B.Tech 3rd Year, ECE

Subject: Integrated Circuit (REC-501)

Solutions

SECTION -A

Q1 (a) Two applications are: (i) Frequency Doubling (ii) Voltage divider using multiplier

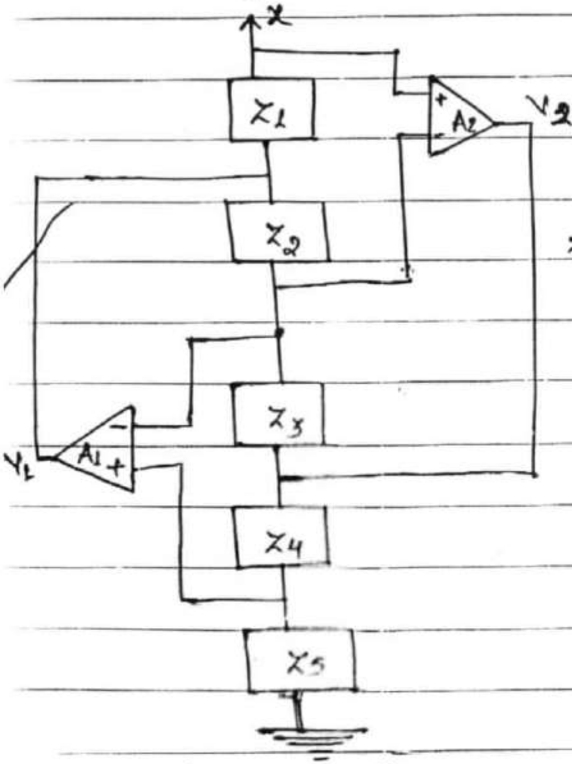
(b) The silicon rectifiers cut in voltage 0.7 volt so voltage less that this value can't be rectified. This defect is overcome by precision rectifier by using Op-Amp rectifier and the voltage in the millivolt range can be obtained.

(c) Roll of rate: The gain falls of rapidly in the stop band is called roll-of rate.

(d) Peak detector

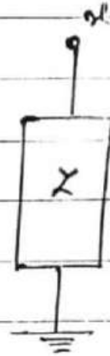
(e) The precision rectifier, also known as a super diode, is a configuration obtained with an operational amplifier in order to have a circuit behave like an ideal diode and rectifier. It is very useful for high-precision signal processing. With the help of precision rectifier the high-precision signal processing can be done very easily

2(g) Generalized Impedance Converter (GIC) -

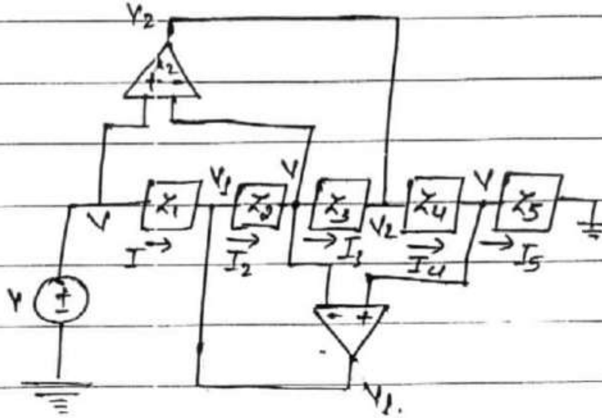


Generated Impedance Converter

$\Rightarrow$



$$= \frac{Z_1 Z_3 Z_5}{Z_2 Z_4}$$



finding equivalent Impedance

Impedance converter active RC circuits design simulate such as frequ dependent such as inductance using active filter synthesis.

Find the equivalent impedance such as $Z = \frac{V}{I}$.

$$I = \frac{V - V_1}{Z_1} \quad \text{or}$$

$$\boxed{V - V_1 = I Z_1} \text{ --- (i)}$$

Summing currents at the node common to Z_2 & Z_3.

$$\frac{V_1 - V}{Z_2} = \frac{V - V_2}{Z_3}$$

$$\frac{V_1 - V}{Z_2} + \frac{V_2 - V}{Z_3} = 0 \text{ --- (ii)}$$

Summing currents at the node common to Z_4 & Z_5.

$$\frac{V_2 - V}{Z_4} + \frac{0 - V}{Z_5} = 0 \text{ --- (iii)}$$

From equation — (iii)

$$\frac{V_2}{Z_4} - \frac{V}{Z_4} = \frac{V}{Z_5}$$

$$V_2 = V\left(\frac{Z_5 + Z_4}{Z_5}\right) \text{ --- (iv)}$$

From eqn (i) $V - V_1 = I Z_1$ — (v)

Substituting $V - V_1 = I Z_1$ from equation (v) in equation (ii), we get

$$\frac{-I Z_1}{Z_2} + \frac{V_2 - V}{Z_3} = 0.$$

$$\frac{V_2 - V}{Z_3} = \frac{I Z_1}{Z_2} \text{ --- (vi)}$$

Substituting V_2 from equation (iv),
In eqn (vi), we get

$$\frac{V(Z_5 + Z_4) - VZ_5}{Z_3 Z_5} = \frac{IZ_1}{Z_2}$$

$$VZ_5 + VZ_4 - VZ_5 = \frac{IZ_1 Z_3 Z_5}{Z_2}$$

$$VZ_4 = \frac{IZ_1 Z_3 Z_5}{Z_2}$$

$$Z = \frac{V}{I} = \frac{Z_1 Z_3 Z_5}{Z_4 Z_2}$$

* Depending on the type of the components we use impedance for Z_1 through Z_5. We configure the circuit for various impedance types.

Imp 2(b)

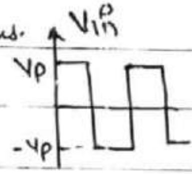
Peak Detector -

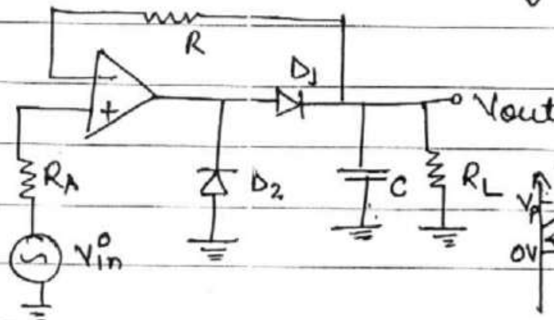
The basic function of peak detector is to capture the +ve peak value of the input signal. The principle of peak detector is based on storing the highest value of the signal on a capacitor. The highest value remains stored untill the capacitor is discharged.

R → Protect op-amp from excessive discharge current.

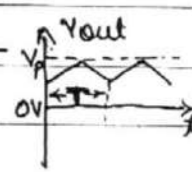
R_A → Minimize offset problems.

D_2 → Prevents the op-amp from going to negative saturation.





Peak Detector ckt.



Output waveform from Peak to Peak detector

Case 1 → During the +ve half cycle of Vin the output of the op-amp D_1 on condition, charging capacitor C to the +ve peak value V_p of the input voltage V_{in} thus, when diode D_1 is forward bias, the op-amp acts as voltage follower.

Case 2 → During the -ve half cycle of the V_{in} diode D_1 is reverse biased & the voltage across C is retained. On the discharge path for C through R_L since the input bi[as] current is negligible.

* For proper operation of the circuit, the charging current t[ime] constant (CR) & discharging time constant (CR_L) must satis[fy] the following conditions.

$$\tau = CR_f << \frac{T}{10} \quad \& \quad CR_L >> 10T \quad \text{—— (i)}$$

where R_f is the forward resistance of the diode; R_L is load resistance and T is the time period of input wave V_{in}.

Q2(C)

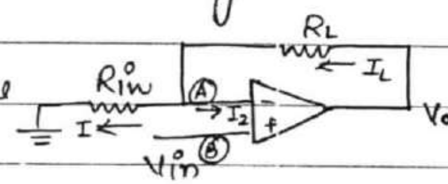
Voltage to current (V to I) Converters (Transconductance ampr) -

In a voltage to current converter, the output load current proportional to the input voltage.

The voltage to current converter can be classified into two categories i.e. depending on the position of the load. They are -

1) Voltage to current (V to I) converter with floating load.
2) Voltage to current (V to I) converter with grounded load.

1) Voltage to current converter with Floating Load -



In this figure load resistance R_L is called floating because it is not connected to ground.

The input voltage is applied to the non-inverting terminal of the op-amp low resistance R_L is connected in place of the feedback resistance. The node B at potential V_{in} the same potential at node A due to virtual ground concept i.e. $V_A = V_B = V_{in}$ — (i)

Applying KCL

$$I = I_L$$

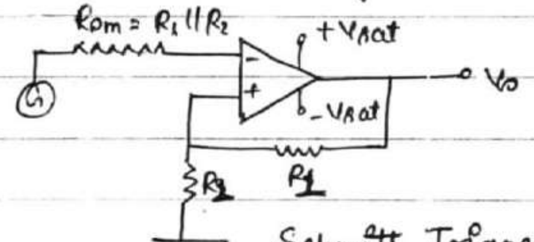
$$\frac{V_{in} - 0}{R_{in}} = I_L \quad \text{or} \quad \boxed{I_L = \frac{V_{in}}{R_{in}}}$$

This eqn indicates that the input voltage V_{in} is converted into an output or load current is $\frac{V_{in}}{R_{in}}$.

So, in this way this circuit will act as V to I converter

3(9)

Schmitt Trigger Circuit (Regenerative Comparactor) -



Schmitt Trigger

- The circuit of Schmitt trigger is shown in fig. It is an inverte comparator with the +ve feedback. The ckt converts an irregulate wave form into square wave or pulse. The I/P voltage Vin (trigger) the O/P every time, it exceeds certain voltag levels called the upper threshold voltage (V_{UT}) & the lower threshold voltage (V_{LT}). When $V_o = +V_{sat}$ the voltage across R_2 is called V_{UT}. The I/P voltage must be sligetly greater than V_{LT}. In order to make the O/P switch than $+V_{sat}$ to $-V_{sat}$.

$$V_o = A(V_1 - V_2) \quad \text{---- (i)}$$

$V_{in} > V_{UT}$ across R we apply the voltage divider rule

$$V_1 = \frac{R_2}{R_1 + R_2} V_o \quad \text{---- (ii)}$$

Case -1. $V_o = +V_{sat}$.

$$V_{UT} = \frac{R_2}{R_1 + R_2}(+V_{sat}) \ldots$$

Case - 2. $V_o = -V_{sat}$.

$$V_{LT} = \frac{R_2}{R_1 + R_2}(-V_{sat}).$$

* The hysteresis voltage is given by

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

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

$V_{UT} \to$ value of V_{in} which forces $+V_{sat} \to -V_{sat}$

$V_{LT} \to$ " " " " $-V_{sat} \to +V_{sat}$.

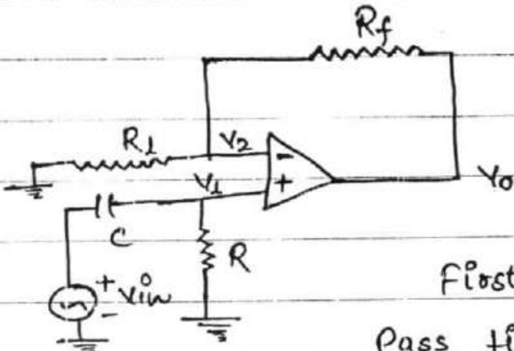
3(b)

First Order high Pass Butterworth Filter -

A first order active high pass filter as its gain indicates attenuates low frequencies & passes high frequency signals. The first order high pass filter can be formed simply by interchanging the resistor R & capacitor C in the first order LPF.

* The roll of rate of first order high pass filter is +20dB/decade

Circuit Diagram -



First order High Pass filter

Apply voltage Divider rule

$$V_1 = \frac{R \times V_{in}}{R + \frac{1}{sC}}$$

$$V_1 = \frac{V_{in} \times R}{R + \frac{1}{j\omega C}} = \frac{R \times V_{in}}{R + \frac{1}{j2\pi f C}}$$

$$V_1 = \frac{(R \times j2\pi f C)\, V_{in}}{1 + j2\pi f RC} \quad \text{—— (i)}$$

Let us substitute $2\pi RC = \frac{1}{f_L}$

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

from eqn (i), $V_1 = \frac{j(f/f_L)\, V_{in}}{1 + j(f/f_L)}$ —— (ii)

Since, we know that Pass band gain of the filter

$A_F = \frac{V_o}{V_1}$ or $V_o = A_f \times V_1$ —— (iii)

using eqn (ii) & (iii)

$$V_o = \frac{A_f\left(j\frac{f}{f_L}\right) V_{in}}{1 + j(f/f_L)}$$

$$\frac{V_o}{V_{in}} = A_F \left[\frac{j\, f/f_L}{1 + j(f/f_L)} \right] \quad \text{—— (iv)}$$

· Hence the magnitude of the voltage gain is

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

where, $A_F = 1 + \frac{R_f}{R_1}$ = Pass band gain of the filter.

f = frequency of the input signal (Hz).

$f_L = \frac{1}{2\pi RC}$ = Low cutoff frequency (Hz).

- The operation of the first order HPF may be explained with the help of equation.

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

1) At very low frequencies i.e. $f < f_L$ we have $\frac{V_o}{V_{in}} < A_f$.

2) With the increase in operating frequency, the filter gain also increases. At $f = f_L$ i.e., the low cut-off frequency.

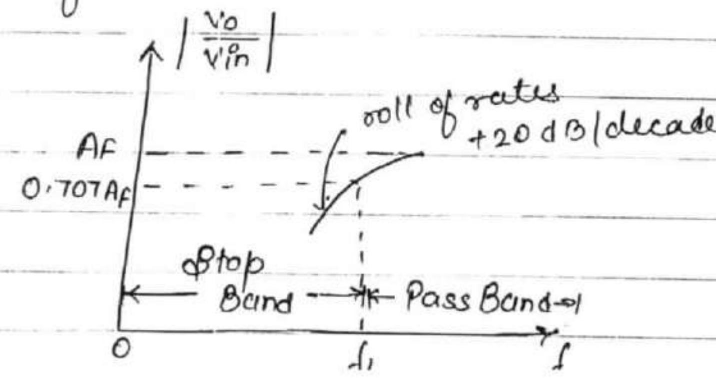
$$\left| \frac{V_o}{V_{in}} \right| = \frac{A_F}{\sqrt{2}} = 0.707\, A_F.$$

Thus, the filter gain is down by 3dB or 0.707 corresponds to -3dB gain.

3) At high frequencies i.e. $f > f_L$ we have $\left|\frac{V_o}{V_{in}}\right| \cong A_F$ i.e. constant.

Hence the filter gain remains constant at A_F in the pass band.

<u>Frequency response of First Order HPF</u> –



4(a)

Que Design a wide band reject filter having $f_H = 400\,Hz$ and $f_L = 2\,KHz$ with a pass band gain of 2 & also draw its frequency response calculate f_C.

Soln Step-I Design of high pass filter.

Let $C = 0.01\,\mu F$, $f_L = 2\,KHz$.

$$f_L = \frac{1}{2\pi RC} \quad \text{or} \quad R = \frac{1}{2\pi f_L C} = \frac{1}{2\pi \times 2\times10^3 \times 0.01\times10^{-6}}$$

$$= 7.957\,K\Omega.$$

Step-II. Design of LPF

Let $C' = 0.05\,\mu F$, $f_H = 400\,Hz$

$$R' = \frac{1}{2\pi f_H C'} = 7.957\,K\Omega.$$

* The pass band gain of both the filter must be equal to 2.

$$A_F = 1 + \frac{R_f}{R_1}.$$

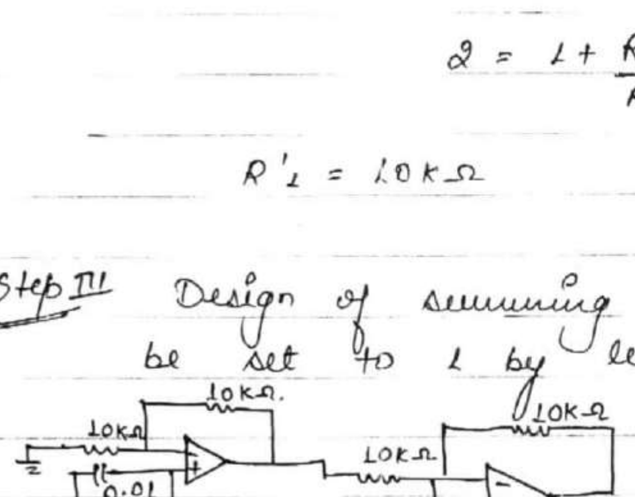
$$2 = 1 + \frac{R_f}{R_1}. \quad \text{Or} \quad R_f = R_1 \quad \text{we select } R_1 = 10\,K\Omega$$

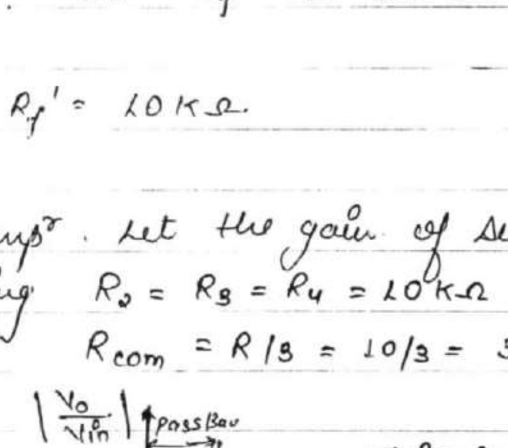
$$R_f = 10\,K\Omega.$$

$R'_1 = 10\,K\Omega$ $\qquad$ $R_f' = 10\,K\Omega.$

Step III Design of summing ampr. Let the gain of summing ampr be set to 1 by letting $R_2 = R_3 = R_4 = 10\,K\Omega$

$$R_{com} = R/3 = 10/3 = 3.33\,K\Omega.$$





$$f_C = \sqrt{f_H f_L}$$
$$= \sqrt{400 \times 2\times10^3}$$
$$= 894.427\,Hz.$$

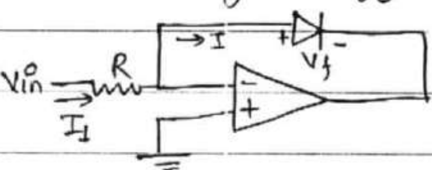
Since we know that op-amp can be used in two modes of operation the linear mode & the saturation mode (non-linear). some non-linear signal processing operations like logarithmic amplifier, anti-logrithmic. Analogue multipliers & many more can be performed using the linear region operation of op-amps.

4(b)

Logarithmic Amplifier-

Logarithmic amplifiers are non-linear circuits in which the output voltage of the ampr is proportional to the logarithm of the input voltage.

The non-linear characteristics of semiconductor devices such as diodes or transistors along with op-amps are used to construct logarithmic ampr shown in given fig.



Since we know that the relationship b/w the current & voltage of a p-n junction diode is given by

$$I = I_s e^{\frac{V_F}{\eta V_T}} \text{ ——— (i)}$$

Taking the logarithm of both sides of equation (i)

$$\log I = \log I_s + \frac{V_f}{\eta V_T}.$$

$$\log I - \log I_s = \frac{V_f}{\eta V_T}.$$

$$V_f = \eta V_T (\log I - \log I_s) \text{ ——— (ii)}$$

$$V_o = -V_f$$

$$= -\eta V_T(\log I - \log I_s) \text{ ——— (iii)}$$

I is given by $I = \frac{V_{in}}{R}$ — (iv)

Substituting equation (iv) in equation (iii), we get

$$V_0 = -\eta V_T \left[\log \frac{V_{in}}{R} - \log I_s \right] \quad \text{— (v)}$$

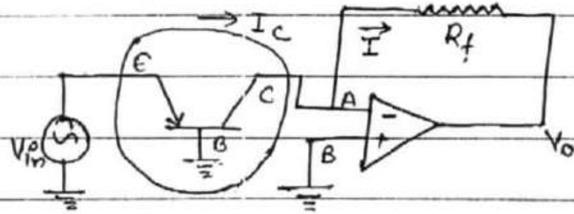
Thus eqn (v) the output voltage of the logarithmic amplifi is proportional to the input voltage.

Now the output voltage of a logarithmic ampr conta two temperature dependent terms :-

(i) Scaling factor ηV_T.
(ii) Offset term $\log I_s$.

Therefore, the logarithmic ampr is very sensitive to temp to minimize this temp effect this process is known as Temperature compensated Logarithmic amplifier.

Antilog Amplifier using Transistor - 5(a)



* The same circuit acts as an antilog of the input. It can be obtained by using a transistor instead of a diode. This circuit is shown in above fig.

$$I_c = I_s e^{V_{in}/\eta V_T} \quad \text{---- (i)}$$

$$I = \frac{0 - V_o}{R_f} = \frac{-V_o}{R_f} \quad \text{---- (ii)} \quad \text{Applying KCL}$$

From equation (i) and (ii)

$$-\frac{V_o}{R_f} = I_s e^{V_{in}/\eta V_T}$$

$$\boxed{V_o = -I_s R_f \cdot e^{V_{in}/\eta V_T}}$$

$$\boxed{V_o = -V_{ref} \cdot e^{V_{in}/\eta V_T}}$$

∴ The output voltage is proportional to V_{in} i.e. the antilog of V_{in}

2.42 SECOND-ORDER ACTIVE FILTERS BASED ON BIQUADRATIC TRANSFER FUNCTION : (b) (BASIC TWO-INTEGRATOR-LOOP BIQUAD) (CKHN Filter)

Consider the second order high pass transfer function

$$\frac{V_{hP}}{V_{in}} = \frac{KS^2}{S^2 + S\left(\frac{\omega_C}{Q}\right) + \omega_C^2} \qquad ...(1)$$

where k is the high frequency gain. ω_C is cut-off frequency, V_{hP} is output of second order high pass filter and V_{in} is input voltage of the filter.

Cross multiplying the equation (1), we get

$$V_{hP} S^2 + S\left(\frac{\omega_C}{Q}\right) V_{hP} + \omega_C^2 V_{hP} = K S^2 V_{in}$$

by dividing both side by S^2 in above equation, we get

$$V_{hP} + \frac{1}{Q}\left(\frac{\omega_C}{S} V_{hP}\right) + \left(\frac{\omega_C^2}{S^2} V_{hP}\right) = K V_{in} \qquad ...(2)$$

For getting V_{hP} in terms of its single- and double-integrated version of V_{in} as

$$V_{hP} = K V_{in} - \frac{1}{Q}\frac{\omega_C}{S} V_{hP} - \frac{\omega_C^2}{S^2} V_{hP} \qquad ...(3)$$

To realize the equation (3) with block diagram as in Fig. 2.42 (*a*).

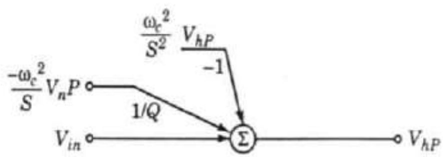


Fig. 2.42 (*a*).

Here the signal $\left(\frac{\omega_C}{S}\right) V_{hP}$ can be obtained by passing V_{hP} through an integrator with a time constt. Equal to $\left(\frac{1}{\omega_C}\right)$. Passing the resulting signal through an another identical integrator results in the third signal as $\left(\frac{\omega_C^2}{S^2}\right) V_{hP}$, block diagram is given in Fig. 2.42 (*b*).

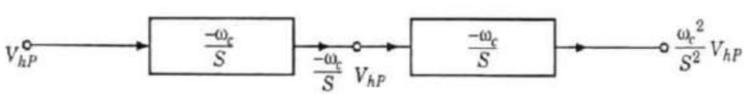


Fig. 2.42 (*b*). Block diagram of two-integrator loop.

Now it is easy to see that a complete block diagram realization can be obtained by combining the integrator blocks with the summer block from Fig. 2.42 (*b*) as in Fig. 2.42 (*c*).

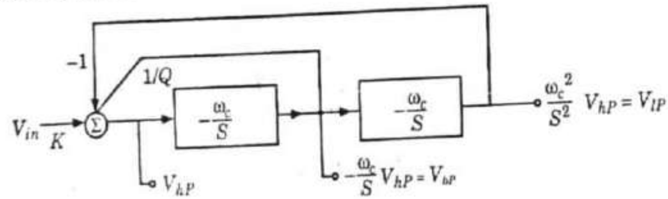


Fig. 2.42 (c). Complete block diagram of biquad filter.

At the output of the summer, realizes the high-pass transfer function $T_{hP} = \frac{V_{hP}}{V_{in}}$. The signal at the output of the first integrator is $-\left(\frac{\omega_C}{S}\right) V_{hP}$ which is a band pass function,

$$\frac{\left(\frac{-\omega_C}{S}\right)V_{hP}}{V_{in}} = -\frac{K\omega_C S}{S^2 + S\left(\frac{\omega_C}{Q}\right) + \omega_C^2} = T_{bP}(S) \qquad ...(4)$$

The signal at the output of the first integrator is labelled V_{bP}, the center-frequency gain of the bandpass filter realized is equal to $-KQ$.

Similarly, the transfer function realized at the output of the second integrator is the low-pass function.

$$\frac{\left(\frac{\omega_C^2}{S^2}\right)V_{hP}}{V_{in}} = \frac{K\omega_C^2}{S^2 + S\left(\frac{\omega_C}{Q}\right) + \omega_C^2} = T_{lP}(S) \qquad ...(5)$$

Transfer Function of Second-order Filtering Function

Transfer function of high pass filter is

$$T_{hP} = \frac{V_{hP}}{V_{in}}$$

where V_{hP} obtained at the output of summer circuit for transfer function of band-pass filter is

$$T_{bP} = \frac{V_{bP}}{V_{in}} = \frac{\left(\frac{-\omega_C}{S}\right)V_{hP}}{V_{in}}$$

$$= \left(\frac{-\omega_C}{S}\right)\frac{KS^2}{S^2 + S\left(\frac{\omega_C}{Q}\right) + \omega_C^2}$$

$$\boxed{T_{bP} = \frac{-K\omega_C S}{S^2 + S\left(\frac{\omega_C}{Q}\right) + \omega_C^2}} \qquad \text{...(6)}$$

Similarly Transfer function of Low-pass filter is

$$T_{lP} = \frac{V_{lP}}{V_{in}} = \left(\frac{\omega_C^2}{S^2}\right) \frac{V_{hP}}{V_{in}}$$

$$\boxed{T_{lP} = \frac{V_{lP}}{V_{in}} = \frac{-K\omega_C S}{S^2 + S\left(\frac{\omega_C}{Q}\right) + \omega_C^2}} \qquad \text{...(7)}$$

and d.c. gain of low pass filter is equal to K