CHAPTER - III

STUDY OF A NEW ACTIVE -R FILTER CIRCUIT.

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3.1 INTRODUCTION :-

The resistance, capacitance, self inductance and mutual inductance are the four basic elements of passive filter. In addition with the development of inexpensive Op.amp., the inductorless filter are developed. These are called active filter, built with resistors, capacitors and op. amps.

In more recent years, there has been a drive to utilize inherent circuit capacitance, thereby eliminating the use of external capacitors also[1]. These active filters without external capacitors are called "active-R" filters[2,3]. The advantages of these circuits are, extended frequency range, miniaturization, ease of design and tunability, low sensitivity.

Originally the parasitic capacitance associated with operational amplifiers was considered undesirable and much attention was given to compensate for their effect.[4] Now many research workers have made use of these parasitic capacitances in the design of active filters. The major non-ideality of the commercial operational op.amp., which imposes several limitations on the performance of active filters is its frequency-dependent gain. The parameter characterizing the frequency dependence of gain is its finite gain-bandwidth product (GB). The gain of many commercial op.amps. is usually internally compensated to have a 6dB/active roll off.[5-7]. Single pole approximation is useful in designing filters in that resistors are the only additional elements needed to construct general second order filter circuit as outlined by Schaumann. With the help of this, various circuits are developed and studied[2,3,5-12].

By Suitablly choosing the transfer functions of the op.amp. blocks, we can systematically simulate the various types of impendances such as inductances, capacitance, FDNR, FDNC, FDNL, FDNCA[13].

The use of active - R filters in high frequency oscillations for continuous phase frequency-shift keyed (CPFSK) waves at relatively high frequency band has been examined[14,15]. Recently there has been a considerable interest in the study of the ripple pass functions (RPF) as their applications include amplitude and phase equalization, variable gains network, notch filter and all-pass filters. This proposes an active-R realization of the RPF[12]. A simple analog phase shifting network has been also presented by using active -R realization[16]. Many circuits are reported for the realization of current mode transfer function using op.amp. poles, which are suitable for high frequency operation and monolithic IC implementation[17,18].

In this chapter a new biquadratic active-R filter circuit is studied which provides all the filter functions such as low-pass, high-pass, bandpass and band reject functions at various output terminals. The circuit is studied for different values of Q. The experimental results are compaired with theoretical value of Q.

3.2 THE NEW ACTIVE R CIRCUIT :-

To formulate a systematic producer for realization of a specified network function, it is necessary to postulate a linear active element having simple mathematical relationship between its input and output variables synthesis techniques are next developed based on such idealized elements. The commonly used active-network elements are the negative impedance converter, the controlled source, the gyrator and the operational amplifier.

In this new biqudratic active-R filter two op.amps and four resistance are used as shown in fig(3.1) where the feedback resistance R1 is tapped at center and resistance R is connected as shown. The circuit is a multiple feedback circuit. The positive feedback depends on the value of

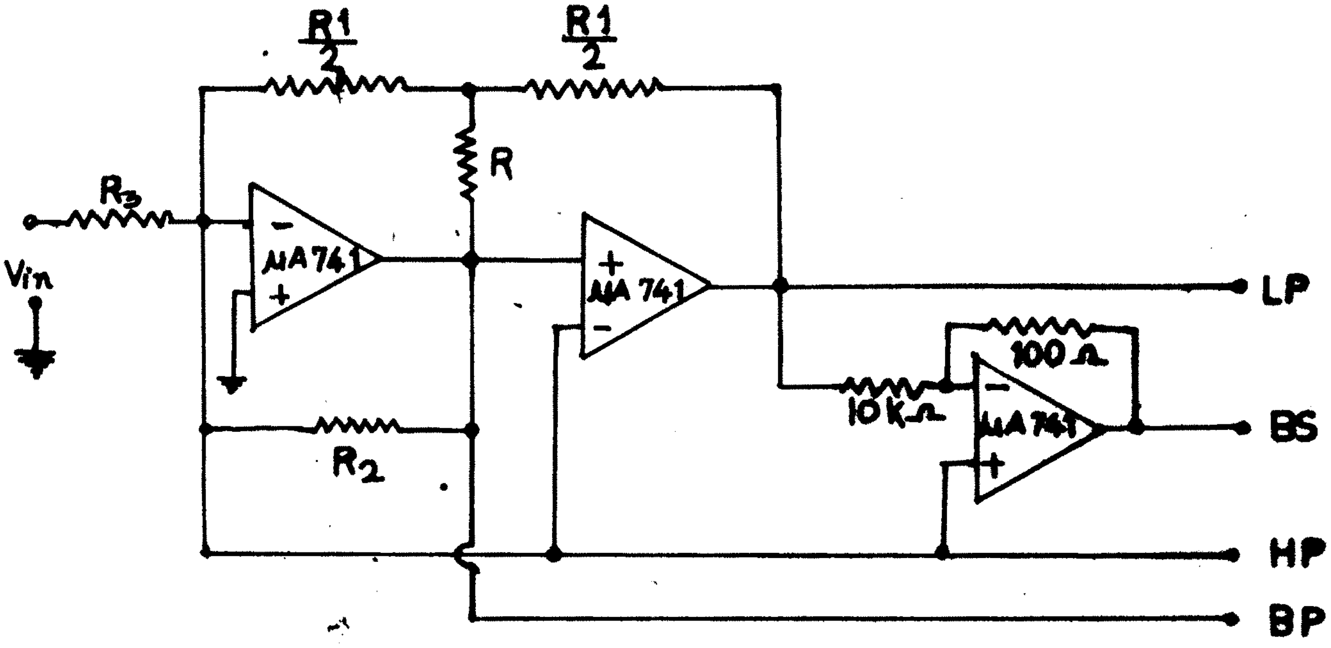

Fig 3.1 Circuit Diagram For New Active-R Biquadratic Filter.

resistance R whereas negative feedback is introduced by resistance R_1 and R_2. The circuit realizes the four biquadratic functions LP, HP, BP and BS at three different output terminals. The resonant frequency and Q of the poles and the location of the zeros can be controlled over a wide range by feedback and feedforward circuit.

3.3 CIRCUIT ANALYSIS :-

The operational amplifier shows the high frequency roll-off due to parasitic capacitance[4]. Rao and Srinivasan have suggested that the pole of an op.amp. could be used to design an active filter[5-7].

$$A(S) = \frac{A_o W_o}{S + W_o} \qquad \ldots\ldots(3.1)$$

This equation represents the op.amps. single pole transfer function[5-7].

Where A_o = open loop dc gain, W_o = open loop 3dB bandwidth

for $w >> W_o$

$$A(S) = \frac{A_o W_o}{S} = \frac{GB}{S} \qquad \ldots\ldots\ldots (3.2)$$

This shows that the operational amplifier is equivalent to an integrator with the gain of magnitude GB.

Most op.amps. are of the internally compensated type, W_o is of the order of 25-100 rad/sec. Since the pole effect of medium Q filters does not come into the picture below about 1KHz, this assumption is not a serious limitation[6].

With the help of this assumption, the voltage transfer functions of new active-R biquadratic filter at three different output terminals are given below,

voltage transfer function for low-pass filter

$$T_{Lp}(s) = \frac{-(1/R_3)GB_1 . GB_2}{S^2[1/R_A+1/R_2+1/R_3]+S[GB_1(1/R_2+2/(4R+R_1))-GB_2(2/R_1-1/R_A)] + GB_1 GB_2(2/R_1-1/R_A)} \qquad ..... (3.3)$$

Voltage transfer function for high pass filter

$$T_{HP}(s) = \frac{(1/R_3)S^2}{S^2[1/R_A+1/R_2+1/R_3]+S[GB_1(1/R_1+2/(4R+R_1))-GB_2(2/R_1-1/R_A)] + GB_1 GB_2(2/R_1-1/R_A)} \qquad ....(3.4)$$

Voltage transfer function for bandpass filter

$$T_{BP}(S) = \frac{-(1/R_3)\, GB_1\, S}{S^2[1/R_A + 1/R_2 + 1/R_3] + S[GB_1(1/R_1 + 2/(4R+R_1)) - GB_2(2/R_1 - R_A)] + GB_1 GB_2 (2/R_1 - 1/R_A)} \quad \ldots (3.5)$$

In developing these transfer functions a_5 small term appearing in the numerator has bean naglected as GB >> S. The value of R_A is given by

$$1/R_A = 2/R_1 - 4R / (4RR_1 + R_1^2) \; \ldots\ldots (3.6)$$

3.4 DESIGN CONSIDERATION :-

Design of this filter is extremely simple . R_1 sets the pole frequency W_o , R_2 , sets the Q and R_3 must be set so that the parallel combination of R_1 ,R_2 ,R_3 and R is 1 ohm. So for the designing the circuit , coefficient matching technique is used.

The general second order transfer function is given by

$$T(S) = \frac{\alpha_2 S^2 + \alpha_1 S + \alpha_o}{S^2 + (W_o/Q)S + W_o^2} \qquad \text{....(3.7)}$$

comparing equations (3.3),(3.4),(3.5) with this equation we get

$$W_o/Q = GB.(1/R_2 + 2/(4R+R_1)) - GB_2(2/R_1 - 1/R_A) \qquad \text{....(3.8)}$$

$$W_o^2 = GB_1 \,.\, GB_2 (2/R_1 - 1/R_A) \qquad \text{........(3.9)}$$

$$1 = 1/R_A + 1/R_2 + 1/R_3 \qquad \text{....(3.10)}$$

where the gain bandwidth products of both amplifiers GB_1 and GB_2 are equal.

Notice that impedance scaling of the R, R_1, R_2, R_3 may be used to obtain more practical values of resistances^3 .By multiplying these by the impedance scale factor 100,we get the practical values of the resistances.

For practical realization the value of R_2 must be positive. Hence, if f_0 and R are assumed, an upper limit is set on the value of Q.

Rearranging equation (3.8) with $GB_1 = GB_2 = GB$

$$\frac{1}{R_2} = \frac{W_0}{QGB} - \frac{2(R_1 - 2R)}{R_1(R_1 + 4R)} \quad \ldots\ldots(3.11)$$

Limit on Q, can be stated by equation

$$Q <= W_0 \frac{R_1(R_1 + 4R)}{2\,GB(R_1 - 2R)} \quad \ldots\ldots(3.12)$$

In other way, if Q is specified the value of W_0 must be limited.This dose not limit the input signal frequency. The circuit is designed for different values of Q with center frequency 10 kHz.

3.5 EXPERIMENTAL STUDY WITH VARIATION OF Q :-

The circuit was designed using commonly available operational amplifier uA 741. The GB value was experimentally determined as $GB = 2\pi * 7.8 * 10^5$ red/sec. Two operational amplifiers with almost identical GB value were selected.The value of R cannot be obtain theoretically and hence was assumed to be R =1.7 ohm.For higher value of R the sensitivity increases. The upper limit for Q for these values of R and f_0 is 1.35 . The performance of circuit was studied for Q=0.2,0.5 and 1.The basic limitation is that none of the outputs may be either saturation limited or slew rate limited . The circuit was assembled with due care to minimize stray capacitance and input was controlled to avoid slew rate limitation.

The output response for low pass , high pass , band pass and band stop filter was studied at four different output terminals. The output responses were first tested on C.R.O. for their distortion free performance and then the reading were taken with an A.C. millivoltmeter. The response is plotted with gain (dB) v/s frequency. This response is compared with the theoretical response. The theoretical response is shown by (__ .__._).

3.6 RESULT AND DISCUSSION :-

(A) Low Pass Response :-

The low-pass response is shown in fig. (3.2). A theoretical response is also plotted for Q = 0.2. It is

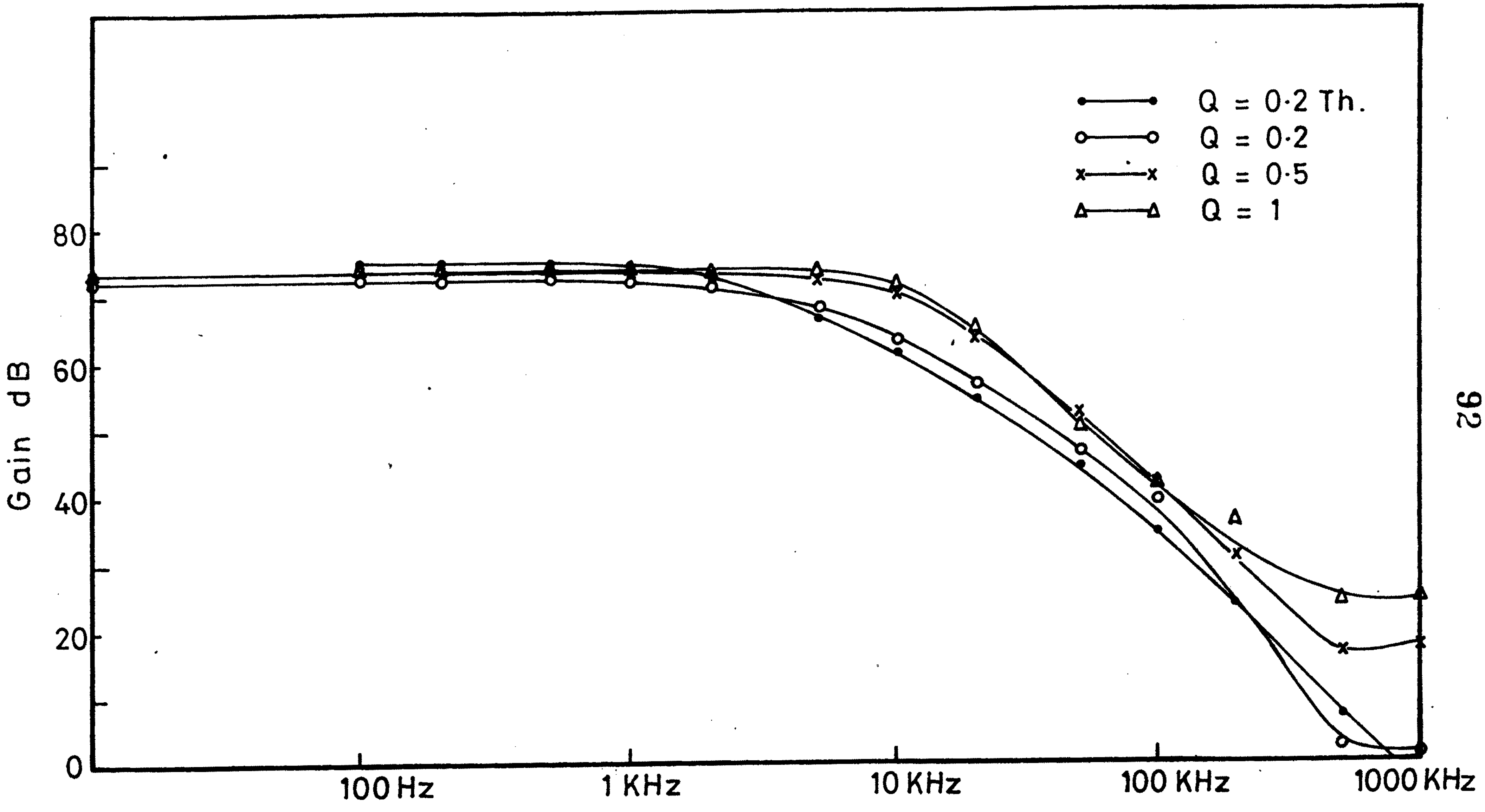

Fig.32 – Low pass response for fo = 10 KHz and diff Q .

noticed that the experimental results are in good agreement with theoretical observations. The frequency response curves for different values of Q with center frequency $f_0 = 10$ kHz are shown. The observed center frequency is also in good agreement with design value. It is observed that below 2kHz the response is independent of Q. It differs slightly near design value as Q changes. Above 500 kHz the response levels off. This may be due to shunting effect of stray capacitance. It is to be noticed that the response is extended up to 10 Hz on low frequency side, no overshoot is observed anywhere in response and high gain (74dB) whereas various circuits reported in the literature show good response from 1 kHz onwards only, overshoot for higher values of Q.

(B) High - Pass Response :

The high pass response is shown in fig. (3.3). In this case also a good agreement in theoretical and practical results are observed. However, for all Q values the theoretical curve and practical curves differs greatly upto 2 to 5 kHz . Above these frequencies the theoretical and experimental curves merge together. The design value of f_0 agrees well with the observed values. The circuit shows excellent response upto 1 MHz. At very low frequencies there is some difficulty because of equipments limitations. However, good response was observed from 200 Hz onwards without any overshoot.

(C) Band - Pass Response :

The band-pass response is shown in fig. (3.4). In this case also good agreement was observed between theoretical

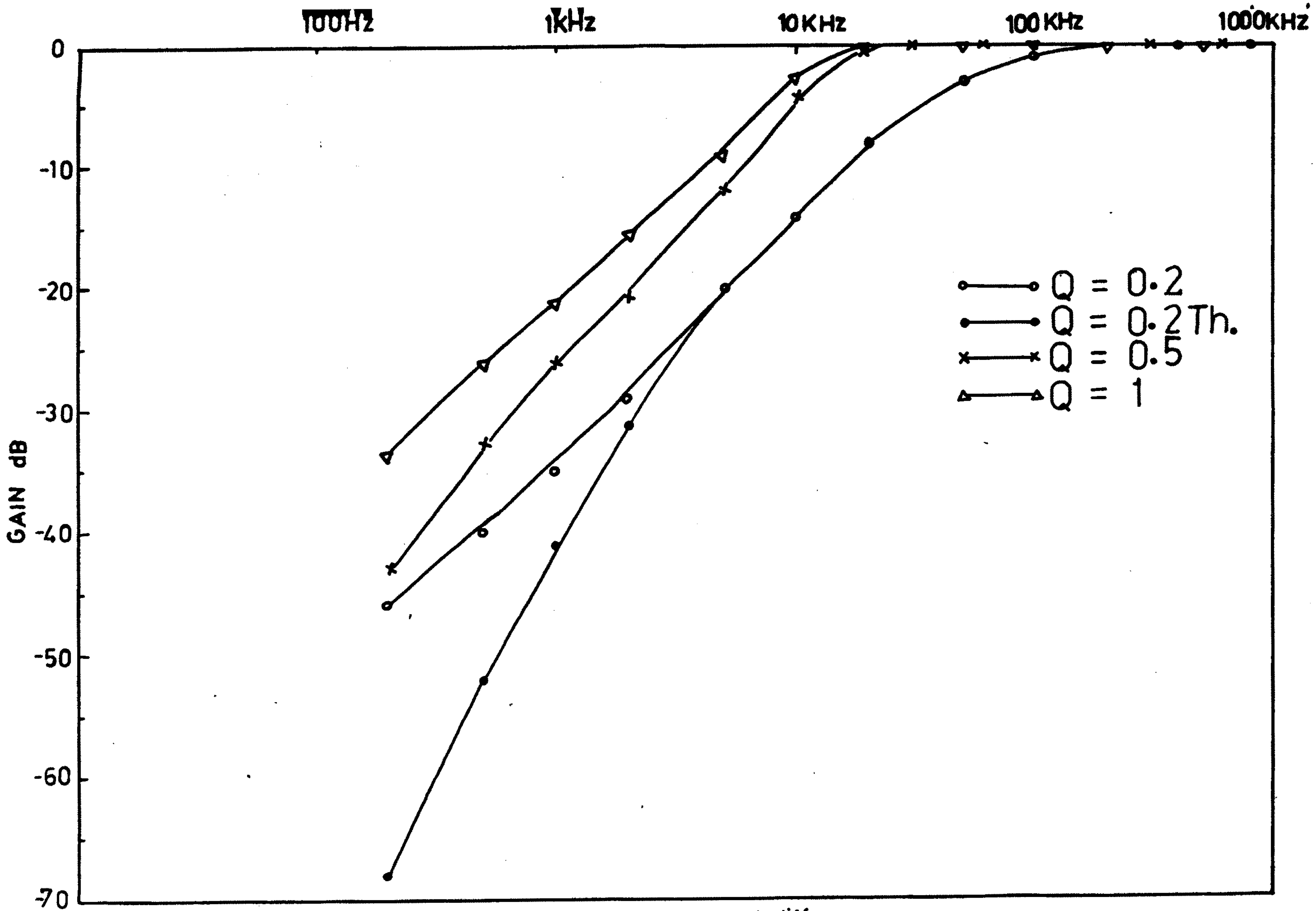

Fig.3.3 High pass response for fo = 10KHz and diff. Q

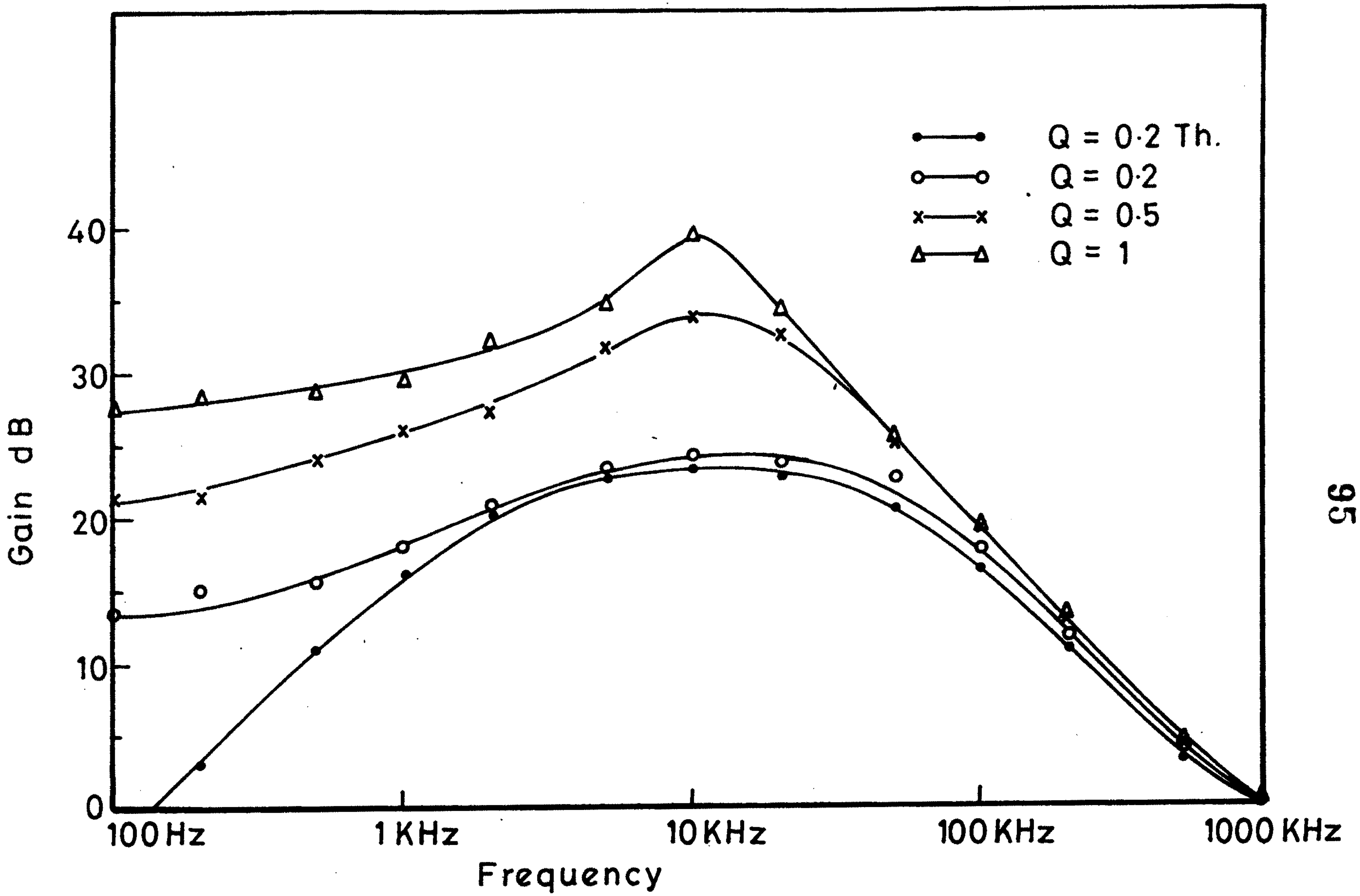

Fig.34 – Band pass responce for fo = 10 KHz and diff Q .

and observed result.Above 1 Khz and as Q increaes,the responce becomes peaked.On very low frequency side,there is degradation.The center frequency is almost equal to the design frequency of 10 Khz.Above 100 Khz. all curves merge together.

(D)BAND - STOP RESPONSE :

The band- stop response is shownin fig.(3.5).It is seen that the change in Q has very little effect on response. Below 10 Khz the reponsse is almost flat and sharply decreases at 100 Khz,giving sharp rejection point at this frequency. Above 100 Khz gain increases upto o db and then response is flat below 10 Khz the curcuit gain is high about 33 dB. However the design frequency does not match in this case.

The value of Q was also calculated using the relation[11].

$$Q^2 = \frac{G_{BP}^2}{G_{HP} \cdot G_{LP}} \qquad \ldots\ldots (3.13)$$

The results are shown in table (3.1)

3.7 SENSITIVITY CONSIDERATION :-

The sensitivity of Q and W_0 of new active R biquadratic filter is given bellow .

1) $$S_R^{W_0} = \frac{W_0}{8R(GB_1 . GB_2)^2} \left[R\, GB_1 . GB_2 + R_1 . W_0^2 \right]$$

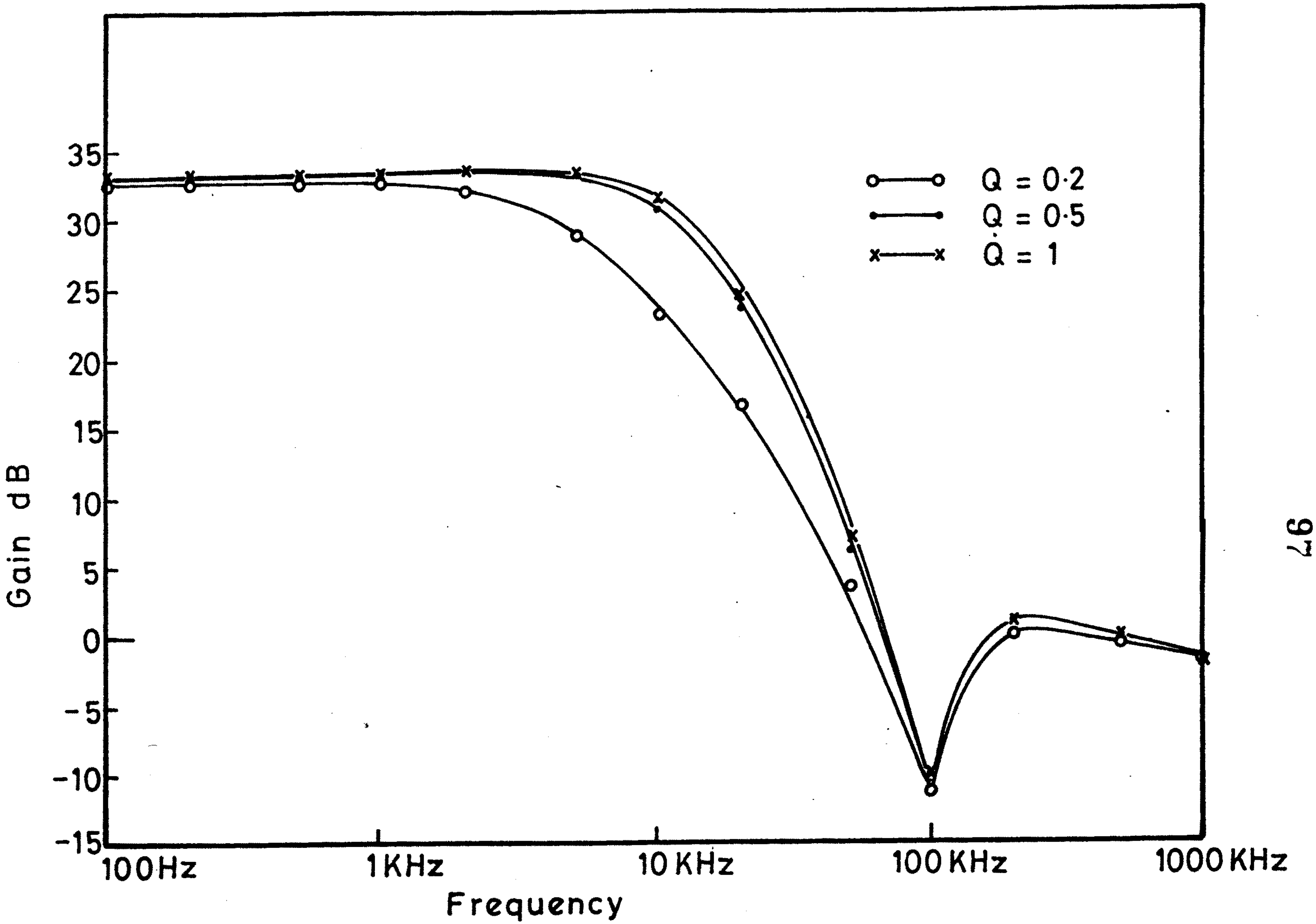

Fig.3.5- Band stop response for fo = 10KHz and diff. Q .

2) $$S_{R_1}^{W_0} = \left(\frac{W_0^2}{16R\ R_1 GB_1 GB_2} \right)^2 [\ 32R^2\ R_1 + 16R\ R_1^3 + 16\ R_1^4 - 16R^2 R_1^3 - 4R_1^4\ R\ ]$$

3) $$S_{R_2}^{W_0} = \frac{1}{2R_2}$$

4) $$S_{R_3}^{W_0} = \frac{1}{2R_3}$$

5) $$S_{GB_1}^{W_0} = S_{GB_2}^{W_0} = \frac{1}{2}$$

6) $$S_R^Q = \frac{QGBR}{W_0} \left[\frac{8}{(4R+R_1)^2} + \frac{4R_1^2}{(4R\ R_1 + R_1^2)^2} \right] + \frac{2R_1^2\ R\ (R_1^2 + 4R\ R_1 - 1)}{(\ 4R\ R_1 + R_1^2\ )^2}$$

7) $$S_{R_1}^Q = \frac{QGBR_1}{W_0} \left[\frac{2}{(\ 4R + R_1\ )^2} + \frac{16R^2 + 8R_1\ R}{(4R\ R_1 + R_1^2)^2} \right] - \left[\frac{1}{R_1} + \frac{R_1 (8R^2 + 4R\ R_1)}{(4R\ R_1 + R_1^2)^2} - \frac{R_1 (2R^2 + R\ R_1)}{(4R\ R_1 + R_1^2)} \right]$$

8) $$S^{Q}_{R_2} = \frac{1}{R_2} \left[\frac{QGB_1}{W_0} - \frac{1}{2} \right]$$

9) $$S^{Q}_{R_3} = - \frac{1}{2R_3}$$

10) $$S^{Q}_{GB_1} = - \left[\frac{QW_0}{GB_2} + \frac{1}{2} \right]$$

11) $$S^{Q}_{GB_2} = \frac{QW_0}{GB_1} + \frac{1}{2}$$

Thus the passive sensitivities are all less than one in magnitude. Active sensitivities are half in magnitude.

The table (3.1) summarizes the overall behavior of the circuit. In this table designed value of F_o is compared with observed value. Also design value of Q, bandpass gain and gain bandwidth product are compared with observed values are presented.

TABLE (3.1) EXPERIMENTAL AND DESIGN VALUES COMPARISION

Q		F_0 kHz		BAND PASS GAIN dB		GAIN BANDWDTH product $2\Pi.10^5$kHz	
DE	EXP	DE	EXP	DE	EXP	DE	EXP
0.2	0.25	10.00	10.00	23.35	24.34	7.8	7.67
0.5	0.69	10.00	10.00	31.64	33.89	7.8	11.03
1.0	1.31	10.00	10.00	37.74	39.32	7.8	9.06

(where DE. = Design value, Exp. = Experimental Value)

3,8 CONCLUDING REMARKS :-

The new active - R filter circuit discussed here shows excellent agreement with theoretical results.The response is extended up to very low frequency region . It gives high gain in pass band but for band pass and high pass response some degradation is observed at very low frequencies. The variation of R can provide a controllable gain,resonant frequency etc.There is upper limit for Q.The center frequency is not disturbed for different values of Q. Low pass response is excellent with higher gain. High pass response is extended up to 200 Hz for lower frequenies. There is no overshoot observed anywhwre in the response .

The new active R biquadratic filter can be used for low Q with excellent performance at low pass,high pass,band pass and band stop filter.

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