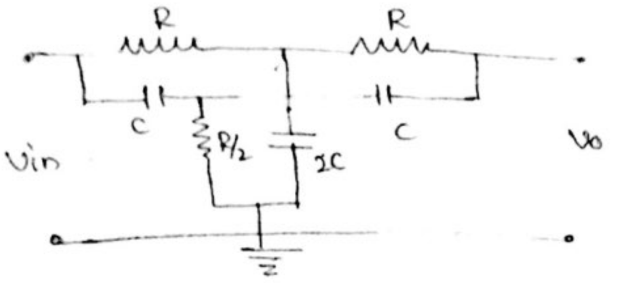
Diag

$f_c = \sqrt{f_H f_L} = \sqrt{2\times10^3 \times 400} =$

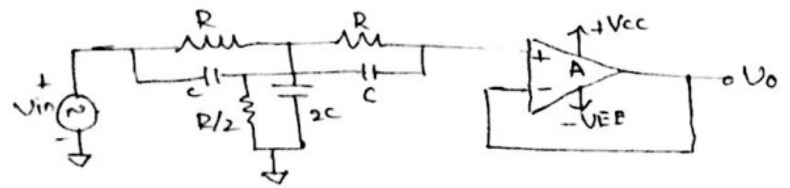
★ **Narrow BRF :-**

The narrow BRF is used to eliminate a single freq of 60Hz. It is also known as notch filter. The most commonly used notch filter is twin-T network which is composed of 2 T shaped n/w. one T n/w consists of 2R and 1C while the other consists of 2C & 1R. The freq where the attenuation occur is $f_n = \frac{1}{2\pi RC}$. The twin T n/w has less gain & less Q value to increase the Q value of ckt it is used with voltage follower ckt.

For designing notch filter for a specified f_n value take $C \leq 1\mu F$ and then calculate R val



Twin T n/w



Twin T n/w with voltage follower ckt.

(1) Design a notch filter to eliminate 120Hz Hum noise

$f_n = 120Hz$.

let $C = 0.1\mu F$.

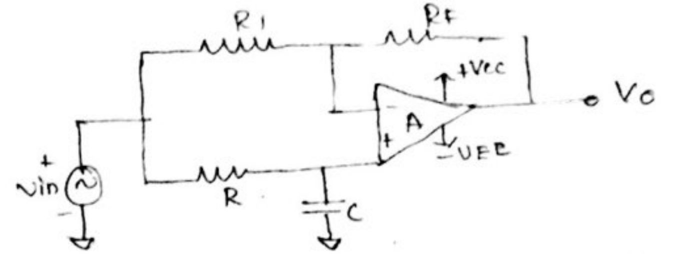
$$f_n = \frac{1}{2\pi RC}$$

$$120 = \frac{1}{2\pi R \times 0.1\times10^{-6}}$$

$$\Rightarrow R = \frac{1}{240\pi \times 0.1\times10^{-6}}$$

Diag.

★ **All pass filter:-**



As the name indicates it pass all freq of i/p signal without attenuation while providing phase shift for the i/p signal. They are also called delay equalizer & phase corrector and this filter is used in transmission lines such as telephone lines to compensate change in phase.

Initially consider non inverting terminal is

then $V_{o1} = \frac{-R_F}{R_1} V_{in}$ (∵ ckt is inv amp)

let $R_F = R_1$

$$\therefore \boxed{V_{o1} = -V_{in}} \quad \text{--- (1)}$$

Consider ckt in non inverting config.

$$V_{o2} = \left(1+\frac{R_F}{R_1}\right)V_1 \qquad R_F = R_1$$

$$= (2)\,\frac{V_{in}\cdot(-jX_C)}{R-jX_C}$$

$$V_{o2} = \frac{2V_{in}}{1+j2\pi fRC} \quad \text{--- (2)}$$

$V_o = V_{o1} + V_{o2}$ (superposition theorem)

$$= -V_{in} + \frac{2V_{in}}{1+j2\pi fRC}$$

$$= \frac{V_{in}\left[-1-j2\pi fRC+2\right]}{1+j2\pi fRC}$$

$$\frac{V_o}{V_{in}} = \frac{1-j2\pi fRC}{1+j2\pi fRC}$$

$$\left|\frac{V_o}{V_{in}}\right| = 1 \qquad \phi = \cancel{-2\tan^{-1}\left(\frac{1}{2\pi RC}\right)}$$

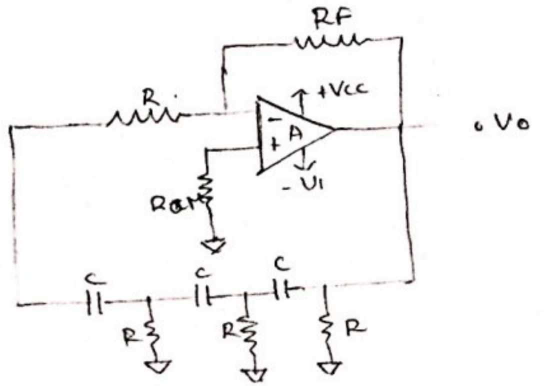
$$= -2\tan^{-1}(2\pi fRC)$$

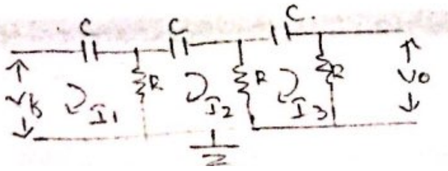
$$\therefore \boxed{V_o = V_{in}}$$

The -ve phase shift indicates that o/p vo lags Vin by angle ϕ.

26/8/17

RC phase shift oscillator:-





An oscillator is a ckt that generates a repetative waveform of fixed amp & freq without any external i/p signal. An RC phase shift oscillator consists of an op-amp as amplifying stage and 3 RC cascaded n/w as f/b ckts. The op-Amp is used in inverting mode ∴ a phase shift of 180° is obtained at o/p and an additional 180° phase shift required for oscillation is provided by cascaded RC n/w. To find freq of oscillations and gain of the ckts apply KVL for the given ckt

$$V_f = I_1\frac{1}{j\omega C} + R(I_1 - I_2) = I_1\left(R+\frac{1}{j\omega C}\right) - I_2R \quad (1)$$

$$I_2\frac{1}{j\omega C} + R(I_2 - I_3) + R(I_2 - I_1) = 0$$

$$\Rightarrow -I_1R + I_2\left(\frac{1}{j\omega C} + 2R\right) - I_3R = 0$$

$$I_3\frac{1}{j\omega C} + R(I_3 - I_2) + V_o = 0$$

$$\Rightarrow -I_2R + I_3\left(2R + \frac{1}{j\omega C}\right) = 0$$

Replace $j\omega = s$ and write the eq in matrix form

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix}\begin{bmatrix} \left(R+\frac{1}{sC}\right) & -R & 0 \\ -R & \left(\frac{1}{sC}+2R\right) & -R \\ 0 & -R & \left(2R+\frac{1}{sC}\right) \end{bmatrix} = \begin{bmatrix} V_f \\ 0 \\ 0 \end{bmatrix}$$

using cramer's rule for above matrix $\left(I_3 = \frac{D_3}{D}\right)$

$$D = \begin{vmatrix} \left(R+\frac{1}{sC}\right) & -R & 0 \\ -R & \left(\frac{1}{sC}+2R\right) & -R \\ 0 & -R & \left(2R+\frac{1}{sC}\right) \end{vmatrix}$$

$$= R + \frac{1}{sC}\left(4R^2 + \frac{4R}{sC} + \left(\frac{1}{sC}\right)^2\right) + R\left[-2R^2 - \frac{R}{sC}\right]$$

$$= 4R^3 + \frac{4R^2}{sC} + R\left(\frac{1}{sC}\right)^2 + \frac{4R^2}{sC} + \frac{4R}{(sC)^2} + \left(\frac{1}{sC}\right)^3 - 2R^3 - \frac{R^2}{sC}$$

$$= 2R^3 + \frac{7R^2}{sC} + \frac{4R}{(sC)^2} + \frac{R}{(sC)^2} + \frac{1}{(sC)^3}$$

$$= \frac{2R^3s^3C^3 + 7R^2s^2C^2 + 4RsC + sCR + 1}{s^3C^3}$$

$$D = \frac{1 + 5sRC + 6s^2C^2R^2 + s^3C^3R^3}{s^3C^3} \quad \text{— (2)}$$

Wkt $D_3 = V_f R^2$ $\qquad I_3 = \frac{D_3}{D}$

Wkt $\Rightarrow V_o = I_3 R$

$$\beta = \frac{V_o}{V_f} = \frac{I_3 R}{V_f} = \frac{\frac{V_f R^2}{D} R}{V_f} = \frac{R^3}{D}$$

$$\therefore \boxed{\beta = \frac{R^3 s^3 C^3}{1 + 5sRC + 6s^2C^2R^2 + s^3C^3R^3}} \quad \text{— (3)}$$

÷ nr & dr by $R^3s^3C^3$

$$\beta = \frac{1}{\frac{1}{s^3R^3C^3} + \frac{5}{s^2R^2C^2} + \frac{6}{sRC} + 1}$$

$$s = j\omega$$

$$= \frac{1}{\frac{1}{-j\omega^3R^3C^3} + \frac{5}{-\omega^2R^2C^2} + \frac{6}{j\omega RC} + 1}$$

Replace $\frac{1}{\omega CR} = \alpha$

$$\beta = \frac{1}{j\alpha^3 - 5\alpha^2 - 6j\alpha + 1}$$

$$\beta = \frac{1}{j(\alpha^3 - 6\alpha) + (-5\alpha^2 + 1)}$$

To have the phase shift of 180° the imag part denominator must be zero

$$\therefore \alpha^3 - 6\alpha = 0$$

$$\alpha(\alpha^2 - 6) = 0$$

$$\therefore \alpha^2 = 6$$

$$\frac{1}{\omega^2C^2R^2} = 6$$

$$\omega^2C^2R^2 = \frac{1}{6}$$

$$\omega CR = \frac{1}{\sqrt{6}}$$

$$2\pi f CR = \frac{1}{\sqrt{6}}$$

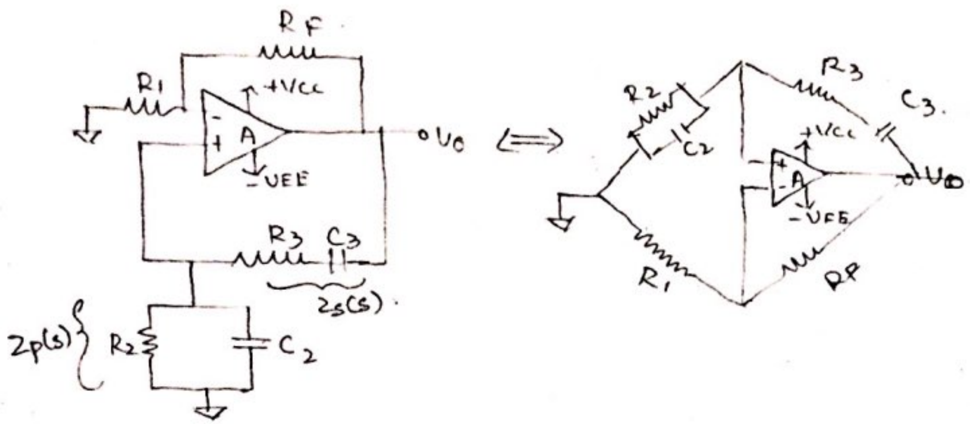
$$\boxed{f = \frac{1}{2\pi RC\sqrt{6}}} \quad \text{— (4)}$$

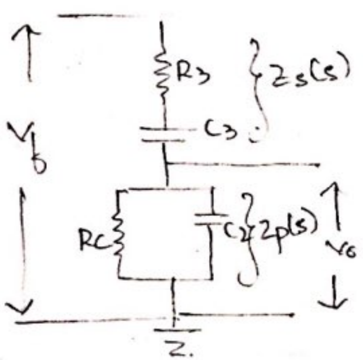
Sub eq (4) in (3)

$$\boxed{\beta = \frac{1}{29}}$$

Wkt $A\beta = 1 \Rightarrow \boxed{|A| = 29}$

* Wein Bridge Oscillator :-





One of the most commonly used audio freq oscillator is wein bridge osc. because of its stability and simplicity. It consists of a series RC n/w and a parallel RC n/w. The phase shift around wien bridge osc is 0° & this condition occurs only when bridge is balanced i.e., at resonance.

$$V_f = \frac{Zp(s)}{Zp(s)+Zs(s)} V_o$$

By using voltage dividing rule above eq.

where $Z_s = R_3 + \frac{1}{j\omega C_3}$ Consider $R_2 = R_3 = R$ & $C_2 = C_3 = C$.

$$Z_p = R_2 \parallel \frac{1}{j\omega C_2}$$

$$Z_p = \frac{R_2 \times \frac{1}{j\omega C_2}}{R_2 + \frac{1}{j\omega C_2}} = \frac{R_2}{jR_2C_2\omega + 1}$$

$$\beta = \frac{V_f}{V_o} = \frac{Zp(s)}{Zp(s)+Zs(s)} = \frac{\frac{R_2}{sR_2C_2+1}}{\frac{R_2}{sR_2C_2+1} + \frac{sR_3C_3+1}{sC_3}}$$

$$= \frac{\frac{R_2}{sR_2C_2+1}}{\frac{sR_2C_3 + s^2R_3C_3R_2C_2 + sR_3C_3 + sR_2C_2 + 1}{(sR_2C_2+1)(sC_3)}}$$

$$= \frac{(sR_2C_2+1)sC_3R_2}{sR_2C_3 + s^2R_3C_3R_2C_2 + sR_3C_3 + sR_2C_2 + 1}$$

$$= \frac{s^2R_2^2C_2C_3 + sC_3R_2}{sR_2C_3 + s^2R_3C_3R_2C_2 + sR_2C_2 + sR_3C_3 + 1}$$

$$= \frac{-\omega^2R_2^2C_2C_3 + j\omega C_3R_2}{j\omega R_2C_3 - \omega^2R_3C_3R_2C_2 + j\omega R_2C_2 + j\omega R_3C_3 + 1}$$

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$$\beta = \frac{RsC}{RsC + s^2R^2C^2 + sRC + sRC + 1} = \frac{RsC}{s^2R^2C^2 + 3sRC + 1} \quad -(1)$$

The voltage gain of op-Amp is $A_v = \frac{V_o}{V_f}$ and i.e.

$$1 + \frac{R_F}{R_1} \quad -(2)$$

wkt $A\beta = 1$.

$\left(1+\frac{R_F}{R_1}\right)\cdot\frac{sCR}{s^2C^2R^2+3sCR+1} = 1.$

$\Rightarrow \left(1+\frac{R_F}{R_1}\right) sCR = s^2C^2R^2+3sCR+1$

put $s = j\omega$.

$\Rightarrow \left(1+\frac{R_F}{R_1}\right) j\omega CR = -\omega^2C^2R^2+3j\omega CR+1$

$\Rightarrow -\omega^2C^2R^2+1 = -3j\omega RC + j\omega R_F + \frac{R_F}{R_1} j\omega CR$

$\Rightarrow -\omega^2C^2R^2+1 = -2j\omega RC + j\omega \frac{R_F}{R_1} CR$

Equate real parts on b/s

$\Rightarrow +\omega^2C^2R^2 = 1$

$\Rightarrow \cancel{4\pi^2f^2}\ \omega = \frac{1}{CR}$

$\Rightarrow \boxed{f = \frac{1}{2\pi RC}}$

To obtain gain equate imag. parts of both sides

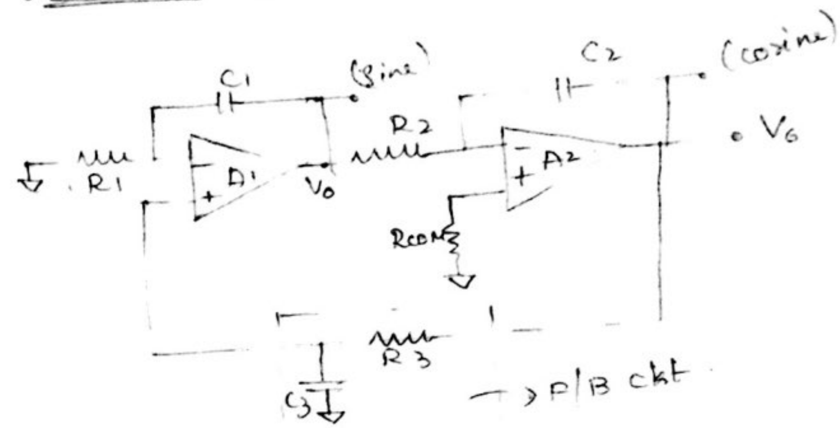
let $1+\frac{R_F}{R} = A$

$\Rightarrow \left(1+\frac{R_F}{R_1}\right) sCR = 3sCR$

$\therefore \boxed{A = 3}$

if $A = 3 \Rightarrow \beta = \frac{1}{3}$ and $R_F = 2R_1$

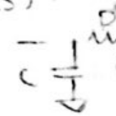
* Quadrature Oscillator:-



OP-Amp A_2 is pure integrator and invertor he it provides $90°/-270°$ phase shift. The remaining $-90°$ & $270°$ of phase shift is obtained from OP-Amp A_1 & feedback ckt R_3, C_3

To calculate freq of oscillations consider feedback ckt. By voltage dividing rule

Gain of OP-Amp A_2 = $V_f(s) = \frac{\cancel{R} \times \frac{1}{sC}}{R+\frac{1}{sC}} V_0(s)$



$= \frac{\cancel{R}}{RsC+1} V_0$

$\beta = \frac{V_f}{V_0} = \frac{1}{1+sR_3C_3}$ — (1)

Gain of OP-Amp A_1 $= \frac{V_0'(s)}{V_f(s)} = \frac{1+sCR}{sCR}$ — (2)

$A_2 = \frac{V_0(s)}{V_0'(s)} = \frac{-1/sC}{R} = \frac{-1}{sCR}$

$A = A_1 \cdot A_2$.

$\Rightarrow A\beta = 1$.

$R_1 = R_2 = R_3 = R$ & $C_1 = C_2 = C_3 = C$

then Substitute

$$\left(\frac{1+sCR}{sCR}\right)\left(\frac{-1}{sCR}\right)\left(\frac{1}{1+sRC}\right) = 1$$

$$-1 = s^2C^2R^2$$

$$\omega^2C^2R^2 = 1$$

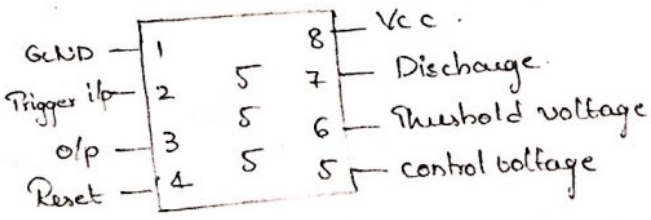
$$\boxed{f = \frac{1}{2\pi RC}}$$

$$\beta = \frac{1}{1+j2\pi fRC} = \frac{1}{1+j\frac{2\pi \cdot 1}{2\pi RC}RC} = \frac{1}{1+j}$$

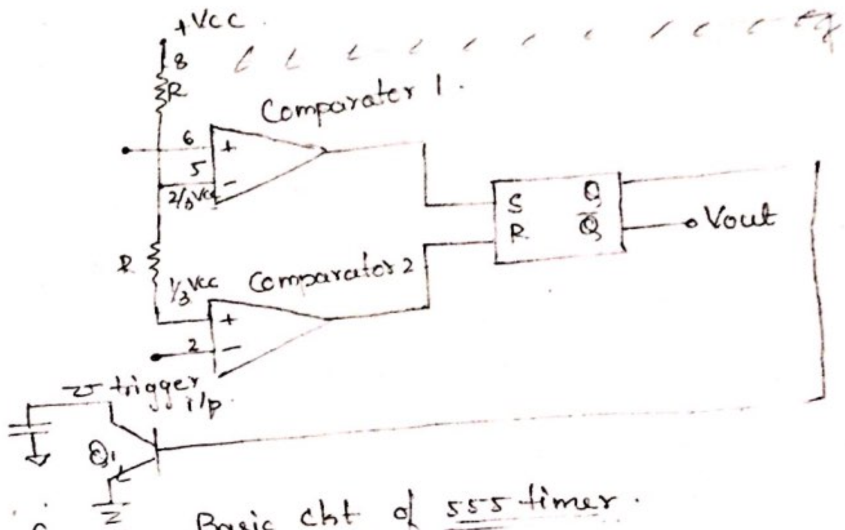
$$|\beta| = \frac{1}{\sqrt{2}}$$

$$\therefore \boxed{A = \sqrt{2}}$$

* 555 Timer :-



Pin diagram



Basic ckt of 555 timer.

One of the most versatile linear integrator ckt i 555 timer. It can be used as DC to DC conver waveform generator, pulse strecher, FSK mod & Demod etc. It is im manufactured by Signetics SE/NE with 8 pin DIP. The 14 pin DIP consists of 2-555 timers fabricated on same chip and named as IC556. It can be used in 2 modes monostable multivibrator & astable multivibrator.

→ The supply voltages ranges from 4.5V to 18V.

→ The SE version operates at $-55°C$ to $+125°C$ and NE version operates from $0°C$ to $+70°C$

→ The o/p of 555 timer is compatable with TTL and CMOS ckt.

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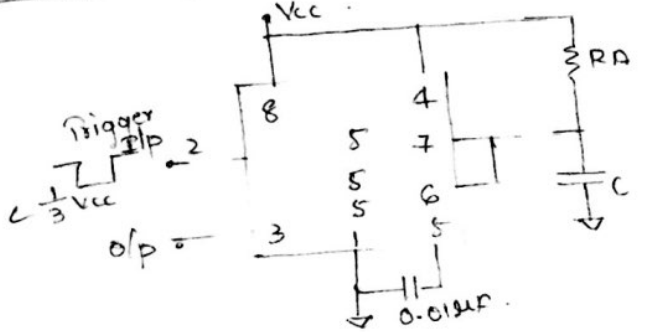
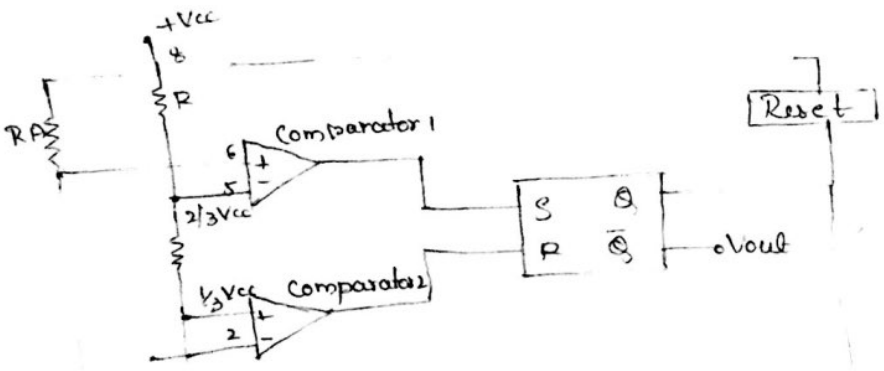
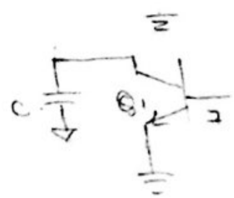
S	R	Q_{t+1}	$\bar{Q}_{t+1}$	
0	0	Q_t	$\bar{Q}_t$	(Previous i/p).
0	1	0	1	(Reset)
1	0	1	0	(Set)
1	1	x	x	(not used)

*555 IC timer as Monostable :-

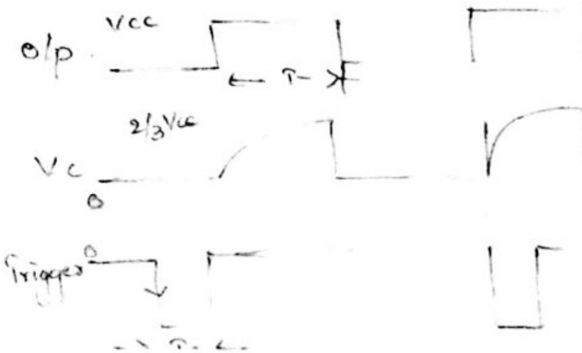






For monostable multivibrator operation an external resistor RA is connected b/w 7 & 8 pins. The duration of pulse generated by pulse are determined by R & C values.

Initially o/p of the monostable mul is low i.e., ckt is in stable state then transistor Q_1 is ON and capacitor C is shorted to GND. When a -ve trigger pulse is applied to pin 2 the comparator 2 o/p goes high and triggers the o/p of FF. The o/p of timer Vout is high which makes transistor Q_1 OFF, the capacitor C starts charging towards Vcc through resistor RA. When the voltage across capacitor reaches $\frac{2}{3}$ Vcc the comp. 1 o/p switches from low to high which in turn triggers the FF. The o/p of timer changes to low state and the transistor Q_1 is ON and hence capacitor C discharges rapidly. the o/p of monostable remains low until a trigger pulse is applied again.



The voltage across capacitor $V_c = V_{cc}(1-e^{-t/RC})$ — (1)

at $t = T$.

$$V_c = \frac{2}{3} V_{cc} \quad \text{— (2)}$$

From (1) & (2)

$$V_{cc}\left[1 - e^{-T/RC}\right] = \frac{2}{3} V_{cc}.$$

$$-e^{-T/RC} = \frac{2}{3} - 1 = -\frac{1}{3}$$

$$e^{T/RC} = 3.$$

$$\frac{T}{RC} = \log_e 3.$$

$$T = RC \ln 3$$

$$\boxed{T = 1.1 R_A C}$$

2) For a monostable mul. $R_A = 100k\Omega$, $C = 0.9\mu F$ find time period of pulse.

$$T = 1.1 \times 100 \times 10^3 \times 0.9 \times 10^{-6}$$

$$T = 99 \text{ msec}$$

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