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STUDY OF KRC FILTERS

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CHAPTER - IV

KRC FILTERS

4.1 INTRODUCTION :-

A single RC stage generates first order low pass response connecting two RC stages in series generates second order response.

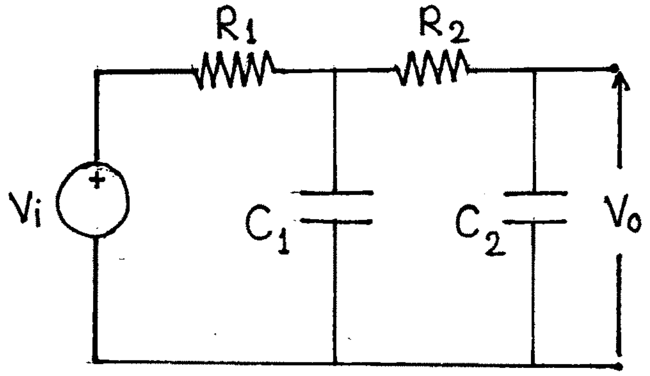

Fig. 4.1 (Second Order Low Pass Response With Passive RC Components)

At low frequency the reactance of capacitor is maximum and all the input signal appear across capacitor and the gain H ≅ 1. At high frequency the reactance of capacitor (Xc) is minimum and there is two step attenuation for input signal.

The passive network shown in fig. 4.1 there is no facility to control the magnitude of the signal, near cutoff frequency fo. The maximum quality factor that can be achieved with passive filter is 0.5. There is limitation on the value of Q due to energy loss in the resistors and due to loading of first RC stage by the second.

The best way to control the magnitude response near cutoff frequency fo is to use an active device like Op. Amp to feed part of the output signal back into the circuit itself. Due to use of Op. Amp. It provides output buffering to make circuit behaviour independent of any output load. Such configuration of passive RC network along with active device Op. Amp. is called Sallen-Key configuration.

4.2 SALLEN KEY LOW-PASS FILTER :-

To correct the magnitude response near cutoff frequency fo active device like Op. Amp. is used to feed part of output signal back into the circuit. This feedback is achieved through capacitor nC to the Op. Amp. output. This feedback is positive feedback. This feedback path is effective only at the cutoff frequency fo

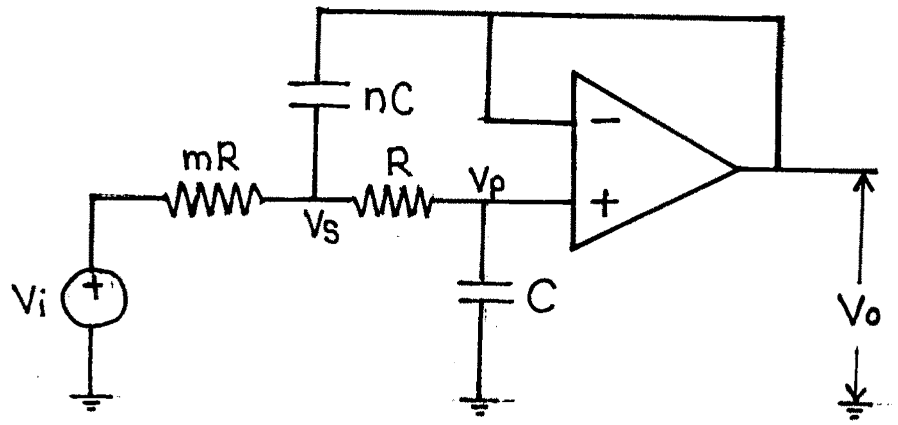

Fig. 4.2 (Unity gain Sallen Key low pass filter)

The value of first RC pair is expressed in terms of the second pair by means of multipliers m and n respectively.

Vp is the voltage at the noninverting input. Op. Amp. is used as a unit gain amplifier therefore Vp = Vo

$$Vo = \frac{Xc}{Xc + R} Vs \qquad \ldots \qquad (4.1)$$

$$Xc \rightarrow \text{reactance of capacitor} = \frac{1}{j2\pi fC} \quad \frac{1}{jwc}$$

$$Vo = \frac{Vs}{1 + jwRC} \qquad \ldots \qquad 4.2$$

From Fig.

$$\frac{Vi - Vs}{MR} = \frac{Vs - Vp}{R} + \frac{Vs - Vo}{1/jwnC} \qquad \ldots \qquad 4.3$$

Multiplying both sides by mR

$$Vi = (1 + m + jwmnRC)\, Vs - (m + jwmnRC)\, Vo \ldots 4.4$$

$$Vi = (1 - w^2mnR^2C^2 + jw\,(m+1\_\ RC)\, Vo \qquad \ldots \qquad 4.5$$

$$w^2mnR^2C^2 = (2\pi f\ \sqrt{mn}\, RC)^2$$

$$= (f/fo)^2$$

$$\text{where } fo = \frac{1}{2\pi \sqrt{mn}\ RC} \qquad \ldots \qquad 4.6$$

Similarly

$$Jw\,(m+1)\,RC = \frac{J\,(f/fo)\,(m+1)}{\sqrt{mn}}$$

$$= (j/\,Q)\,(f/fo)$$

$$\text{Where } Q = \frac{\sqrt{mn}}{(m+1)} \qquad \ldots \quad 4.7$$

The quality factor Q depends on resistance ration m and the capacitance ration n. While cutoff frequency fo depends on R and C as well as on m and n.

4.3 KRC LOW PASS FILTER :-

The Butterworth response requires Q = 0.707. The Sallen Key low pass filter in Fig. 4.2 is used for fixed cutoff frequency and quality factor. If tuning is required to compensate the effect of component tolerances then that circuit has the drawback that adjusting one parameter also affect the other according to equation 4.6, 4.7 and 4.8.

For high value of Q it requires larger capacitance spread to remove this drawback operational amplifier is used with gain (K) greater than one. Such type of filter with gain K > 1 is called KRC filter. Fig. 4.3 shows KRC filter

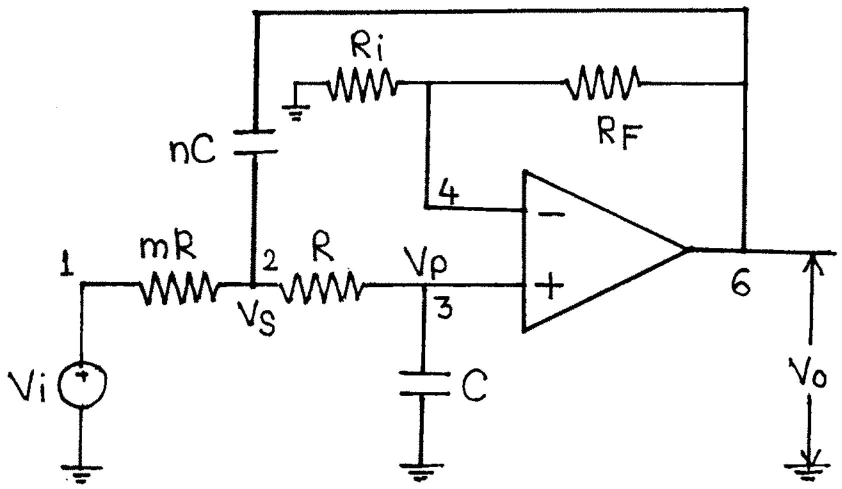

Fig. 4.3 (KRC Lowpass Filter)

The gain of the Op. Amp. used in noninverting mode is

$$K = (1 + R_F / R_i) \quad \ldots \quad 4.9$$

The output voltage $Vo = (1 + R_F / R_i)\, Vp$

Where $Vp = Vs / (1 + jwRC)$

From Fig. 4.3

$$\frac{Vi - Vs}{mR} = \frac{Vs - Vp}{R} + \frac{Vs - Vo}{1/jwnc}$$

Multiplying both sides by mR and eliminating Vs

$$Vo = \frac{K}{1 - (f/fo)^2 + (j/Q)(f/fo)}\, Vi$$

The voltage gain

$$H = \frac{Vo}{Vi} = \frac{K}{1 - (f/fo)^2 + (j/Q)(f/fo)} \quad \ldots \quad 4.10$$

Where

Gain = K = (! + R_F / R_i)

$$fo = \frac{1}{2\pi \sqrt{mn}\ RC} \quad \ldots \quad 4.11$$

and $$Q = \frac{\sqrt{mn}}{m + 1 + mn(1 - K)} \quad \ldots \quad 4.12$$

Equation 4.11 shows that cutoff frequency fo, not depends on the gain K of the amplifier.

The quality factor Q depends on K. Therefore Q is adjusted without affecting fo.

The resistor mR is used to adjust the desired cutoff frequency fo but it also affect Q.

The resistor Ri is used to achieve desired Q but it does not affect cutoff frequency fo.

A) Study of Second Order KRC Low Pass Filter With Variation of m :-

According to equation 4.11 and 4.12, the cutoff frequency fo does not depends on gain K. The cutoff frequency is determined by both m and n. Where m is the ratio of resistance and n is the capacitance ratio m and n both also controls the quality factor Q of the filter circuit.

Design Of Second Order Low Pass Filter :-

To design the second order low pass KRC filter first take m= 1 that is equal resistance in the range 10 K to 100 K i.e. Rx.

Then calculate $Cx = \dfrac{1}{4\pi Q f o R_x}$

Then calculate $n_x = 4Q^2$

Take closest capacitance C and $n_x C$

Use newly found value of n to calculate $k = n/Q^2-2$ and then calculate $m = [K+ \ (K^2-4)] / 2$

Then find $R = \dfrac{1}{[2\pi \sqrt{mn} \ fo\ C]}$

Then select the resistance closest to R and mR

If m = n = 1 then according to equation 4.11 and 4.12

$$fo = \frac{1}{2\pi RC} \quad \ldots \quad 4.13$$

and

$$Q = \frac{1}{2\pi RC} \quad \ldots \quad 4.14$$

If m and n are kept 1 then it avoids excessive component spread for high Q. But for this case the gain k of the amplifier plays important role. Q=10 for K=2.9 i.e. $R_F / R_i = 1.9$.

If the ratio of R_F / R_i changes by ± 1% then Q changes from 8.3 to 12.5.

The circuit is more sensitive to component tolerance.

i) Practical design of second order low pass filter for different m:-

To study the performance of second order low pass filter for different resistance ratio m, the operational amplifier μA 741 is used. The resistances used for the circuit are carbon composition resistance with ± 5% tolerance. The capacitor used in the circuit are ceramic capacitors

The frequency response of second order low pas KRC filter for different values of m is shown in Fig. 4.4.

The circuit is designed for

Gain (K) = 2

Cutoff frequency (fo) = 1000 Hz

Vi = 200 mv.

$R_i = R_F$ = 56k Ohm

The actual component values used to study the effect of variation of m on the frequency response of second order low pass filter (KRC filter) are shown in Table 1.

C = nC = 0.01 μf

Table 1

R K Ohm	mR K Ohm	M	Q
33	8.2	0.2484	0.4983
15	15	1	1
10	27	2.7	1.6431
8.2	33	4.08	2.0199
6.8	39	5.73	2.3937

According to the frequency response of the second order lowpass KRC filter with increase in the value of m the quality factor Q increases.

When frequency f is near to the cutoff frequency fo, a family of curves is obtained depending on the value of Q.

For low m, the transition from passband to stopband is very gradual. For high m, there is a range of frequencies in the neighborhood of fc, where passband gain of lowpass filter is greater than unity, indicating that filter provides gain there. This gain peaking is similar to resonance in RLC circuits.

When Q= 0.707 the curve is maximally flat and response is called the butterworth response. The borderline between gradual and peaked response occurs at Q= 0.707.

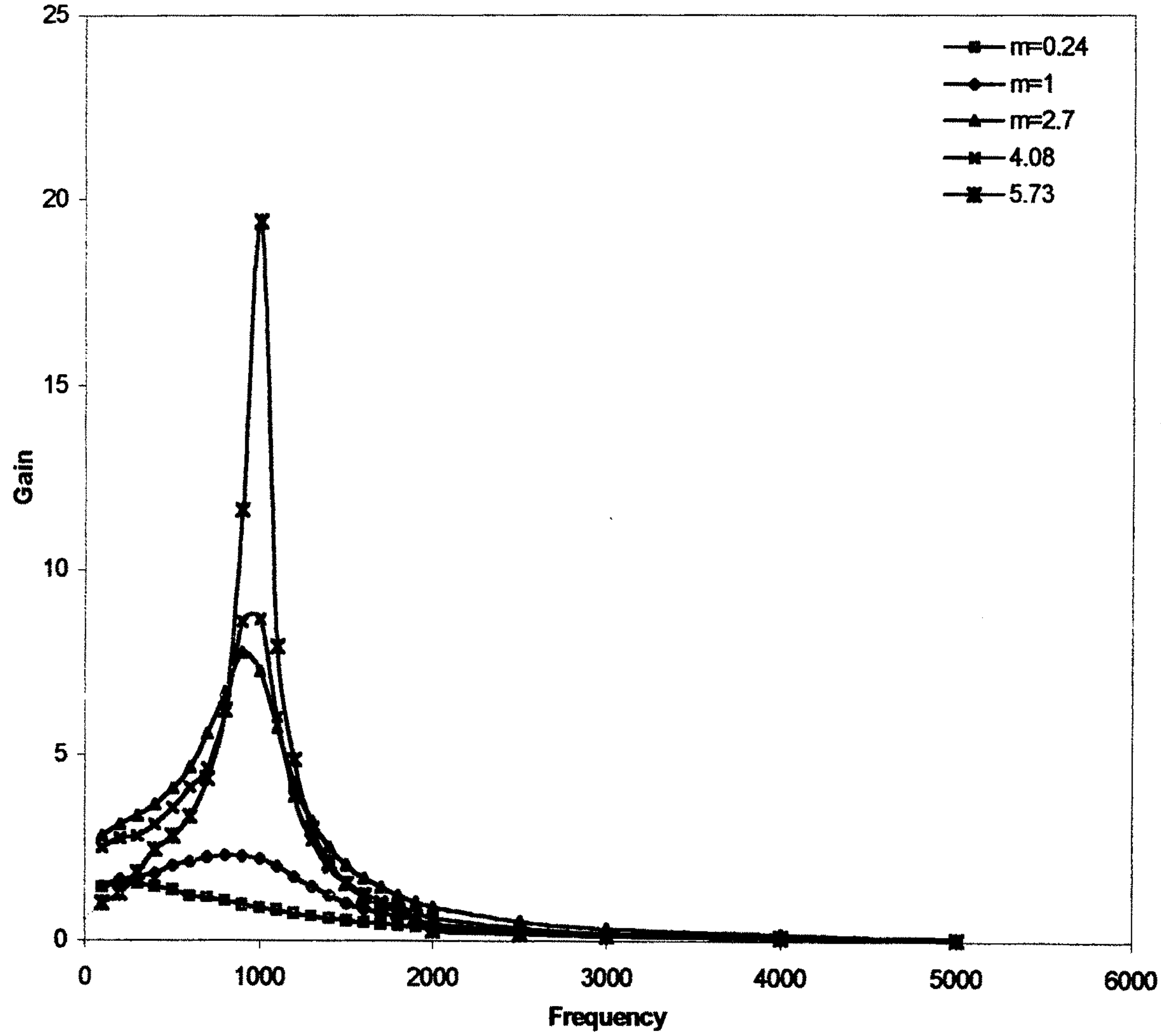

Fig. 4.4

(Frequency response of second order low pass filter for different m)

ii) Study of Low Pass Filter With Variation of m Using PSpice:-

To study the response of KRC low pass filter, student version of simulation software PSpice is used. Due to simulation software it is possible to quickly test circuit over variety of conditions.

In KRC filters, operational amplifier is used to provide gain (K) to the circuit. The operational amplifier is used as a voltage controlled voltage source. To model the operational amplifier as a VCVS, the following parameters of operational amplifier .741 are used

R_i	=	Input resistance	=	2 M. Ohm
R_o	=	Output resistance	=	75 Ohm
A_d	=	Large signal voltage gain	=	20000 K

Using this parameters of IC μA 741 the practical operational amplifier model is shown in Fig.4.5

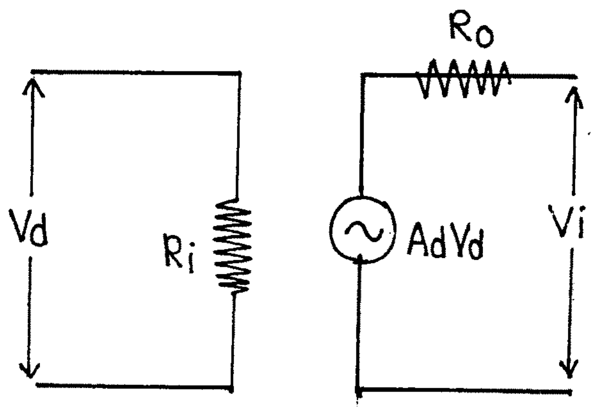

Fig. 4.5 (Practical Operational Amplifier Model)

PSpice Simulation Program for Second Order Low Pass KRC Filter for Different m :-

```
*       Second order low pass KRC filter
*       For different m
Vs      1       O       AC 200mV
• PARAM         m       0.2
R23     2       3       {15913.43/m}
R12     1       2       {15913.43 * m}
C30     3       0       .01µ
R4      4       6       56k
C26     2       6       0.01u
R3      4       0       56K
*       Operational Amplifier
RI      3       4       2 MEG
Ro      5       6       75
Eop     5       03      4       2E+5
*       Output
•. AC DEC 10 a 1 MEG; AC Analysis
•. STEP     PARAM   m   LIST   0.2484   1  2.7   4.08   5.73
•. PRINT AC V[6] V[3]
•. PROBE
•. END
```

The AC analysis of second order lowpass KRC filter is performed from 1 Hz to 1 MHz. The resistance ratio m is varied from 0.2484 to 5.73 the AC analysis of the filter is performed for different value of m.

The frequency response of second order lowpass KRC filter, using simulation software PSpice is shown in fig. 4.6.

iii) Conclusion :-

The frequency response was studied for different values of m. It is noticed that the variation of 'm' affects the Q of the circuit with increase in m the Q of the circuit also increases. The quality factor Q depends on resistance ratio m while cutoff frequency fo also affected by m. The gain peaking was observed while increasing the m. There was no change in the rolloff of gain. It shows that the performance of the filter shows marked dependence on m, the ratio of resistance as well as on the tolerance of the resistors. The sensitivity of Q depends on resistance tolerance and m.

Capacitance ratio n=1

Gain K =2

Cutoff frequency fo= 1000 Hz.

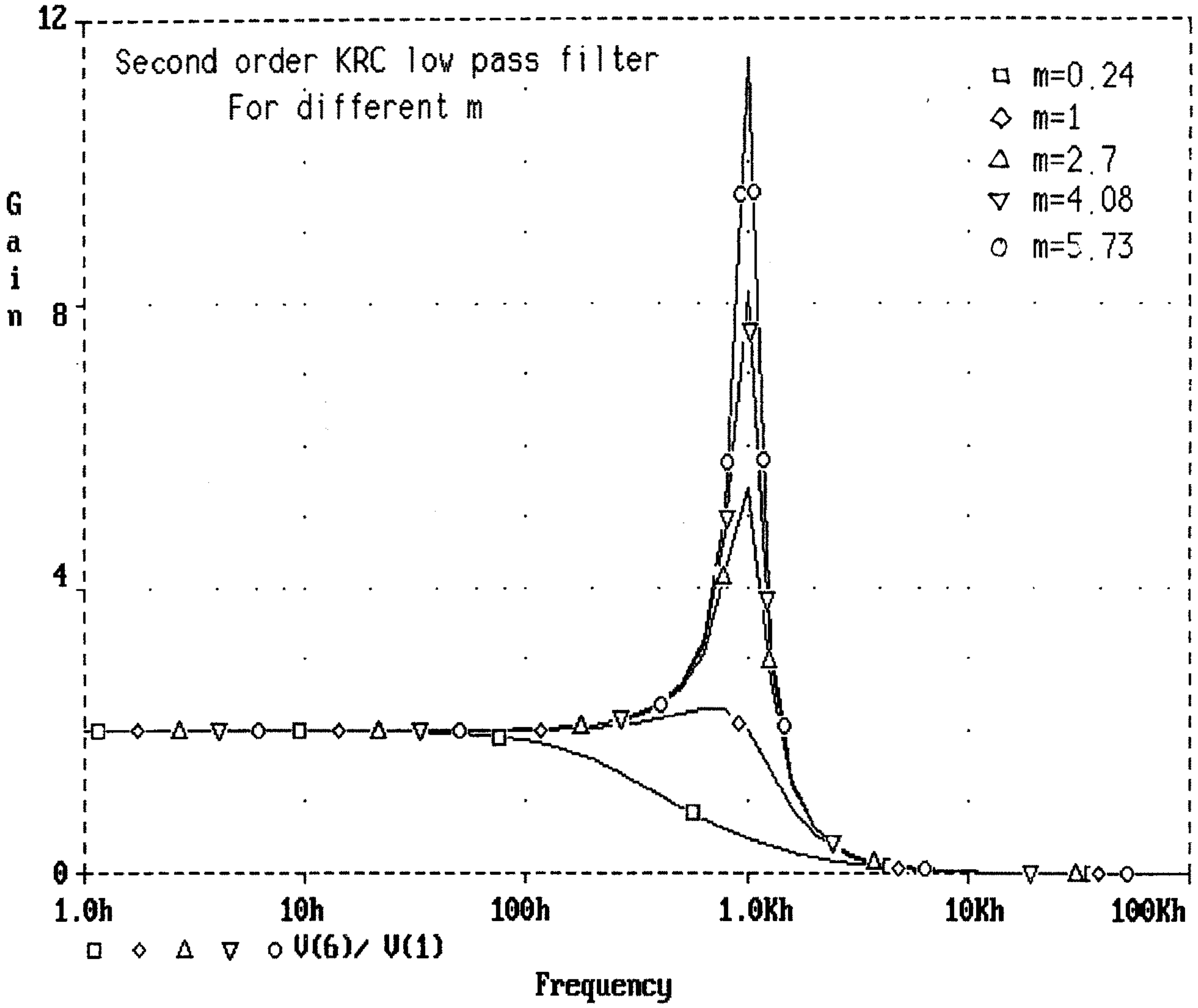

Fig 4.6

Frequency response of second order KRC Low pass filter for different m

B) Study of Second Order KRC Low Pass Filter With Variation of n :-

i) Practical design of low pass filter for different n :

To study the effect of variation of capacitance ratio n on the frequency response of the second order low pass KRC filter, the resistance ratio m is kept constant. The response is studied for different values of n and the gain (K) of the filter circuit is kept constant. According to equation 4.11 and 4.12 the capacitance ratio n and the quality factor Q depends on both resistance ratio m and the capacitance ratio n. The variation of n also affects the cutoff frequency fo. The second order low pass KRC filter is designed for cutoff frequency fo = 1000 Hz.

The resistance ratio m is 0.2

The resistances used are all carbon composition type resistors with tolerance ± 5%.

The gain of the noninverting amplifier is 2 by using equal value resistance $R_i = R_F = 56$ K Ohm.

m = 0.2
fo = 1000 Hz
k = 2

The actual component values used to study the effect of variation of n, on the frequency response of second order low pass KRC filter are shown in table 2.

Table 2

n	$C_{\mu f}$	$nc_{\mu f}$	R K	mR K	Q
1.4242	0.0033	0.0047	100	22	0.5831
1.50	0.0022	0.0033	133	27	0.6085
2.136	0.0022	0.0047	110	22	0.8380
3.3	0.001	0.0033	194	39k	1.5044
4.7	0.001	0.0047	165	33	3.7286

The frequency response of second order low pass KRC filter for different value of n is shown in fig. 4.7. According to frequency response, with increase in the value of n the quality factor Q increases. When the frequency f is near to the cutoff frequency fo a family of curve is obtained depending on the value of Q. Upto n =2 the transition from pass band to stopband is very gradual and obtain a flat frequency response. For higher value of n the gain peaking is observed in the frequency response of the circuit. There is large spreading of capacitor ratio as compares to resistance ratio. The borderline between the peaked response and flat response is observed for Q = 0.707 or n =2.

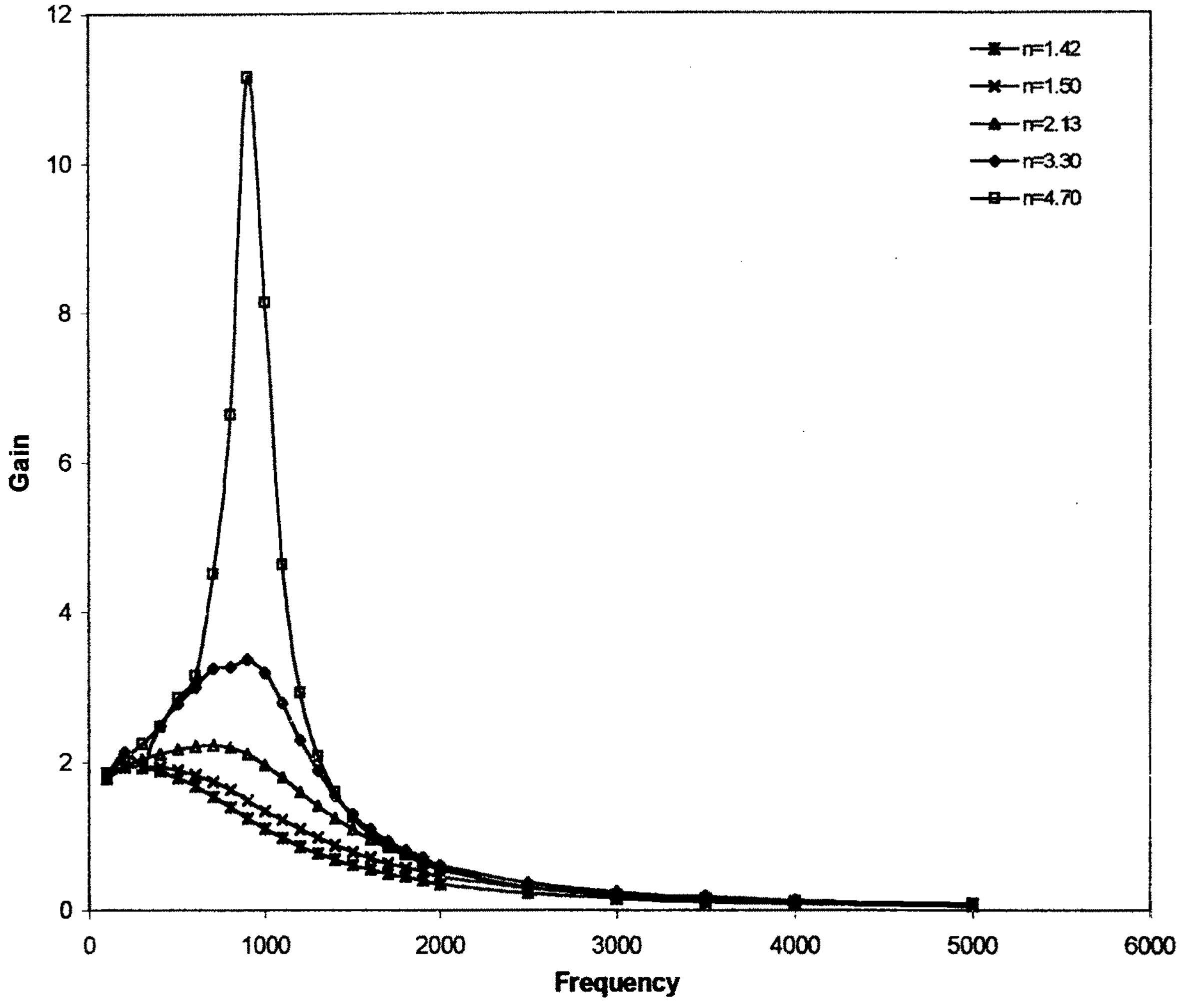

Fig. 4.7

(Frequency response of second order low pass filter for different n)

ii) Study of low pass filter with variation of n using PSpice :-

To study the effect of variation of n, the following simulation programme is used.

```
*       Second order low pass KRC filter
*       For different n
•       PARAM     n     1
VS      1     0     AC     200MV
R12     1     2     33k
R23     2     3     165k
C30     3     0     0.001u
C26     2     6     {0.001u * n}
R4      4     0     56k
R46     4     6     56k
*       Operational Amplifier
RI      3     4     2MEG
RO      5     6     75
EoP     5     0     3     4     2E+5
*       OUTPUT
• AC DEC 10 1 1 MEG
• STEP  PARAM  N  LIST  0.1  0.21  0.33  0.5  1
• PROBE
• END
```

The frequency response obtained using simulation softwares. PSpice and graphical co-processor PROBE is shown in fig. 4.8. From the graph it is observed that the gain peaking is observed exactly at cutoff frequency fo (1000 Hz). For higher value of n gain peaking increases.

iii) Conclusion :-

The capacitance ratio n changes from 1.42 to 4.7 then the quality factor Q changes from 0.5831 to 3.7286. In theoretical curve. The maximum gain in 7 for n = 4.7. In practical frequency response the maximum gain is 11 for n = 4.7. The gain is constant in low frequency range in both response. With increase of n gain peaking is observed exactly at cutoff frequency fo.

Resistance ratio m=0.2

Cut off frequency fo = 1000Hz

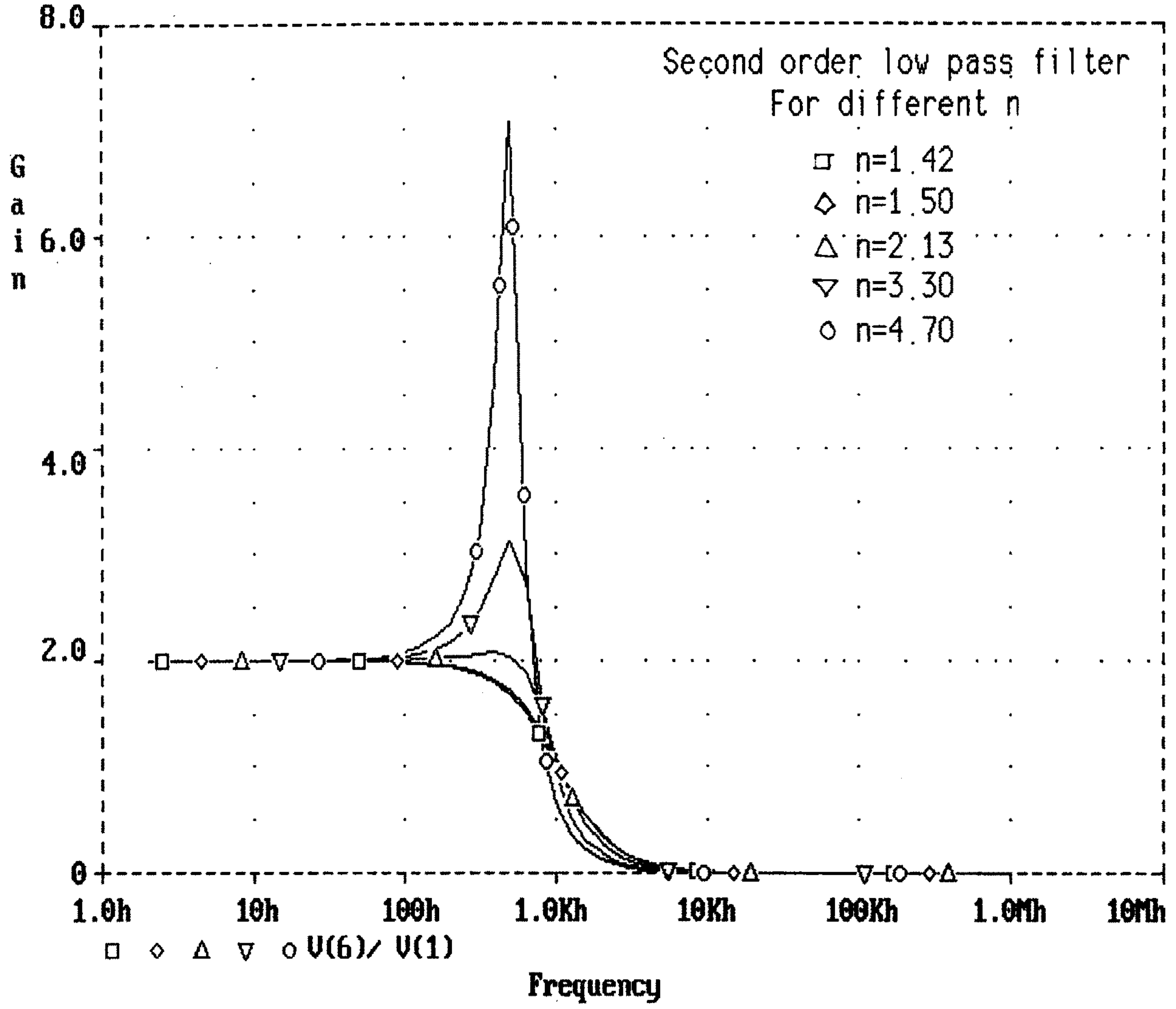

Fig 4.8

(Frequency response of second order KRC low pass filter for different n)

C) Study of Second Order KRC Low Pass Filter With Variation of K :-

The formula for cutoff frequency fo, for second order low pass KRC filter is

$$fo = \frac{1}{2\pi\sqrt{mn}\,RC}$$

It shows that cutoff frequency fo does not depends on the gain K of the amplifier.

The quality factor of second order low pass KRC filter is

$$Q = \frac{\sqrt{mn}}{m + 1 + mn\,(1-k)}$$

According to equation 4.12 the quality factor Q depends on the gain (K) of an amplifier.

If n =1 i.e. equal capacitors are used and the gain (K) of an amplifier is 2 i.e. $R_F = R_i$

Then according to equation 4.12 and 4.11

$Q = \sqrt{m}$

$fo = 1 / 2\pi Q RC$

If m = n = 1 then

$$f_o = \frac{1}{2\pi RC} \quad \ldots \quad 4.15$$

and

$$Q = \frac{1}{3 - K} \quad \ldots \quad 4.16$$

This method avoids excessive component spread the ratio of resistance R_F / R_i must be very precise, since small variation of k may lead to an unacceptably large variation of Q.

If K becomes equal to 3 then according to equation 4.12, Q becomes infinite, causing the circuit to oscillate. Because of the high sensitivity of Q to component tolerances, this circuit is usually restricted to application with $Q < 10$.

i) Practical Design of Low Pass Filter For Different K :-

To study practically the effect of variation of gain (K), on the frequency response of second order KRC low pass filter the operational amplifier μA 741 is used in noninverting mode. All the resistors used in the circuit are carbon composition resistors with ± 5% tolerance. The capacitor used are ceramic disc capacitors. The circuit diagram of second order KRC low pass filter is shown in Fig. 4.3 The resistance ratio m is 0.2484 with R = 33 k and mR = 8.2 k. The capacitance ratio n is 1 with c = nc = 0.01 μf. The circuit is designed for cutoff frequency fo = 1 K Hz. The actual components that are used to study the effect of variation of K on the frequency response of the filter is shown in table 3.

Table 3

R_f	R_i	Gain (K)	m	n	Q
56 k	56 k	2	0.24	1	0.4898
120 k	56 k	3.142			0.6446
150 k	56 k	3.67			0.7952
220 k	56 k	4.92			1.7496
270 k	56 k	5.82			12.24

The frequency response of second order KRC low pass filter for different value of gain (K), observed practically is shown in Fig. 4.9.

The frequency response curve shows that the quality factor Q increases with gain (K). For higher value of gain (K) the gain peaking is observed exactly at cutoff frequency fo. The variation of gain does not affect the cutoff frequency of the filter circuit. The small variation of k, lead to large variation of Q. The high sensitivity of Q is observed to component tolerances. Due to drift or aging the resistance ratio m or capacitance ratio n changes then there is a large variation in Q as compared to change in m or n.

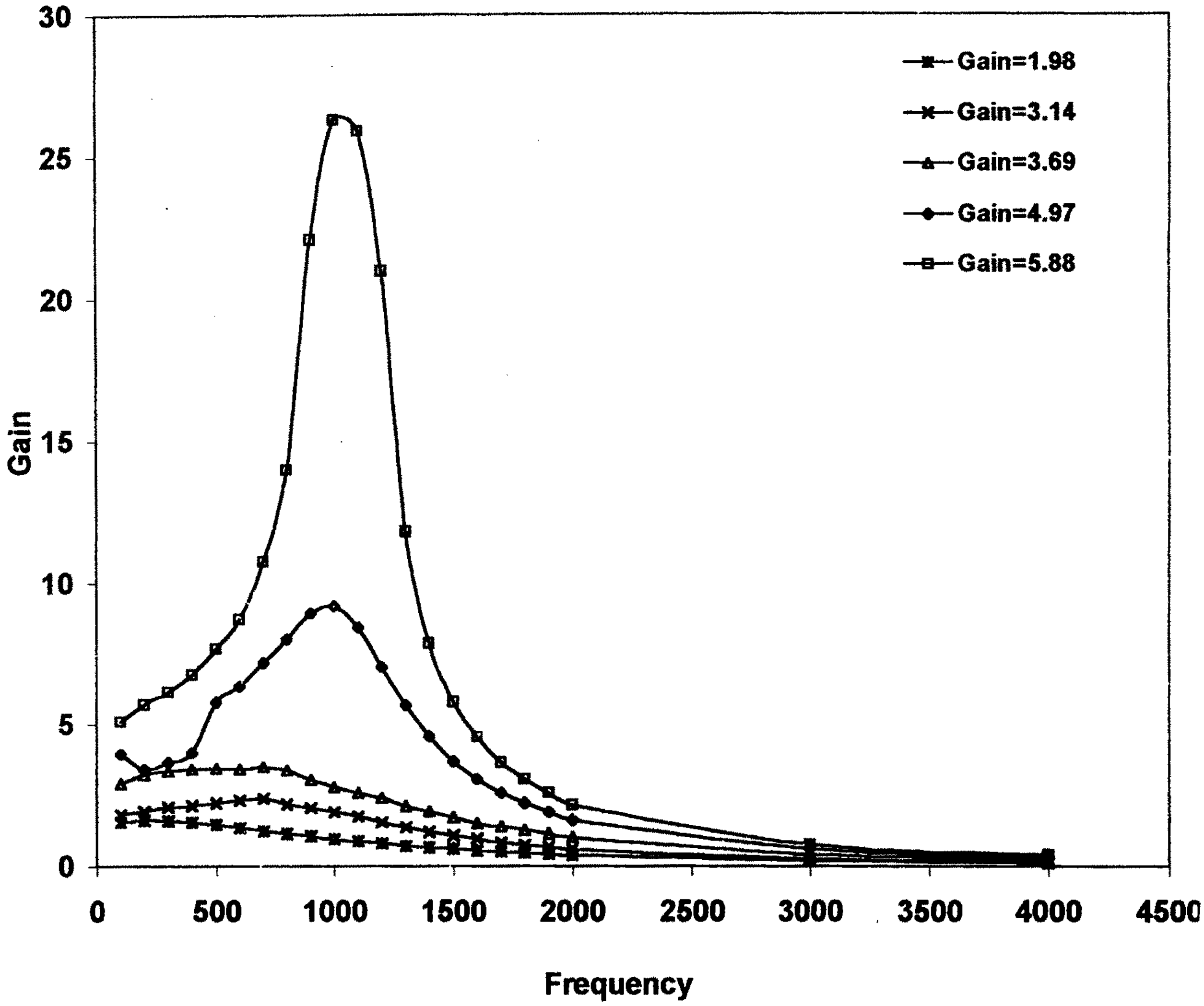

Fig. 4.9

Frequency response of second order KRC low pass filter for different gain (K)

ii) Study of low pass filter with variation of (K) using PSpice :-

To study the effect of variation of gain (K0 on the frequency response using PSpice, linear model of operational amplifier is used. The operational amplifier act as a voltage controlled voltage source. For modelling of operational amplifier parameters of Op. Amp. μA 741 are used. The PSpice programme to study the effect of gain an frequency response is

```
*  Second order low pass KRC filter
*  With variation of k
• PARAM  A12   1 k
VS    1    O    AC    200MV
R23   2    3    33 k
R12   1    2    8.2 k
C30   3    0    0.01 U
Rf    4    6    {A12}
RI    4    0    56 k
C26   2    6    0.01U
*     Operational Amplifier
RJ    3    4    2MEG
RO    5    6    75
EOP   5    0    3    4    2E+5
*     OUTPUT
• AC DEC 10     1     1 MEG
• STEP  PARAM  A12  LIST  56 k  112 k  168k  224 k  280 k
• PROBE
• END
```

The frequency response of low pass filter for different values of k, using graphical co-processor of PSpice is shown in Fig. 4.10.

iii) Conclusion :-

The comparative study of theoretical and practical frequency response for different gain (K), it shows that quality factor Q is depended on K. For resistance ratio m = 0.24 and capacitance ratio n = 1, the quality factor Q changes from 0.48 to 12.24 with change in gain from 2 to 5.82. When K = 5.82, m = 0.24, n = 1 the maximum gain observed practically is 27..Whereas theoretical gain observed is 48. In practical Op. Amp. for large K Op. Amp. drives into saturation.

Resistance ratio m=0.24
Capacitance ratio n = 1
Cut off frequency fo = 1000 Hz.

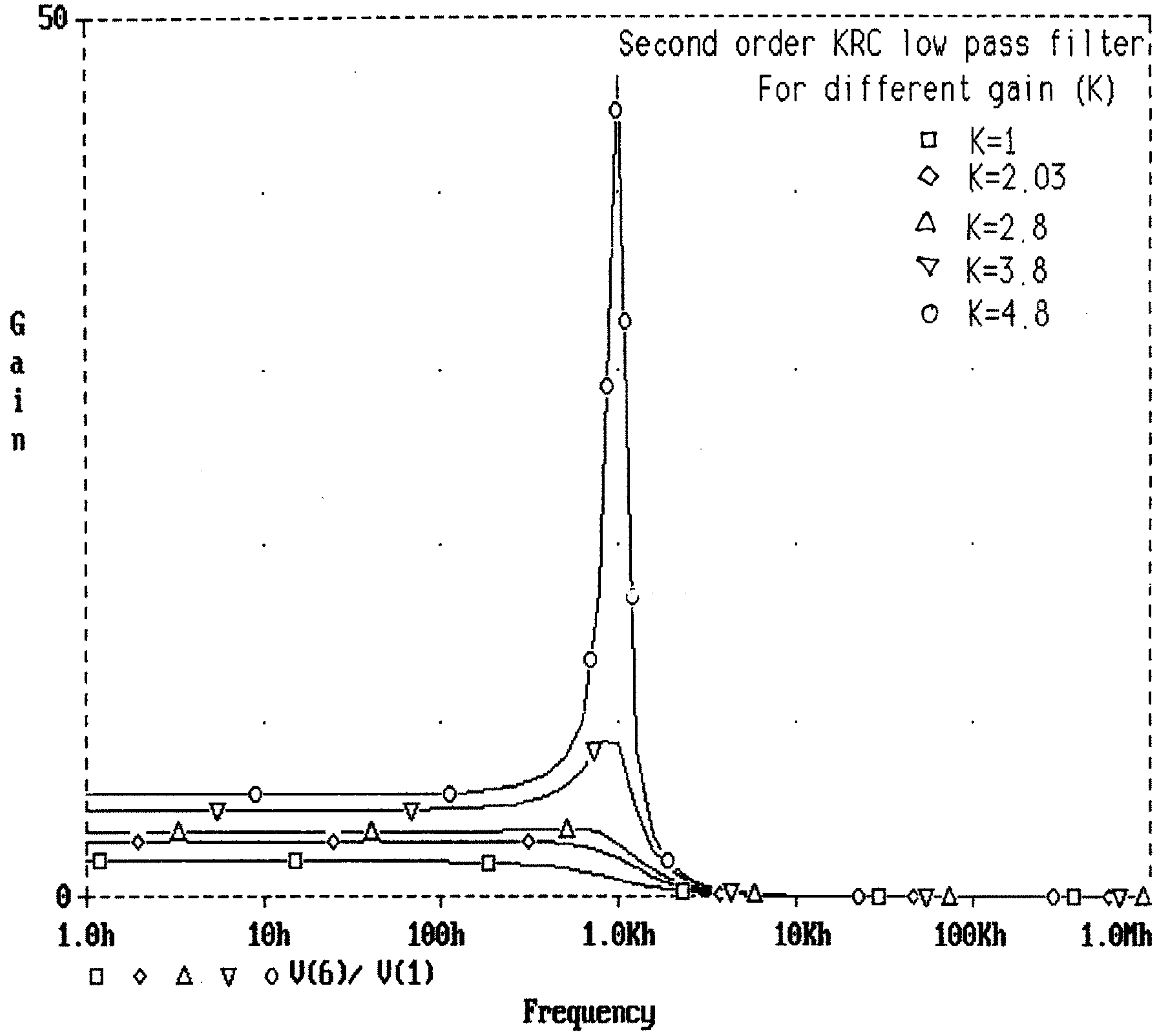

Fig 4.10

(Frequency response of second order KRC Low pass filter for different gain (K))

4.4 STUDY OF KRC HIGH PASS FILTER :-

By interchanging the resistors and capacitors in the unity gain Sallen key low pass filter in Fig. 4.2, turns it into unity gain Sallen key high pass filter shown in Fig.4.11.

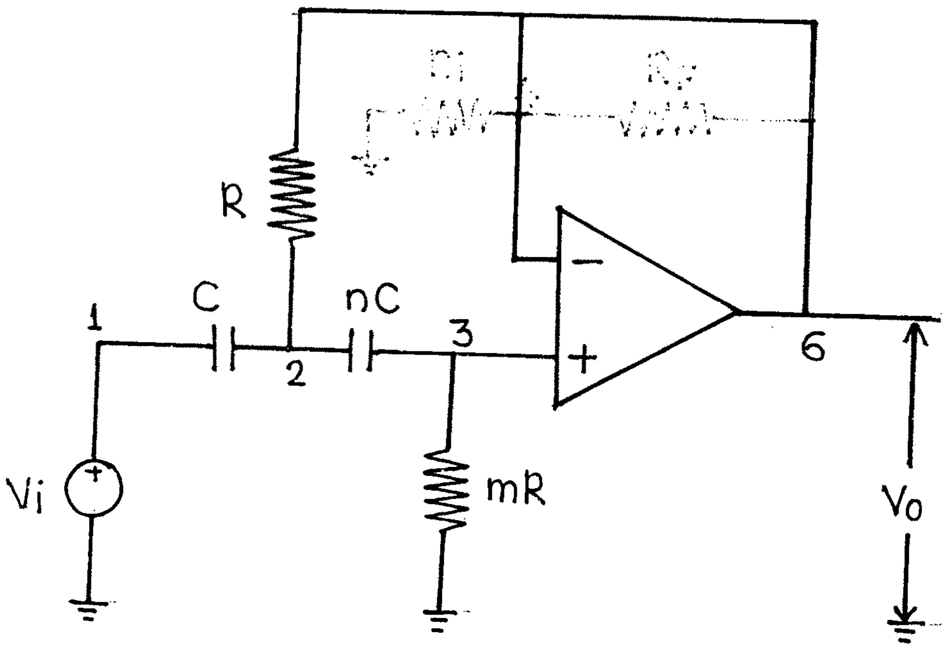

Fig.4.11 (Unity gain Sallen key high pass filter)

The resistance and capacitance are represented in terms of m and n. Where m is resistance ratio, and n is the capacitance ratio.

The transfer function H of unit gain Sallen key high pass filter is

$$H = \frac{-(f/fo)}{1-(f/fo)^2+(j/Q)(f/fo)} \qquad 4.15$$

Where fo is cutoff frequency

$$fo = \frac{1}{2\pi \sqrt{mn}\ RC} \qquad 4.16$$

And quality factor Q is

$$Q = \frac{\sqrt{mn}}{n+1} \qquad 4.17$$

Like low pass filter, Q in high pass filter depends on resistor and capacitor ratio m and n, while fo depends on R and C, as well as on ratio m and n.

The gain of unit gain Sallen key high pass filter is one. The gain K is added in the circuit by using resistors R_F and Ri and the circuit is converted into KRC high pass filter.

Second Order KRC High Pass Filter :-

The tuning difficulties and component spread drawback of unity gain configuration of fig. 411, the gain K > 1 is allowed in the amplifier and circuit is called KRC high pass filter as shown in Fig. 4.12.

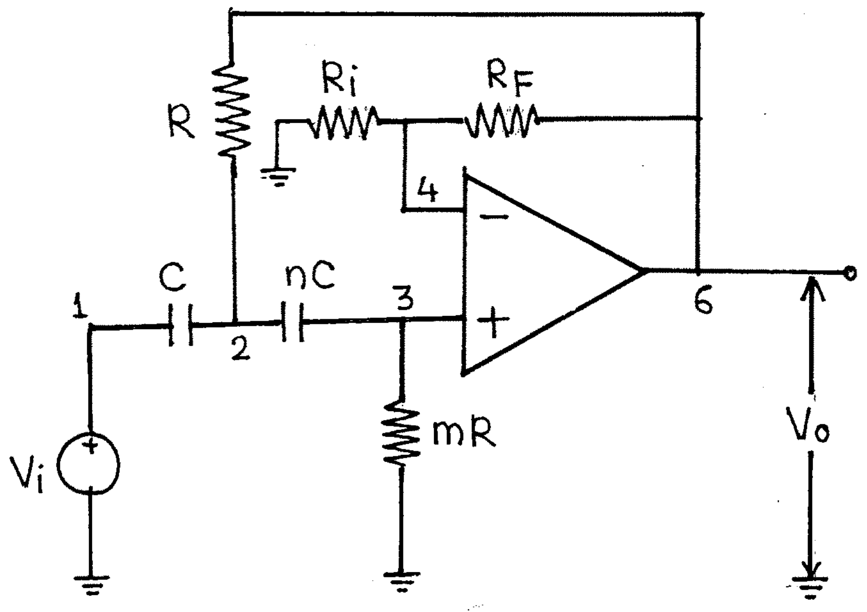

Fig.4.12 (Second Order KRC High Pass Filter)

The resistor R_f and R_I provides gain (K) to the amplifier circuit.

The gain

$$K = \left(1 + \frac{RF}{Ri}\right) \quad \dots \quad 4.17$$

The gain of noninverting amplifier.

By adjusting K the tuning difficulties and component spread drawbacks are removed.

The transfer function H for second order KRC high pass filter is

$$H = \frac{-K\,(f/fo)^2}{1 - (f/fo)^2 + (j/Q)\,(f/fo)} \quad \dots \quad 4.18$$

Where

$$K = 1 + \frac{RF}{Ri}$$

The cutoff frequency fo

$$fo = \frac{1}{2\pi \sqrt{mn}\, RC} \qquad \ldots \quad 4.19$$

The quality factor

$$Q = \frac{\sqrt{mn}}{n + 1 + mn\,(1-K)} \qquad \ldots \quad 4.20$$

Using equations 4.18 to 4.20 the KRC high pass filter circuit is designed.

Design of Second Order KRC High Pass Filter :-

For given cutoff frequency fo, quality factor Q and the gain (K) the search for a suitable set of standard component values meeting the specifications proceeds as follows

1) Use equal capacitors (n = 1) and determine the required value of m to active given q using equation 4.20

2) Select the pair of resistance in the range of 1 K to 1 M to satisfy the ratio m.

3) Using equation 4.19 calculate C and select the closest standard capacitance.

4) Using equation 4.19 recompute R and use the closest standard resistance values to R and mR.

5) The gain K is calculated using equation 4.17 (a). Select proper values of R_A and R_B to obtain desired gain (K).

A) STUDY OF SECOND ORDER KRC HIGH PASS FILTER WITH VARIATION OF m :-

i) Practical design of high pas filter for different m :-

To study the effect of variation of resistance ratio m on the performance of the high pass filter circuit. The capacitance ratio n is kept 1 by using equal capacitors c = nc = 0.01 µf.

The gain (K) of the circuit is kept 2 by using equal value resistors $R_f = R_I = 56$ K.

The circuit is designed for fo = 1000 Hz

By changing the resistances R and mR, the resistance ratio m is changed for different values of m like 0.2, 0.4, 0.6, 0.8 etc.

The resistors used in the circuit are all carbon composition resistors with tolerance of ± 5%.

The capacitors used are all mica capacitors. The operational amplifier used is µA 741.

The actual component values used to study the effect of variation of m are shown in the table.

Table 4

R k. ohm	mR k. ohm.	M	Q	C = nc	fo Hz
36.3	6.8	0.187	0.2385	0.01 µf	1013
25.3	10	0.395	0.3917	0.01 µf	1000
20	13.3	0.665	0.6108	0.01 µf	975
27	13.9	0.5148	0.4805	0.01 µf	821
15	15	1	1	0.01 µf	1060

$R_F = R_i = 56$ K

Gain = 2

Using the components shown in table 4 the frequency response of the high pass filter is studied from 10 Hz to 100 K Hz. The frequency response of second order KRC high pass filter observed for different values of m is shown in Fig. 4.13.

From the frequency response in fig. 4.13, the quality factor Q is dependent on the resistance ratio m. when the capacitance ratio n and resistance ratio m are unity. Then according to equation 4.20 quality factor Q of the circuit is

$$Q = \frac{1}{3 - K} \qquad 4.21$$

When both n and k are constant, then quality factor Q is determined by the resistance ratio m.

When gain (K) of the amplifier is 3 with m = 1 and n =1, then quality factor Q of the circuit becomes infinite and circuit works as a oscillator.

From frequency response it is observed that with increase of resistance ratio m the gain peaking is observed at frequency near to the cutoff frequency. The transition from stop band to pass band is gradual for m = 0.7. For higher m the peaked response are observed.

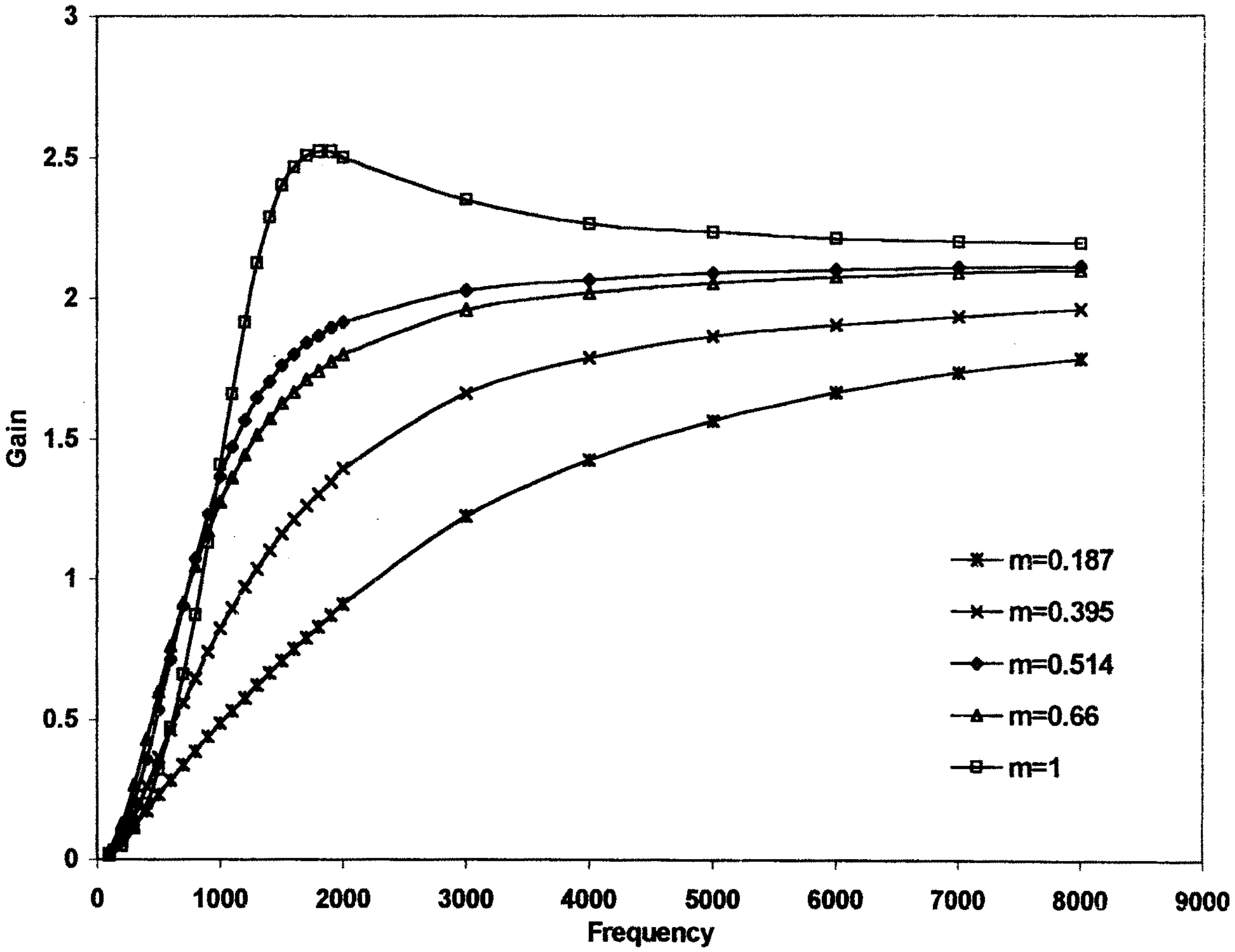

Fig 4.13

(Frequency response of second order KRC High pass filter for different m)

ii) Study of high pass filter with variation of m using PSpice :-

The simulation programme to study the effect of variation of m is

```
*       Second order KRC high pass filter
*       For different m
• PARAM  m     0.2
• Vs   1    O     AC    200mV
C1     1    2     0.01 U
C2     2    3     0.01 U
Rm     3    0     {M * 15913}
R1     2    6     .{15913/ M}
Ri     4    0     56k
Rf     4    6     56 k
*       Operational Amplifier
RI     3    4     2 MEG
Ro     5    6     75
Eop    5    0     3     4     2E+5
•. STEP PARAM m LIST 0.2  0.4  0.6  0.8   1
• AC DEC 10    1     1 MEG
•. PROBE
•. END
```

In the simulation programme the ac analysis is done from 1 Hz to 1 M Hz. The parametric analysis is done for different values of m from 0.2 to 1 in the step of 0.2. After execution of the programme the frequency response is observed using graphical coprocessor PROBE. The frequency response observed using PROBE is shown in Fig. 4.14.

The frequency response observed from fig.4.14 is identical with the response observed practically.

iii) Conclusion :-

The frequency response of high pass filter for constant gain (K) = 2 and capacitance ratio n = 1, with variation of m from 0.187 to 1 shows that quality factor Q changes from 0.23 to 1. The quality factor Q is exactly equal to the resistance ratio m. For higher m the gain peaking is observed. The flat response is observed upto m = 0.7. The gain o f the peak observed is 2.5 in both theoretical and practical curves.

Capacitance ratio n=1

Cutoff frequency fo = 1000 Hz.

Gain (K) = 2

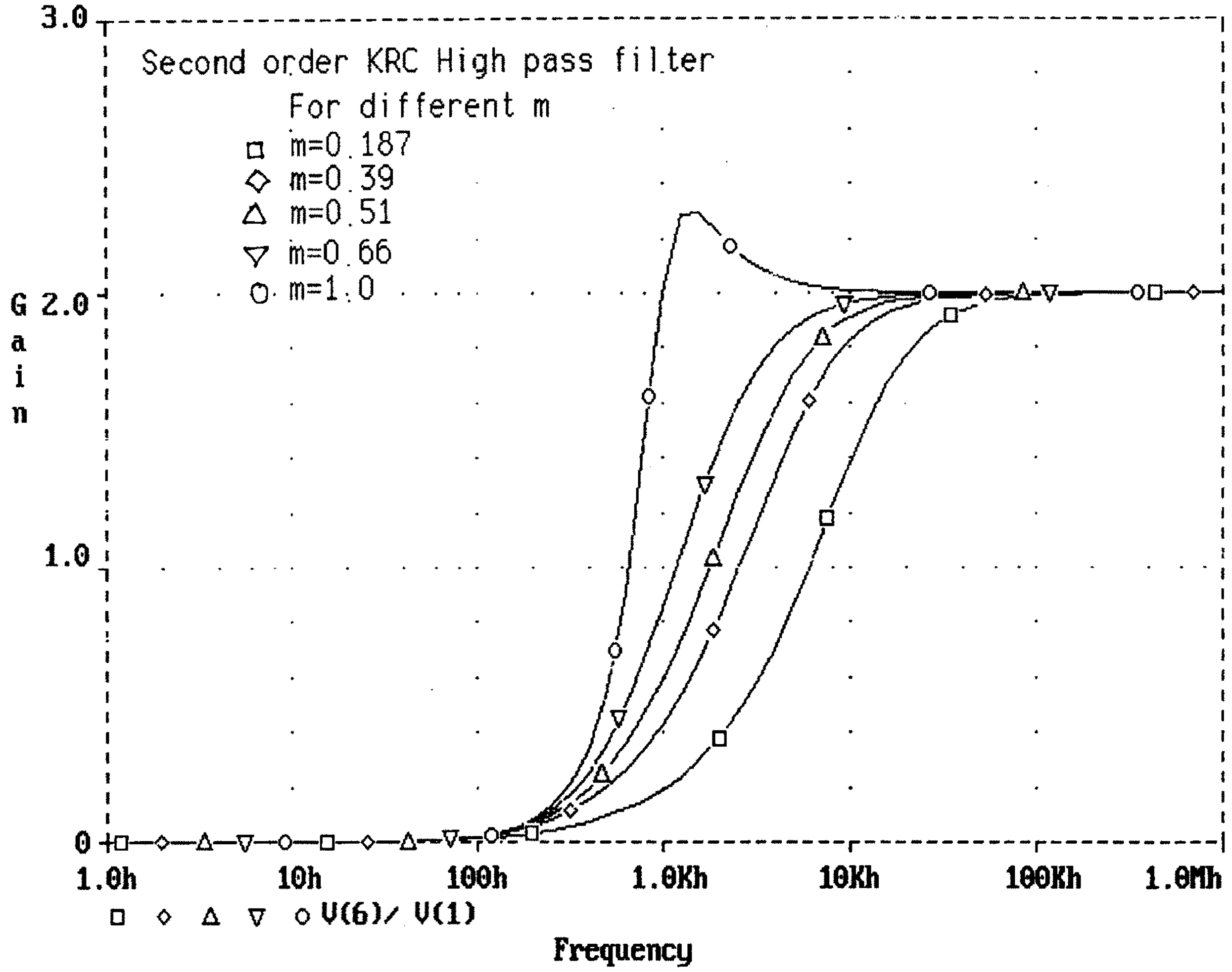

Fig. 4.14

(Frequency response of second order KRC High pass filter for different m)

B) STUDY OF SECOND ORDER KRC HIGH PASS FILTER WITH VARIATION OF n :-

i) Practical design of high pass filter for different n :-

To study the effect of variation of capacitance ratio n on the performance of high pass filter circuit the resistance ratio m is kept constant at m = 1. The gain (K) of the circuit is kept 2 by using equal value resistors $R_F = R_i = 56$ k. The circuit is designed for cutoff frequency fo = 1000 Hz.

By changing the capacitance c and nc, the capacitance ratio n is changed for different values of n like 0.213, 0.485, 0.702 1.44 and 2.06.

All the capacitors used are mica capacitor.

The actual component values used to study the effect of variation of capacitance ratio n are shown in Table 5

Table 5

C µf	nC µf	n	R= mR k. ohm	Q	fo Hz.
0.022	0.0047	0.213	17	0.46	921
0.0068	0.0033	0.485	33	0.69	1018
0.0047	0.0033	0.702	39	0.83	1036
0.01	0.0068	0.68	20	0.82	964
0.0033	0.0068	2.06	33	1.43	1018

The practical frequency response of second order KRC high pass filter for different values of n is shown in Fig. 4.15. From frequency response it is observed that it in the frequency region near fo, a family of curves is observed depending on the value of n. With variation of n from 0.2 to 2.06 the Q changes from 0.4 to 1.43.

For higher value of n gain peaking is observed at cutoff frequency fo. It indicates that the frequency response is sensitive to the capacitance ratio. Sensitivity of Q depends on the n, the capacitance ratio. Such peaked responses are useful in the cascade synthesis of higher order filters.

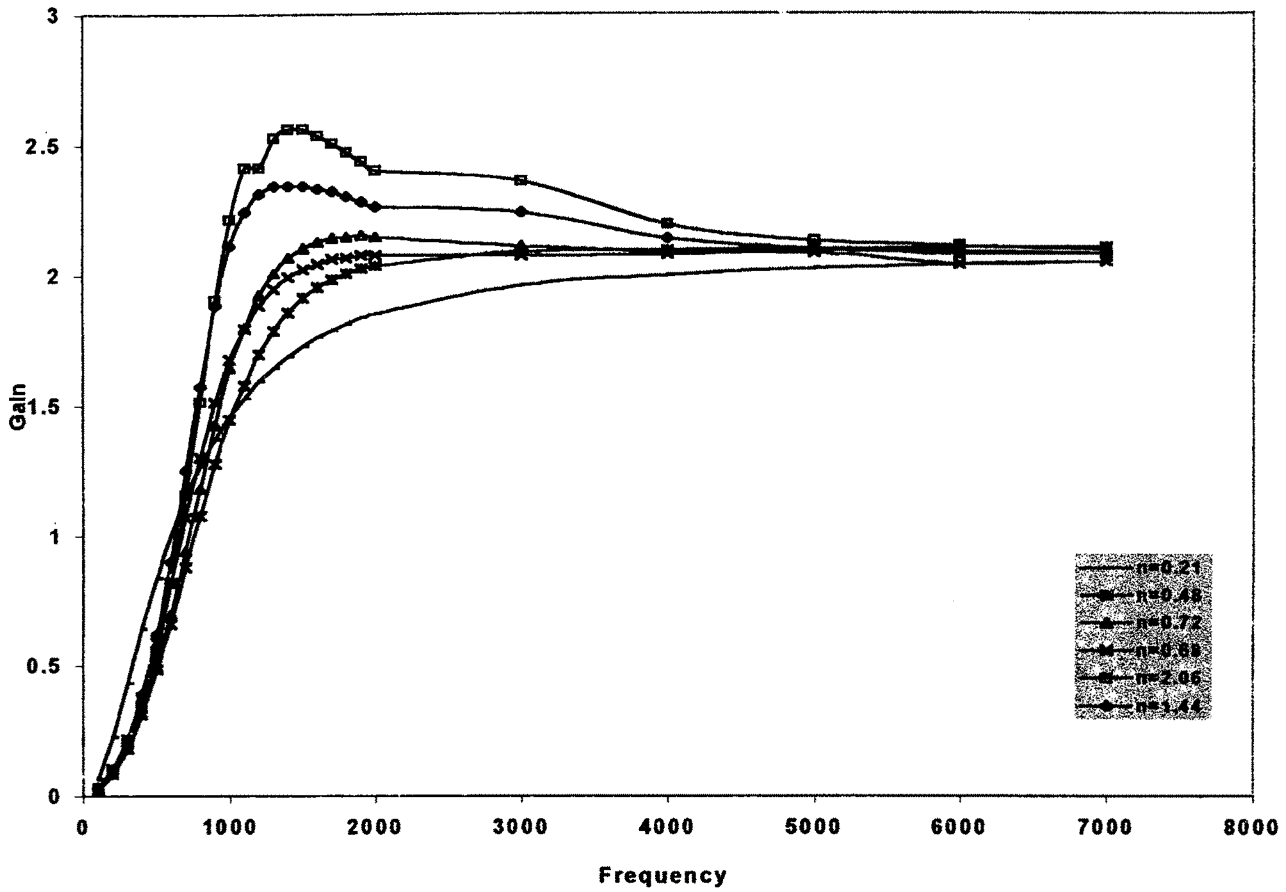

Fig. 4.15

(Frequency response of second order KRC High pass filter for different n)

ii) Study of high pass filter with variation of n using PSpice :-

To study the effect of variation of n, the parametic analysis is done using PARAM statement. The value of n is changed from 0.2 to 1.4. The PSpice programme to study the effect of variation of n is

```
*       Second order KRC high pass filter
*       For different m
• Vs    1     O     AC     200mV
• PARAM       A12   1
C12     1     2     0.01 U
C22     2     3     {A12 * 0.01 U}
R1      2     6     16 k
R2      3     0      6 k
RF      4     6     68 k
RG      4     0     68 k
*       Operational Amplifier
RI      3     4     2  MEG
Ro      5     6     75
Eop     5     0     3     4     2E+5
*       OUTPUT
• AC  DEC  10     1     1 MEG
•. STEP PARAM A12 LIST  0.21   0.48   0.70   0.68   2.06
•. PROBE
•. END
```

The frequency response for different values of n, using PSpice is shown in fig. 4.16. The gain peaking is observed for higher value of n.

iii) Conclusion :-

Theoretical and practical frequency response are identical with each other. The peak value of gain is 2.5 in practical response, and 3 in theoretical response. Q changes with n. For higher value of n gain peaking is observed exactly at fo.

Resistance ratio m =1

Gain (K) = 2

Cutoff frequency fo = 1000Hz.

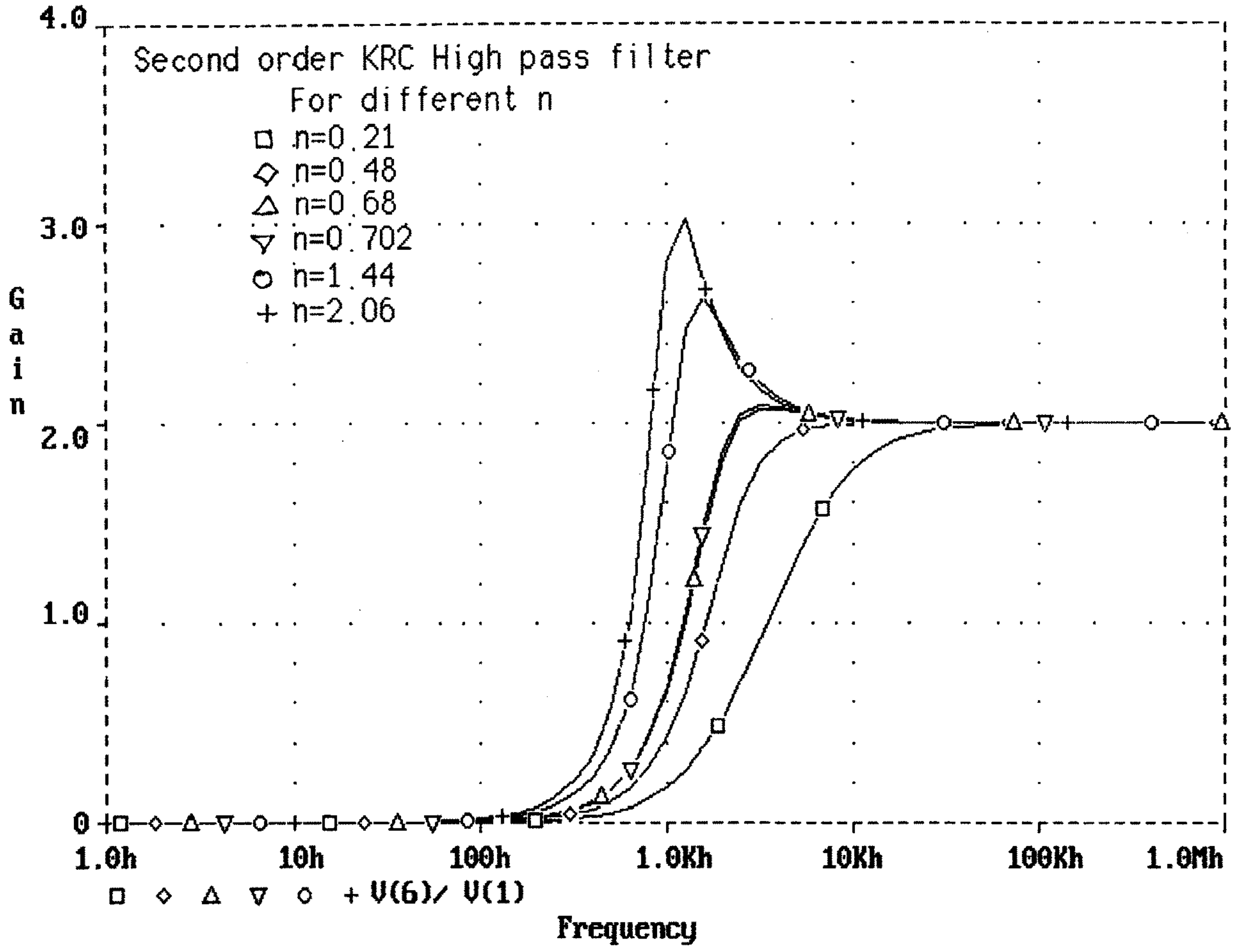

Fig. 4.16

(Frequency response of second order KRC high pass filter for different n)

C) STUDY OF SECOND ORDER KRC HIGH PASS FILTER WITH VARIATION OF GAIN (K) :-

i) Practical design of high pass filter for different K :-

The gain of KRC high pass filter is

$$K = \left(1 + \frac{R_F}{R_I}\right)$$

The gain of the circuit is determined by resistance R_F and R_i. To study the effect of variation of gain, the resistance ratio m is kept constant at 0.187. The capacitance ratio n is constant by using equal value capacitors n = nc= o.01 μf. The circuit is designed for cutoff frequency fo = 1000 Hz. The component value used practically to study the effect of variation of gain are shown in table 6.

Table 6

R_F k. ohm	R_i k.ohm	Gain	MR k. ohm	R k. ohm	m	nc μf	C μf	n
56	56	2						
168	56	4						
168	33	6	6.8	36.3	0.187	0.01	0.01	1
39	5.6	8						
43.3	4.7	10						

The frequency response observed practically for different gain (K) is shown in Fig. 4.17.

Frequency response shows that there is no effect of gain on the quality factor Q of the filter circuit and all the curves are flat without gain peaking. The gain peaking is not observed due to less value of m = 0.187. When m = 1 and n =1, then according to equation 4.20.

$$Q = \frac{1}{3 - K}$$

When gain k = 3 Q becomes infinite

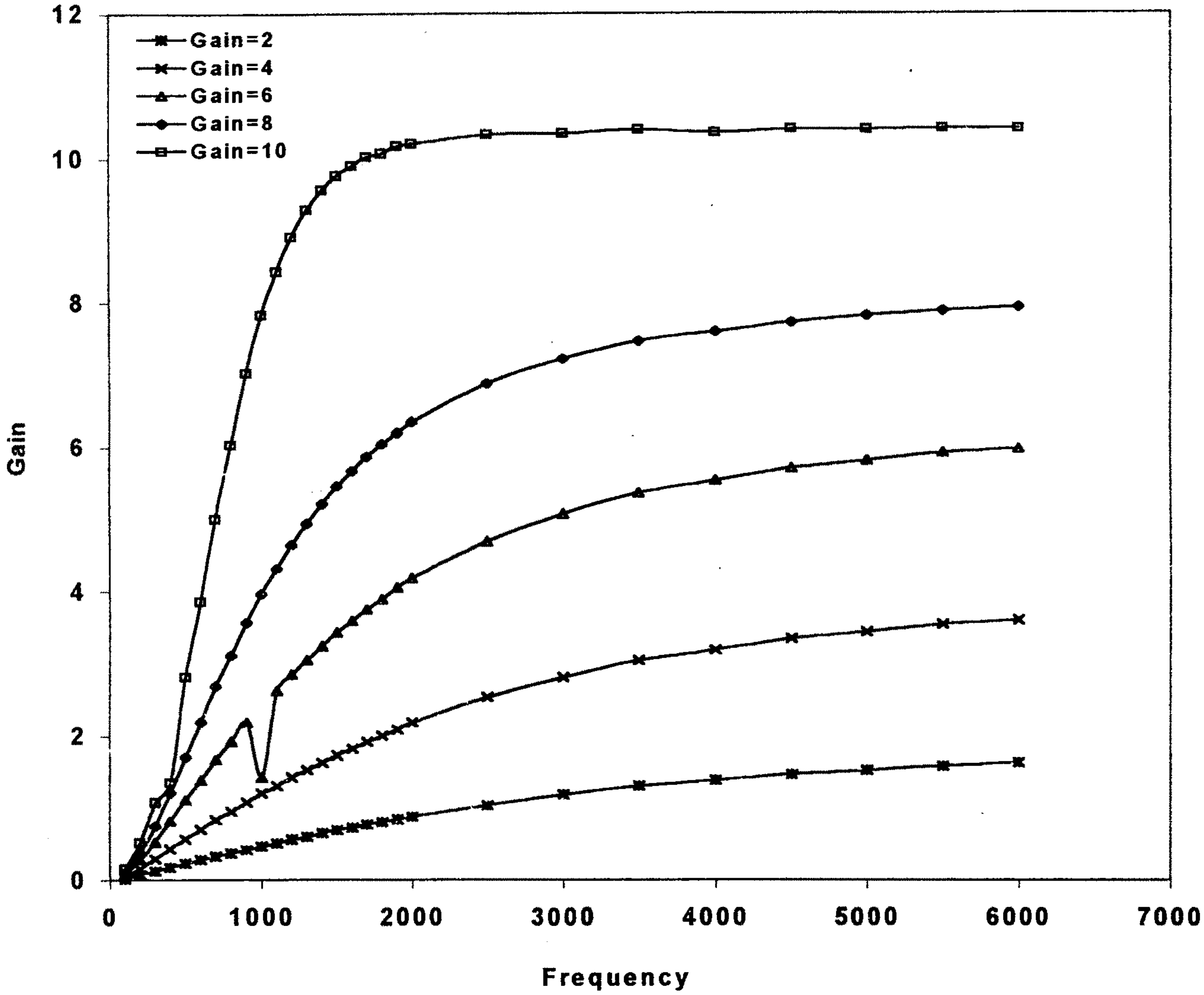

Fig. 4.17

Frequency response of second order KRC high pass filter for different gain (k)

ii) Study of high pass filter with variation of gain (K), using PSpice :-

The PSpice programme to study the effect of variation of K on frequency response is

```
*   Second order KRC high pass filter
*   For different gain (K)
• Vs   1     O     AC    200mV
• PARAM   Rx    56 k
C12   1     2     0.01 U
C23   2     3     0.01 U
R1    2     6     36.3 k
R2    3     0      6.8 k
RF    4     6      {R x}
Ri    4     0     56 k
*     Operational Amplifier
RI    3     4     2  MEG
Ro    5     6     75
Eop   5     0     3     4     2E+5
*     OUTPUT
•  AC  DEC  10    1     100 k
•. STEP PARAM  Rx LIST   56 k   112 k   168 k   224 k   280 k
•. PROBE
•. END
```

The frequency response observed using PSpice is shown in fig.4.18.

iii) Conclusion :-

There is no gain peaking observed in high pass filter. Due to smaller value of m there is no effect of variation of K and flat frequency response is observed for higher K.

Resistance ratio m=0.187
Capacitance ratio n=1
Cutoff frequency fo = 1000Hz

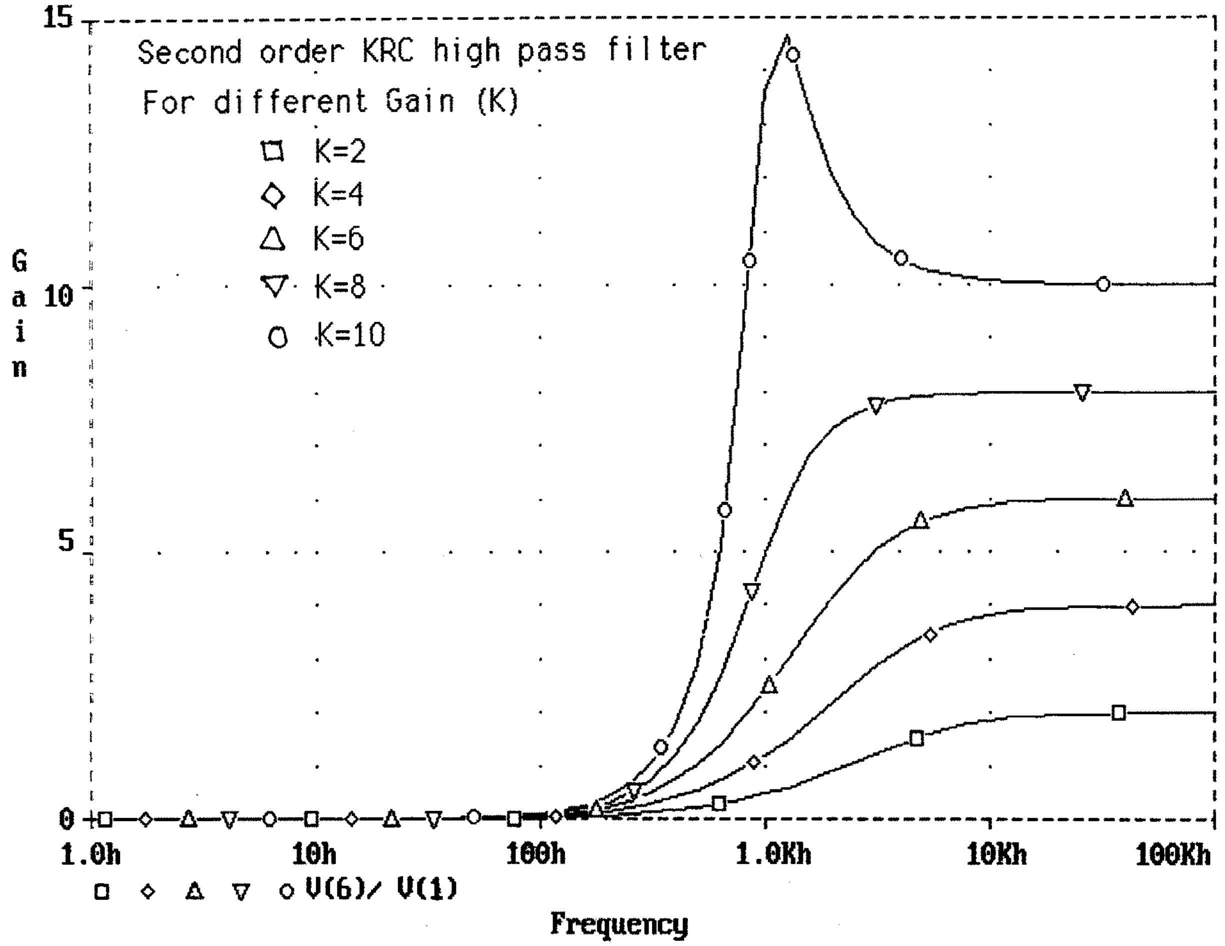

Fig 4.18

Frequency response of second order KRC high pass filter for different gain (K)