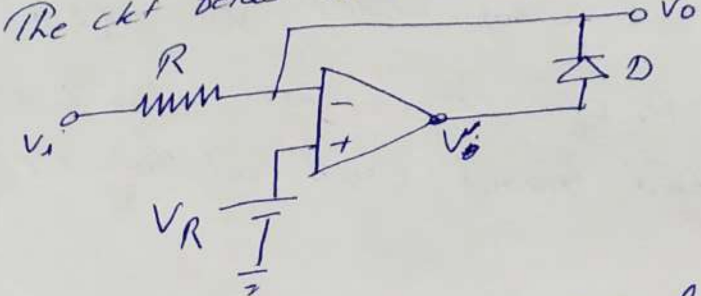
Precision clamp

— The ckt below illustrate Precision clamp ckt.



- If $V_i < V_R$ than V' is +ve and D conduct and $V_o = V_R$.
- If $V_i > V_R$ then V' is −ve and D is OFF then $V_o = V_i$
- Hence the o/p follows the i/p for $V_i > V_R$ and V_o is clamped to V_R if $V_i < V_R$ by about 0.1 mV.

Fast Half-wave Rectifier

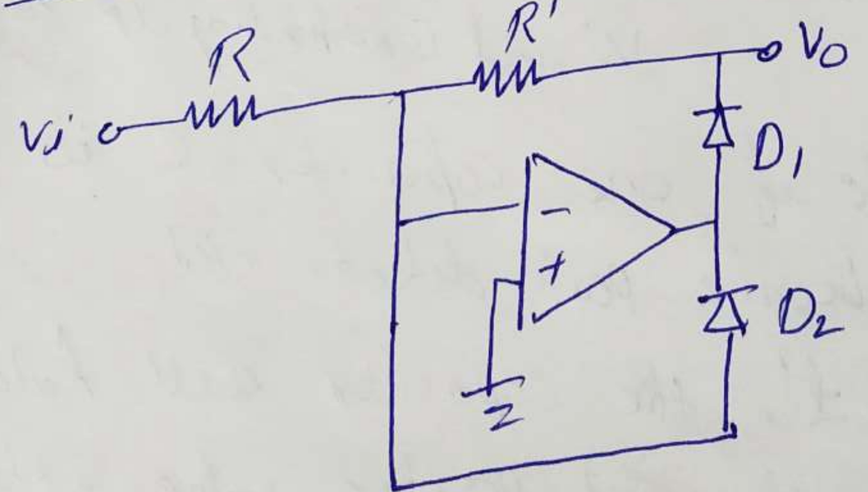


Fig:- A half wave Rectifier

- The fast half wave rectifier is shown above.
- For V_i to be $-ve$ D_1 conduct and $D_2 = OFF$ and ckt behaves as an inverting OPAMP, $V_o = -(R'/R)V_i$.
- For V_i to be $+ve$ D_1 OFF D_2 CONDUCT, due to F/B through D_2 a virtual ground exists at the i/p and $V_o = 0$.
- A rectification upto 100MHz is possible.

Active Peak Detector

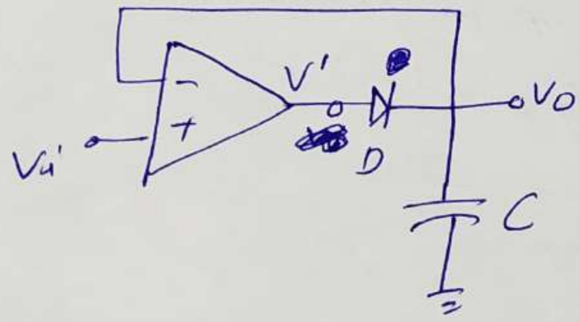
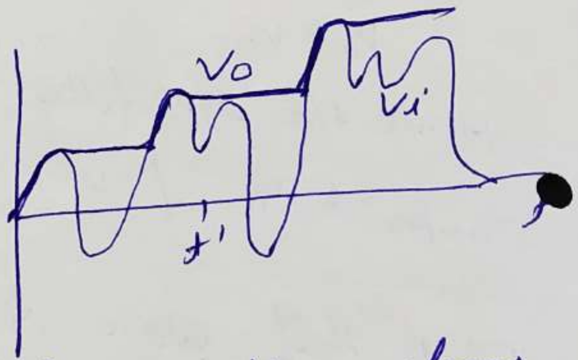


Fig (a) +ve peak detector



(b) Arbitrary i/p waveforms Vi and corresponding o/p Vo.

- In the precision diode if one capacitor C is added then the circuit became peak detector ckt
- Consider the graph at t', the capacitor will hold the O/P at $t = t'$ to the most positive value attained by the i/P V_i prior to t'.

- The ckt is a voltage follower ckt and also can be consider to a special case of sample and hold ckt
- If $V_i > V_o$, OPAMP o/p V_o = +ve and D conducts The capacitor C is charged through D by the o/p current of ampr.
- As V_i falls below capacitor volt, the OPAMP gets -ve and diode become reverse biased. Thus the capacitor gets charged to the most +ve value of the i/p. Hence called peak detector.

Logarithmic Amplifiers

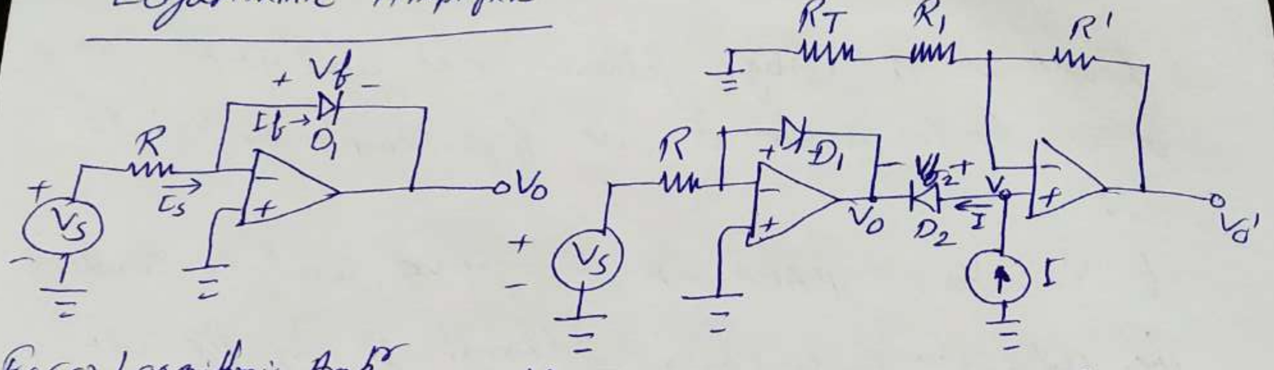


Fig (a) Logarithmic Ampr   (b) Temp. - Compensated Ampr.

- In the logarithmic ampr, feedback resistor R is replaced by diode D_1 and also it gives logarithmic value of i/p volt at the o/p volt.

- Now as we know, volt-amp. diode characteristic

$$I_f = I_0 (e^{V_f/\eta V_T} - 1) \simeq I_0 e^{V_f/\eta V_T}$$

also, $V_f/\eta V_T \gg 1$ or $I_f \gg I_0$

Hence $V_f = \eta V_T (\ln I_f - \ln I_0)$ — (i)

Now due to virtual ground at the ampr i/p we have

$i_f = i_s = V_s/R$

$$V_0 = -V_f = -\eta V_T \left(\ln \frac{V_s}{R} - \ln I_0\right) \text{ — (ii)}$$

Now eqn (ii) reflects V_0 is temp. dependent due to scale factor ηV_T and also due to saturation current I_0. This effect can be reduced by Fig (b) arrangement.

From Fig (b) and from eq (II) we have

$V = V_{f2} + V_0$

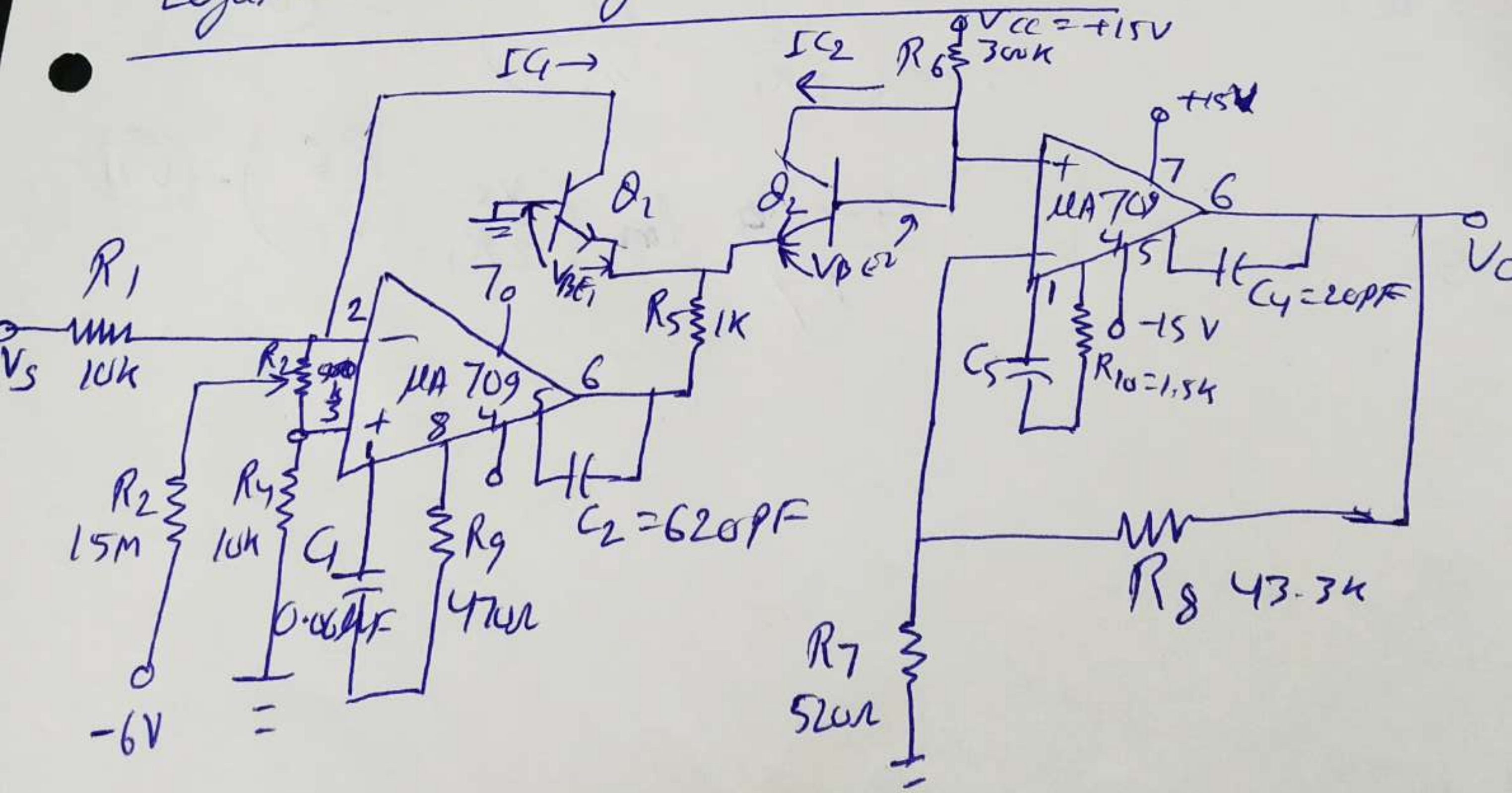
$= \eta V_T (\ln I - \ln I_0 - \ln \frac{V_0}{R} + \ln I_0) - \eta V_T \ln \frac{V_S}{RI}$ — (III)

Thus O/p volt V_0' becomes

- $$V_0' = - \frac{R_T + R_1 + R'}{R_1 + R_T} \eta V_T \ln \frac{V_S}{RI} \quad \text{— (IV)}$$

- Hence in eq (IV) R_T will be selected in accordance to compensate the effect of ηV_T.

Logarithmic Amp^r using Matched Transistor



Logarithmic Amp^r using Transistor

- In the previous equation of V_o', term η was present, whose value depends on the current flowing through diode. To get rid of that term matched transistor pair are used.

- Q_1 is F/B ampr and Q_2 act as temp. compensator.
- If we neglect $V_{BE1} - V_{BE2}$ w.r.t to V_{CC} and as $I_{B2} << I_{C2}$ then

$$I_{C2} \simeq \frac{V_{CC}}{R_6} \quad \text{and } I_{C1} = \frac{V_S}{R_1 + R_4} = \frac{V_S}{2R_1} \quad \text{— (V)}$$

Now as we know

$$V_{BE1} - V_{BE2} = V_T \ln I_{C1} - V_T \ln I_{C2}$$

$$= V_T \ln\left(\frac{V_S}{2R_1} \cdot \frac{R_6}{V_{CC}}\right) \quad \text{— (VI)}$$

So $$V_o = -V_T \frac{R_7 + R_8}{R_7} \ln\left(\frac{V_S}{2R_1} \cdot \frac{R_6}{V_{CC}}\right) \quad \text{— (VII)}$$

Antilog Amplifier

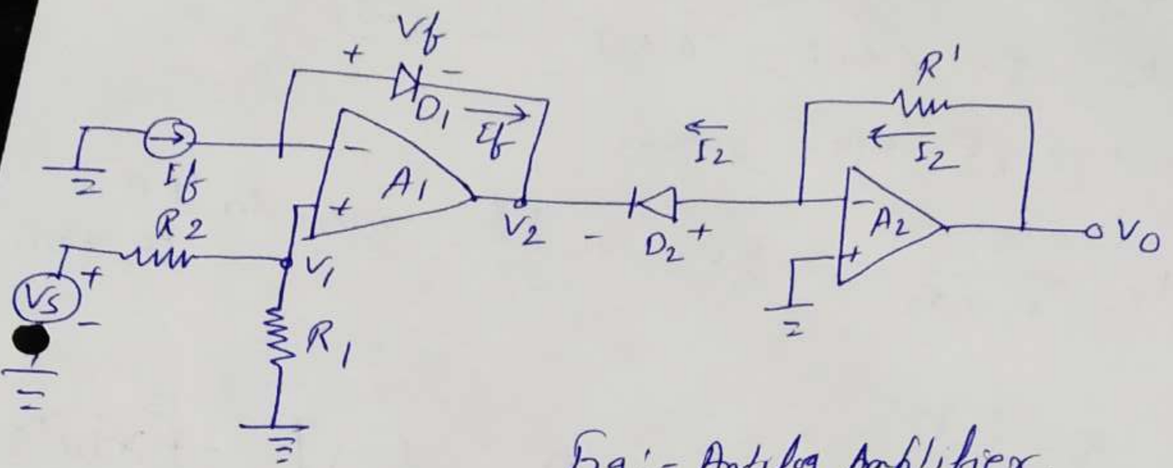


Fig:- Antilog Amplifier.

- The above diagram shows the circuit with OPAmp for antilog amplification.

- In the antilog ampr we can find antilog of i/p V_i signal at the O/p as V_o.

- In logarithmic ampr $V_o \propto (\ln) V_i$ or $V_o = K_1 \ln K_2 V_S$ — (VIII)

- $V_o = K_3 \ln^{-1} K_4 V_S$ or $V_o \propto (\ln^{-1}) V_i$ — (IX)

- Consider infinite i/p resistance for A_1 & A_2 as well as zero differential i/p volt. for each OP Amp we have

$$V_2 = -V_f + V_1 = \eta V_T(\ln I_f - \ln I_o) + \frac{R_1}{R_1+R_2} V_S \quad \text{— (X)}$$

As V_2 is the negative of voltage across D_2

$$V_2 = -\eta V_T (\ln I_2 - \ln I_0) \quad \text{——} \quad (XI)$$

Combining (X) & (XI) yields.

$$V_S \frac{R_1}{R_1+R_2} = \eta V_T \ln \frac{I_f}{I_2} = \eta V_T \ln \frac{I_f R'}{V_0} \quad (XII)$$

as $V_0 = I_2 R'$

$$V_0 = R' I_f \ln^{-1}\left[-V_S\left(\frac{R_1}{R_1+R_2} \frac{1}{\eta V_T}\right)\right] \quad \text{—} \quad (XIII)$$

Logarithmic Multipliers

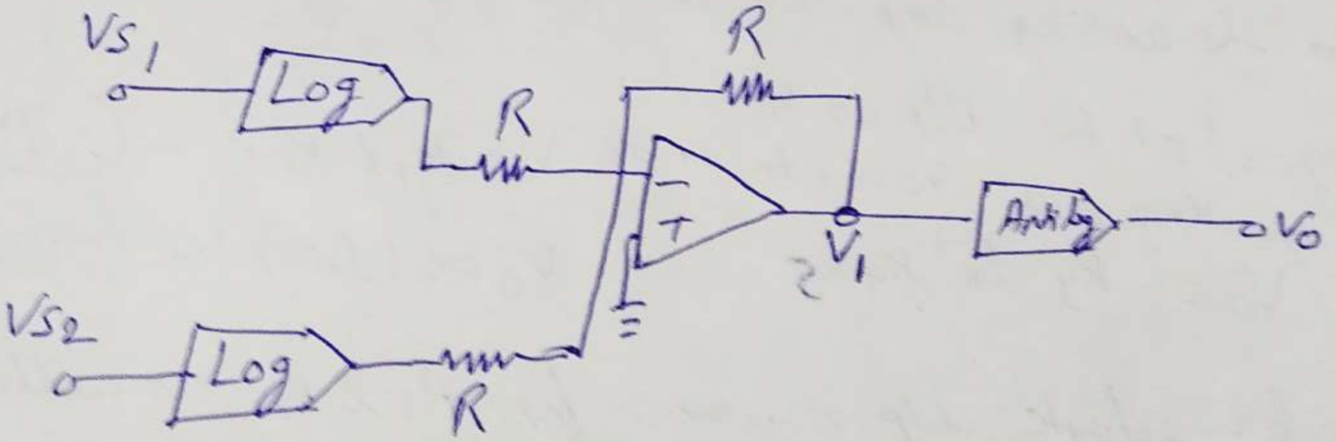


Fig Logarithmic multiplier of two signal V_{S_1} & V_{S_2}

The log and antilog can be used for multiplication or division of two analog signal V_{S_1} & V_{S_2}.

Now $V_1 = K_1 \ln V_{S1} + K_1 \ln V_{S2}$

$= K_1 \ln V_{S1} V_{S2}$ — (XIV)

and $V_0 = K_2 \ln^{-1} K_3 V_1$

$= K_2 \ln^{-1} (K_3 K_1 \ln V_{S1} V_{S2})$ — (XV)

If $K_3 K_1 = 1$ then

$V_0 = K_2 V_{S1} V_{S2}$ — (XVI)

- For the division operation substraction of $\log V_{S1}$ from $\log V_{S2}$ to be done and then antilog to be performed.

- Logarithmic multiplication ~~of~~ or division is useful for unipolar inputs only. Hence it is called as one-quardrant operation.

Differential Amplifier Multiplier

— As we know o/p volt. of a differential ampr depends on source current I.

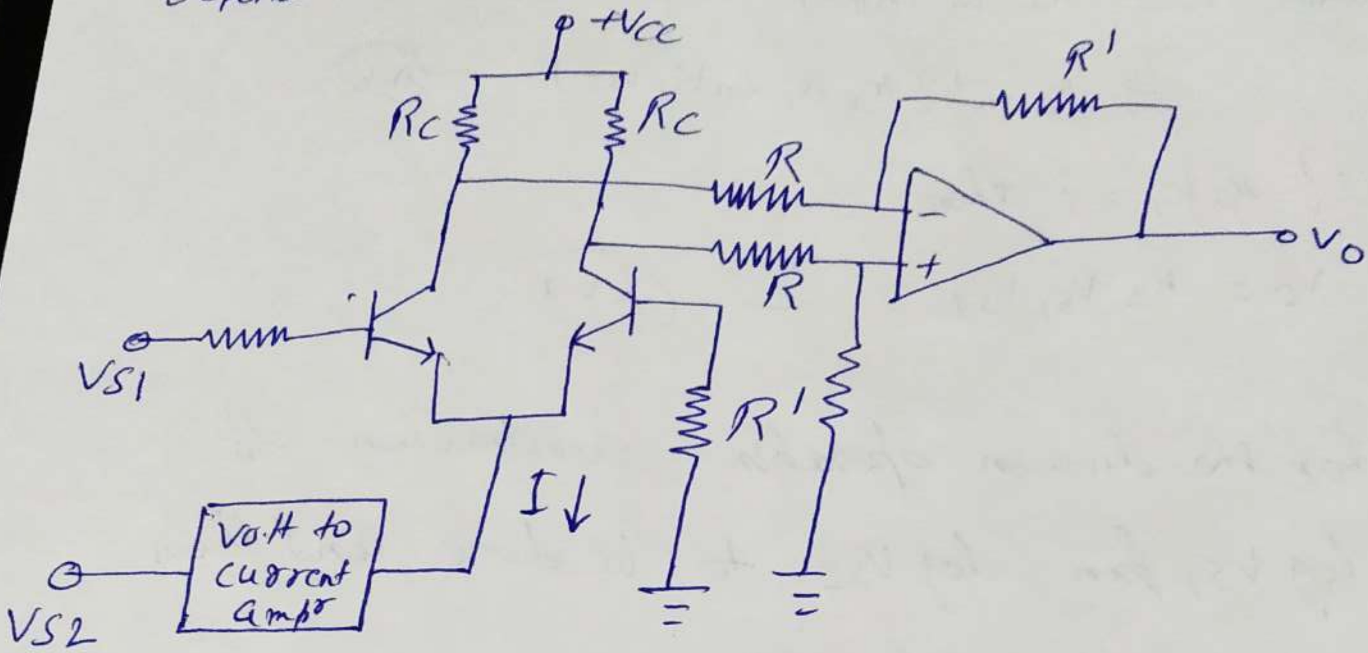
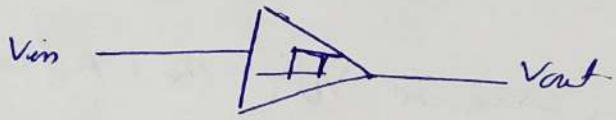


Fig:— Variable transconductance multiplier
($V_0 = k V_{S1} V_{S2}$)

- If V_{S1} is applied to one i/p and V_{S2} is used to vary I as shown above, the o/p will be proportional to the product of two signals V_{S1}, V_{S2}.

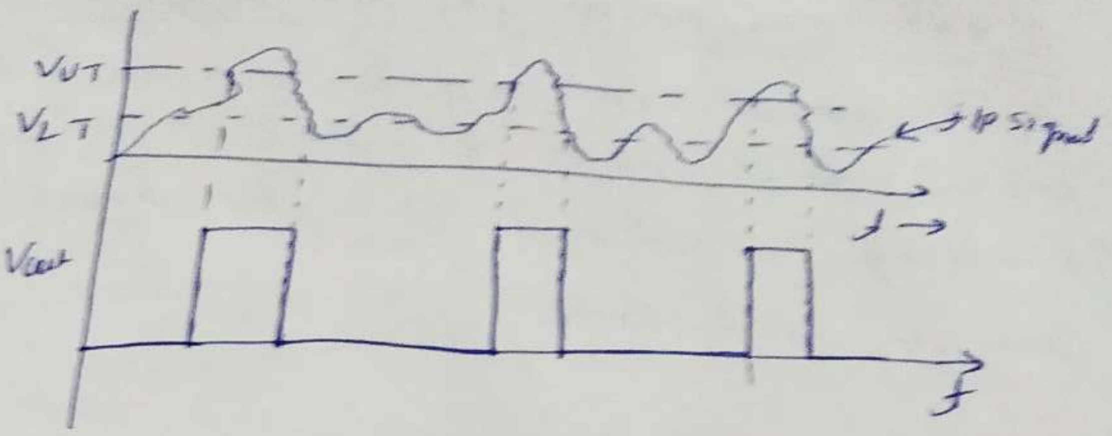
Regenerative Comparator (Schmitt Trigger)

- General comparator is not very much immune to the noise and the o/p get effected due to it. Hence Schmitt trigger is introduced. It is also known as comparator with hysteresis.



- It is also known as squaring circuit as it is use to convert any regular or irregular shaped i/p waveform into a square wave o/p volt or pulse.
- They are also called as regenerative comparator, due to the fact that they change their o/p state when i/p signal crosses predetermined switching levels.
- Schmitt trigger generally contains two levels namely upper limit and lower limit, and any practicle graph or volt having random behaviour can be represented by these two levels.

In the upcoming graph one i/p signal (random volt) is shown and two threshold level namely Lower threshold (V_{LT}) and upper threshold (V_{UT}) is shown.



- Now as i/p signal crosses the V_{UT} the o/p of volt shows a upper rectangular peak and it remains in that state till the i/p signal drop below to V_{LT}. Similarly a rectangular lower pulse is indicated for the same. And as the i/p signal again cross the upper threshold (V_{UT}) the graph goes to upper threshold till it again drop below to lower level (V_{LT}).

- The volt. between V_{LT} & V_{UT} is known as hysteresis volt and this also define noise immunity of the circuit.

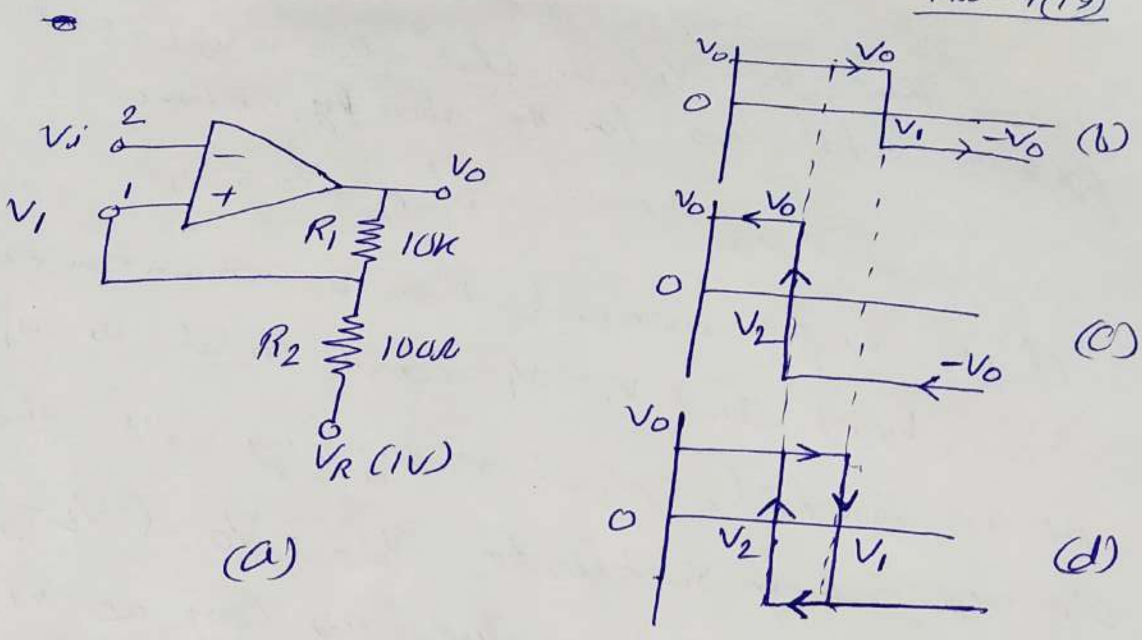


Fig (a) schmitt trigger. The transfer characteristics (b) encreasing Vi (c) decreasing Vi (d) Composite i/p - o/p curve.

- The above figure shows schmitt trigger along with its characteristics. The i/p volt is applied to inverting terminal 2 and feedback to terminal 1.
- The feedback factor $\beta = \frac{R_2}{R_1+R_2}$ for $R_1 = 10K$ & $R_2 = 100\Omega$

Hence $A_V = -5,000$ the loop gain

$$-\beta A_V = 0.1 \times \frac{5000}{10.1} = 49.5 >> 1$$

Assume that $v_i < V_1$ so that $v_o = +V_o$ (+5V)
By using superposition from the above fig we have.

$$v_1 = \frac{R_1}{R_1+R_2} V_R + \frac{R_2}{R_1+R_2} V_o = V_1$$

- If now v_i get increased then v_o remain constant V_o (V_{UT}) and $v_1 = V_1$ = const. untill $v_i = V_1$. At this threshold, critical or triggering volt the o/p regeneratively switches to $v_o = -V_o$ (V_{LT}) and remains at this value as long as $v_i > V_1$. The whole funct^n is shown in transfer characteristics.

- The volt at non-inverting terminal for $v_i > V_1$ is

$$v_1 = \frac{R_1}{R_1+R_2} V_R - \frac{R_2}{R_1+R_2} V_o = V_2$$

Putting values of R_1 & R_2 with $V_o = 5V$ we have

$V_1 = 1.04V$ & $V_2 = 0.94V$

- Difference between V_1 & V_2 is V_H called as hysteresis. $V_H = V_1 - V_2 = \frac{2R_2 V_o}{R_1+R_2} = 0.1V$

If v_i get decreased then the o/p remains at $-V_o$ untill v_i equals the volt. terminal 1 or until $v_i = V_2$. At this volt a regenerative transition takes place and o/p returns to $+V_0$ almost instantaneously.

- As per the transfer characteristics of Schmitt trigger arrow is indicating the variation of v_i. As fig (b) denote increasing v_i, fig (c) denotes decreasing v_i and fig (d) indicate composite i/p - o/p curve.

- The value of V_H should be small, due to large backlash range will affect the proper function of the circuit.

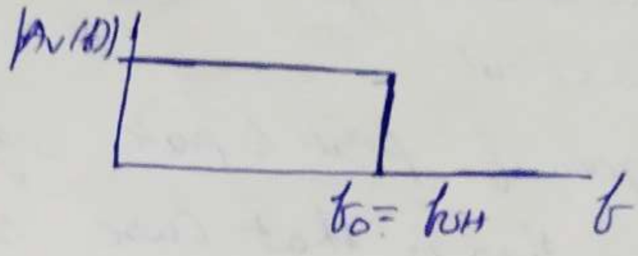
- Again if peak to peak signal were smaller than V_H than in that case Schmitt trigger can't reset itself ie it will continue to any one state and remain on that state only not jump from V_0 to $-V_0$ or vice versa.

Active Filters

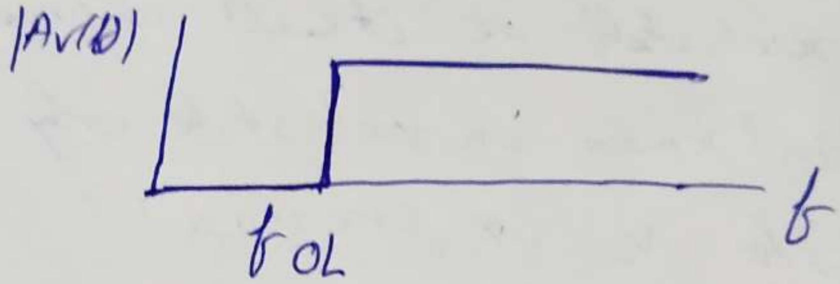
- Filters are circuit that pass only a certain range of signal frequencies and attenuate unwanted frequencies.
- In accordance to band of frequencies filter can be divided as low pass, high pass, band pass and band reject (stop) filters.

Filter | Ideal Characteristics

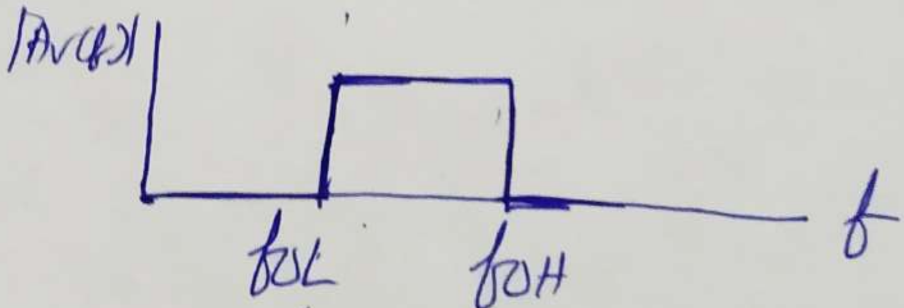
(i) Low pass



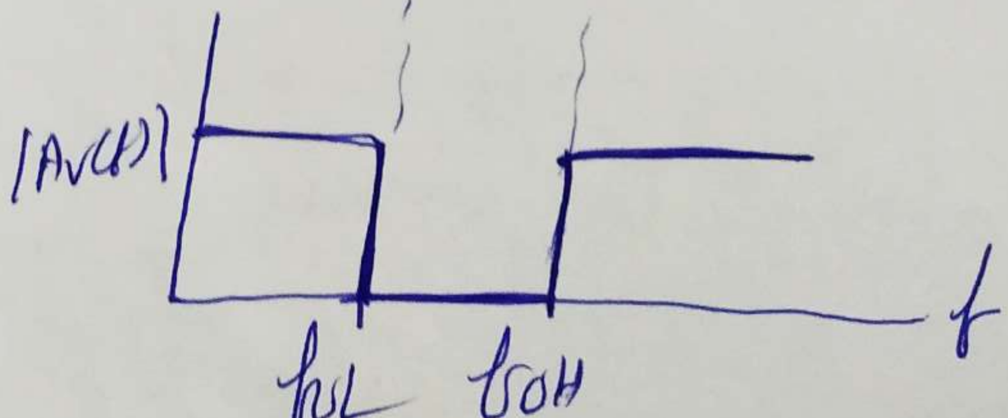
(ii) High pass



) Band pass



Band Reject



Butterworth Filter

- For an ideal low pass filter, an approximation is given in the form

$$A_v(s) = \frac{1}{P_n(s)} \quad \text{—— (i)}$$

where $P_n(s)$ — Polynomial in the variable s with zeros in the left-hand plane

- In the butterworth filter a little change in eq (i) is desired

$$A_v(s) = \frac{A_{V_0}}{B_n(s)} \quad \text{with } s = j\omega \quad \text{—— (ii)}$$

$$|A_v(j\omega)|^2 = A_v(s) A_v(-s) = \frac{A_{V_0}^2}{1 + (\omega/\omega_0)^{2n}} \quad \text{—— (iii)}$$

Equating (ii) & (iii) we have

$$|B_n(j\omega)| = \sqrt{1 + \left(\frac{\omega}{\omega_0}\right)^{2n}} \quad \text{—— (iv)}$$

- For the realization of Butterworth filter, we have to concentrate the normalized butterworth polynomial table and also on the first column. As we find that at higher order of n, the graph of butterworth L-P-F is tending towards ideal condition

Table Normalized Butterworth polynomials

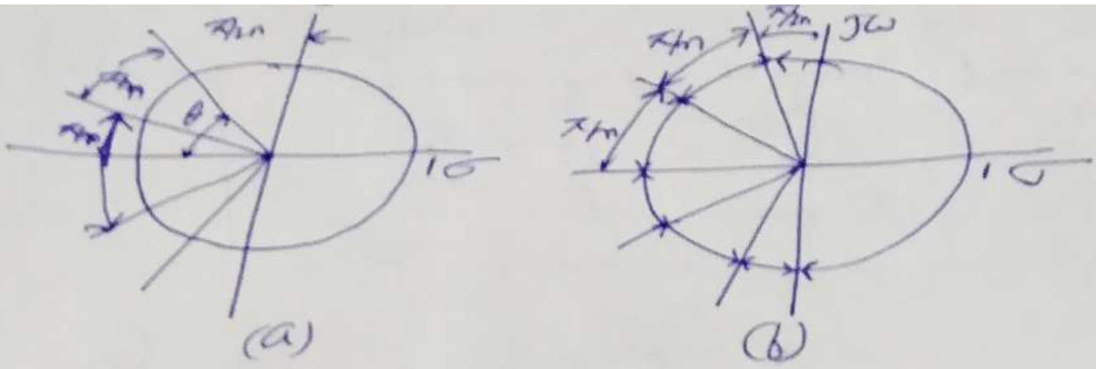
n	Factors of polynomials $B_n(s)$
1	$(s+1)$
2	$(s^2+1.414s+1)$
3	$(s+1)(s^2+s+1)$
4	$(s^2+0.765s+1)(s^2+1.848s+1)$
5	$(s+1)(s^2+0.618s+1)(s^2+1.618s+1)$
6	$(s^2+0.518s+1)(s^2+1.414s+1)(s^2+1.932s+1)$
7	$(s+1)(s^2+0.445s+1)(s^2+1.247s+1)(s^2+1.802s+1)$
8	$(s^2+0.390s+1)(s^2+1.111s+1)(s^2+1.663s+1)(s^2+1.962s+1)$

- In the above table for n even the polynomials are product of quadratic forms and for n odd there is present of an additional factor $s+1$.

- Damping factor k is defined as one half the coefficient of s in each quadratic factor of Table above. Like for $n=4$ the damping factor are $\frac{0.765}{2} = 0.383$ and $\frac{1.848}{2} = 0.924$.

where $k = \cos\theta$

$\theta \rightarrow$ defined with butterworth circle each for even & odd shown below.



The Butterworth circle for (a) n even and (b) n odd (one of zero must be at $s=-1$)

- From the Butterworth table one can realized that

for first order filter $\dfrac{AV(s)}{AV_0} = \dfrac{1}{s/\omega_0+1}$ — (V)

second order filter $\dfrac{AV(s)}{AV_0} = \dfrac{1}{(s/\omega_0)^2+2\kappa(s/\omega_0)+1}$

where $\omega_0 = 2\pi f_0$ is the high freq^n 3 dB point

Practical Realization

For the practical realization let us consider a circuit of generalized active-filter prototype as shown below along with its second order low pass section and first order low pass-section

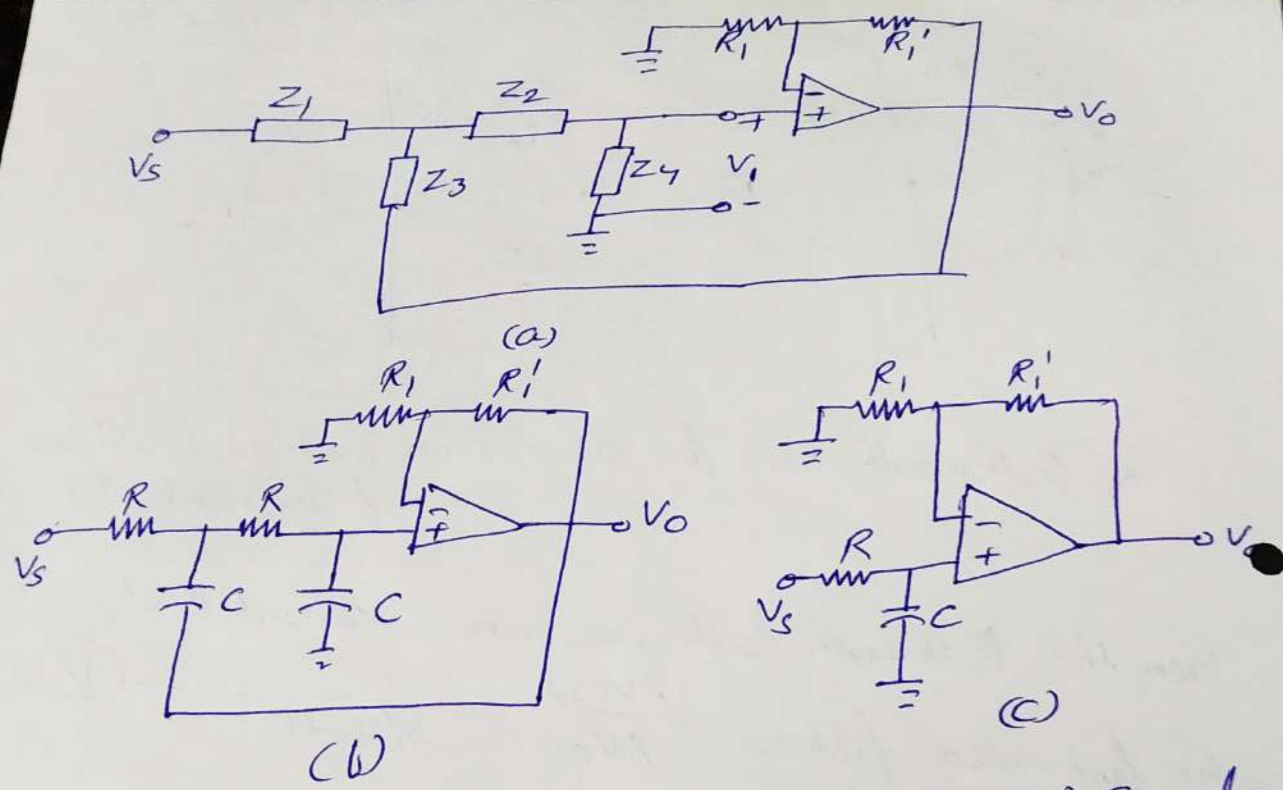


Fig:- (a) Generalized active-filter prototype (b) second-order low pass section (c) First order LPF.

Consider Fig (a) having a stable midband gain $\frac{V_o}{V_i} = A_{Vo} = \frac{R_1 + R_1'}{R_1}$ has to be determined - we assume that the ampr i/p current is zero hence

$$A_v(s) = \frac{V_o}{V_S} = \frac{A_{Vo} Z_3 Z_4}{Z_3(Z_1+Z_2+Z_4) + Z_1 Z_2 + Z_1 Z_4 (1 - A_{Vo})} \quad \text{(VII)}$$

If this n/w is a LPF then Z_1 & Z_2 are resistances and Z_3 & Z_4 are capacitances, having value R & C respectively.

mid 1 (23)

Fig (b) illustrate the second LPF with transfer func^n as

$$A_v(s) = A_{V_0} \frac{(1/RC)^2}{s^2 + \left(\frac{3 - A_{V_0}}{RC}\right)s + \left(\frac{1}{RC}\right)^2} \quad \text{— (VIII)}$$

Comparing (VI) & (VIII)

$$\omega_0 = \frac{1}{RC}$$

- and $2K = 3 - A_{V_0}$ or $A_{V_0} = 3 - 2K$ — (IX)

For analysing even order Butterworth filter eq^n (X) with identical R & C is sufficient;

But in case of odd order Butterworth filter.

it is necessary to cascade (VI) (first order) with

- Second order as shown in fig (b).

- For example a 3rd order Butterworth active filter consists of the ckt in Fig (b) in cascade of Fig (C) with R & C chosen so that $RC = 1/\omega_0$ with A_{V_0} in Fig (b) Selected to $K = 0.5$ (from table $n=3$) and A_{V_0} in Fig C chosen arbitrarily.

Designing consideration of other filters

(i) High-pass prototype:—

- In eqn (vi) interchange $\left.\frac{s}{\omega_o}\right|_{LPF}$ with $\left.\frac{\omega_o}{s}\right|_{HPF}$

- Also interchange R & C in fig (b) in a 2nd order HPF

(ii) Bandpass filter

- Cascade a ~~LPF~~ Low Pass 2nd order having cutoff f_{OH} with a high pass 2nd order section whose cutoff freqn is f_{OL} provided $f_{OH} > f_{OL}$.

) Band Reject filter

- By paralleling a High pass section whose cutoff is f_{OL} with a low pass section whose cutoff freqn is f_{OH} and also $f_{OH} < f_{OL}$.