CHAPTER - III

STUDY AND DESIGN OF A NEW ACTIVE-R FILTER CIRCUIT

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3.1 INTRODUCTION

The filter circuits have become an integral part of many electronic systems for a very long time. They have been used for different applications as mentioned earlier. Before the advent of transistors and operational amplifiers, the passive filters dominated the field. They used components such as resistance, capacitance and inductance which resulted in considerable loss of signal. With the availability of high performance operational amplifiers the trend was shifted to design and use of active filters with op-AMP as the main active device. Further the difficulty in integrating the inductor in IC fabrication led to the design of circuits using R-C components only.

The operational amplifier frequency response curve is almost similar to the response of a low pass filter. This enables one to consider the operational amplifier as a single pole integrator. In other words, inherent parasitic capacitance associated with the device is utilized in designing filter circuits with resistor as only external passive component. These circuits are known as Active-R filter circuits. In this dissertation theory, design and the response of a new Active-R filter circuit is discussed.

3.2 CIRCUIT DIAGRAM

Fig.(3.1) shows a new Active-R filter configuration. It is seen that all the four filter functions are provided at various output terminals. It is also noted that it is a multiple feedback circuit and both the positive and negative feedback are provided. The resistance 'R' provides both the feedbacks. The resistance 'R_1' is tapped to control the feedback while the resistance 'R_2' introduces a constant negative feedback. The tapping point variation will control the gain of both the operational amplifiers and the frequency response of the overall circuit. The low pass and high pass action, when combined by the third operational amplifier, provide band stop action.

3.3 CIRCUIT ANALYSIS

As mentioned earlier, the operational amplifier can be considered as a single pole integrator. Mathematically, therefore, the operational amplifier can be represented by,

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

where A_o is open loop d.c. gain and w_o is the open loop -3dB bandwidth in rad/sec.

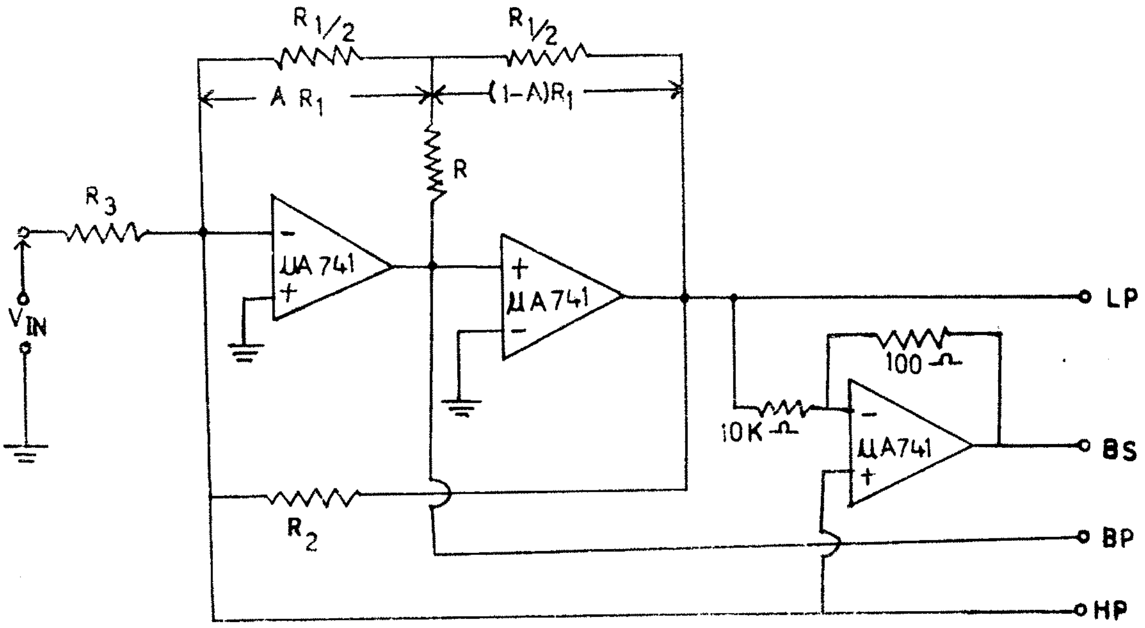

FIG.(3.1): CIRCUIT DIAGRAM OF A NEW ACTIVE-R BIAQUADRATIC FILTER.

This can be written as,

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

when $w \gg w_o$,

where $A_o w_o = GB$ represents the gain-bandwidth product of the operational amplifier.

Most of the operational amplifier are internally compensated and w_o is of the order of 25-100 rad/sec. Using equation (3.2) various transfer functions of the circuit can be obtained, as shown below,

(1) For Low pass filter

$$T_{LP}(S) = \frac{(-1/R_3)\ .\ GB_1.GB_2}{S^2\left[\left(\frac{1}{R_3}+\frac{1}{R_2}+\frac{1}{R_{1/2}}\right)-\left(\frac{R}{R_{1/2}}\right)\left(\frac{1}{2R+R_{1/2}}\right)\right] + S\left[\frac{GB_1}{2R+R_{1/2}}\right] + GB_1.GB_2\left[\frac{1}{R_2}+\left(\frac{R}{R_{1/2}}\right)\left(\frac{1}{2R+R_{1/2}}\right)\right]} \qquad ..(3.3)$$

(2) For High pass filter

$$T_{HP}(S) = \frac{(1/R_3)\ S^2}{S^2\left[\left(\frac{1}{R_3}+\frac{1}{R_2}+\frac{1}{R_{1/2}}\right)-\left(\frac{R}{R_{1/2}}\right)\left(\frac{1}{2R+R_{1/2}}\right)\right] + S\left[\frac{GB_1}{2R+R_{1/2}}\right] + GB_1.GB_2\left[\frac{1}{R_2}+\left(\frac{R}{R_{1/2}}\right)\left(\frac{1}{2R+R_{1/2}}\right)\right]} \qquad ..(3.4)$$

(3) For Band pass filter

$$T_{BP}(S) = \frac{(-1/R_3)\,.\,GB_1.S}{S^2\left[\left(\frac{1}{R_3}+\frac{1}{R_2}+\frac{1}{R_{1/2}}\right)-\left(\frac{R}{R_{1/2}}\right)\left(\frac{1}{2R+R_{1/2}}\right)\right] + S\left[\frac{GB_1}{2R+R_{1/2}}\right] + GB_1.GB_2\left[\frac{1}{R_2}+\left(\frac{R}{R_{1/2}}\right)\left(\frac{1}{2R+R_{1/2}}\right)\right]} \quad ..(3.5)$$

3.4 DESIGN CONSIDERATION

The design of a new Active-R circuit is quite straight forward. The procedure involves the comparison of the transfer functions with the general second order transfer function given by,

$$T(S) = \frac{\alpha_2 S^2 + \alpha_1 S + \alpha_o}{S^2 + (W_o/Q)\,S + W_o^{\,2}} \quad \ldots (3.6)$$

It is notice that the resistance R_1 and R control the pole frequency w_o while R_2 and R control the 'Q' value. Comparing the various coefficients in equation (3.6) with the transfer functions. Following equations are obtained.

$$\left[\left(\frac{1}{R_3}+\frac{1}{R_2}+\frac{1}{R_{1/2}}\right)-\left(\frac{R}{R_{1/2}}\right)\left(\frac{1}{2R+R_{1/2}}\right)\right] = 1 \quad \ldots (3.7)$$

$$\left[\frac{GB_1}{2R+R_{1/2}}\right] = \frac{W_o}{Q} \quad \ldots (3.8)$$

$$GB_1 . GB_2 \left[\frac{1}{R_2} + \left(\frac{R}{R_{1/2}}\right) \left(\frac{1}{2R + R_{1/2}}\right) \right] = W_o^2 \qquad \ldots (3.9)$$

The design requires the calculation of four resistive components. However, only three equations are available. The fourth equation can be obtained from sensitivity considerations. The various sensitivities for this circuit are calculated and given in Table (3.1). It is noted that both the sensitivities $S_R^{W_o}$ and S_R^Q can be used for this purpose. In this study, $S_R^{W_o}$ is used for providing the fourth equation required. Further to obtain maximum possible value of 'R'. $S_R^{W_o}$ was assumed to be unity. This leads to the value of R equal to 41 ohms. For higher values the feedback will be reduced and for large value of R, R_1 appears in parallel with R_2. Hence, for the design, value of 'R' should be less than limiting value of 41 ohms. It should be possible to calculate the all four resistances for a given value of w_o and Q. However, such a approach was found to be inconvenient because of highly involved calculations.

Further, for practical circuit all the components must be positive. This requirement places an upper limit on 'R'. Equation (3.7), (3.8) and (3.9) can be used to express R_1 and R_2 as,

$$R_1 = \frac{2GB_1 \cdot Q}{w_o} - 4R \qquad \ldots (3.10)$$

$$R_2 = \frac{GB_1 \cdot GB_2(4RR_1 + R_1^2)}{[w_o^2(4RR_1+R_1^2)-4R.GB_1.GB_2]} \qquad \ldots (3.11)$$

These equations clearly show that the values of R_1 and R_2 can become negative for wrong choice of 'R'. Hence, for the study of the circuit, the value of 'R' is assumed and all other components are calculated.

3.5 SENSITIVITY CONSIDERATION

The various sensitivities for this new circuit are calculated using standard formulae. (Table 3.1) shows all these sensitivities.

Table (3.1) -Various sensitivities of new a Active-R filter circuit.

1 $$S^{wo}_{R} = \frac{4R(R_1^2 + 2RR_1)}{(R_1^2 + 4RR_1)^2} \left[\frac{GB_1 \cdot GB_2}{w_o^2} - 1\right]$$

2 $$S^{wo}_{R_1} = \frac{4R(R_1^2 + 2RR_1)}{(R_1^2 + 4RR_1)^2} \left[1 - \frac{GB_1 \cdot GB_2}{w_o^2}\right] + \frac{1}{R_1}$$

3 $$S^{wo}_{R_2} = \frac{1}{2R_2} \left[1 - \frac{GB_1 \cdot GB_2}{w_o^2}\right]$$

4 $$S^{wo}_{R_3} = \frac{1}{2R_3}$$

5 $$S^{wo}_{GB_1} = S^{wo}_{GB} = \frac{1}{2}$$

6 $$S^{Q}_{R} = \frac{4R}{(4R + R_1)} + \frac{2R_1^2 R}{(R_1^2 + 4RR_1)^2} \left[\frac{GB_1 \cdot GB_2}{wo^2} - 1\right]$$

7 $$S^{Q}_{R_1} = \frac{R_1^2 - 2(4R + R_1)}{R_1(4R + R_1)} + \frac{4R(R_1^2 + 2RR_1)}{(R_1^2 + 4RR_1)^2} \left[\frac{GB_1 \cdot GB_2}{w_o^2} - 1\right]$$

8 $$S^{Q}_{R_2} = -\frac{1}{2R_2} \left[1 + \frac{GB_1 \cdot GB_2}{w_o^2}\right]$$

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

10 $S^{Q}_{GB_1} = S^{Q}_{GB_2} = -\dfrac{1}{2Q}$

It is found that all passive sensitivities are less than one in magnitude but Active sensitivities are half in magnitude.

3.6 CALCULATION OF 'Q'

The standard equation for second order filter introduces the designed frequency w_o and Q as w_o/Q. The coefficient of second term in denominator of equation (3.6) can be utilized to calculate 'Q', when all other parameters are specified. However, a different approach is described.[44-104]

In this article, 'Q' is expressed as,

$$Q = \frac{G^2_{BP}}{G_{LP} \cdot G_{HP}} \qquad \ldots(3.12)$$

It is found that this result also holds good for the new circuit presented here. Here G_{HP} is the gain of the circuit for high pass action and G_{BP} is gain of band pass action and G_{LP} is gain for low pass action. The gains are determined from the graphs and 'Q' values were calculated using above equations. The results are tabulated in Table (3.3).

The gain-bandwidth product is also determining from the graphs and using the relation,

$$GB = Gain \times Bandwidth \qquad ...(3.13)$$

These values are included in the same table.

3.7 DESIGN AND EXPERIMENTAL STUDY WITH VARIATION OF CENTRAL FREQUENCY (F_o)

The circuit was designed using commonly available µA741 operational amplifier. The analysis of the circuit shows that the only operational amplifier parameter important is the gain-bandwidth product GB. The GB value for a number of operational amplifiers was obtained experimentally in the laboratory and the operational amplifiers with almost equal GB value ($2\pi \times 7.8 \times 10^5$ rad/sec.) were chosen for assembly of the circuit. Every care was taken during the assembly to avoid the effects of stray capacitances. For design, following values were assumed,

(1) $Q = 1$, $R = 33$ ohms

The calculations were made for different values of F_o = 10 KHz, 30 KHz, 50 KHz, 70 KHz and 110 KHz. The values of R_1, R_2 and R_3 are then calculated. The actual components used are the standard values or the combinations of standard resistors. The component values are given in Table (3.2). The circuit was assembled and the frequency response was studied from 100 Hz to 1 MHz. The results are shown graphically in Fig.(3.2), (3.3), (3.4) and (3.5). To compare the performance with the theoretical expectations, a theoretical curve is also included in each case and is indicated by —o—o—.

3.8 RESULTS AND DISCUSSION

The response of the circuit was studied from 100 Hz to 1MHz for all the four outputs. From the study of the graphs, following observations are made.

(1) LOW PASS RESPONSE

The low pass response is shown in Fig.(3.2). It is observed that the gain decreases in the passband as design frequency increases. It is also noted that the design frequency agrees well with the observed value. For F_O above 50 KHz a slight peaking is observed near 100 KHz. The overall response is quite satisfactory. A theoretical curve is also included for F_O = 10 KHz, it is seen that the observed gain is slightly less (5 dB) in passband. There is peaking at 10 KHz in theoretical curve. Above 10 KHz, the response shows the gain-roll off of 29 dB/decade. In the stop band both curves show same rejection but above 100

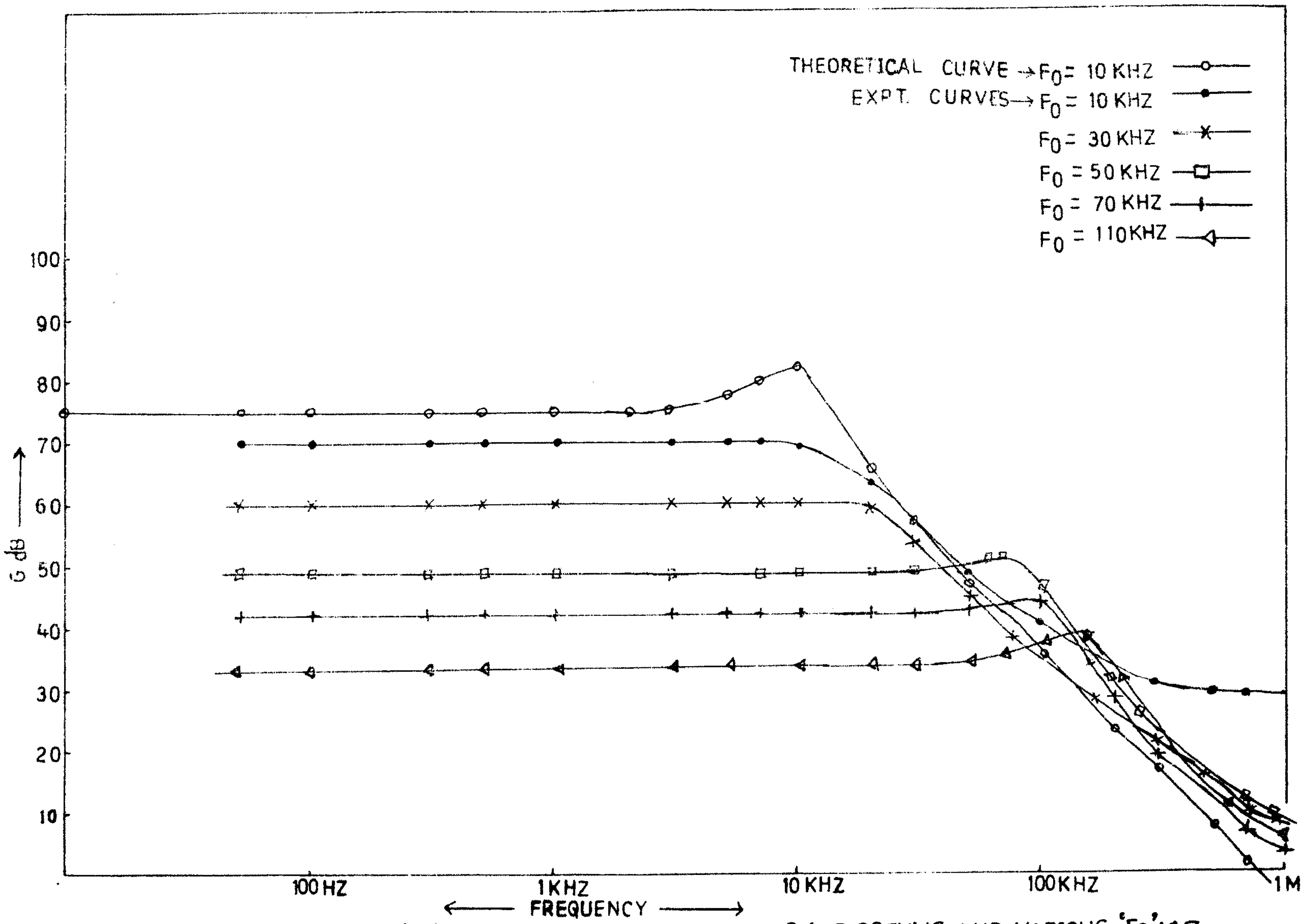

FIG.(3·2): LOW PASS RESPONSE FOR Q=1, R=33OHMS AND VARIOUS 'Fo' KHZ.

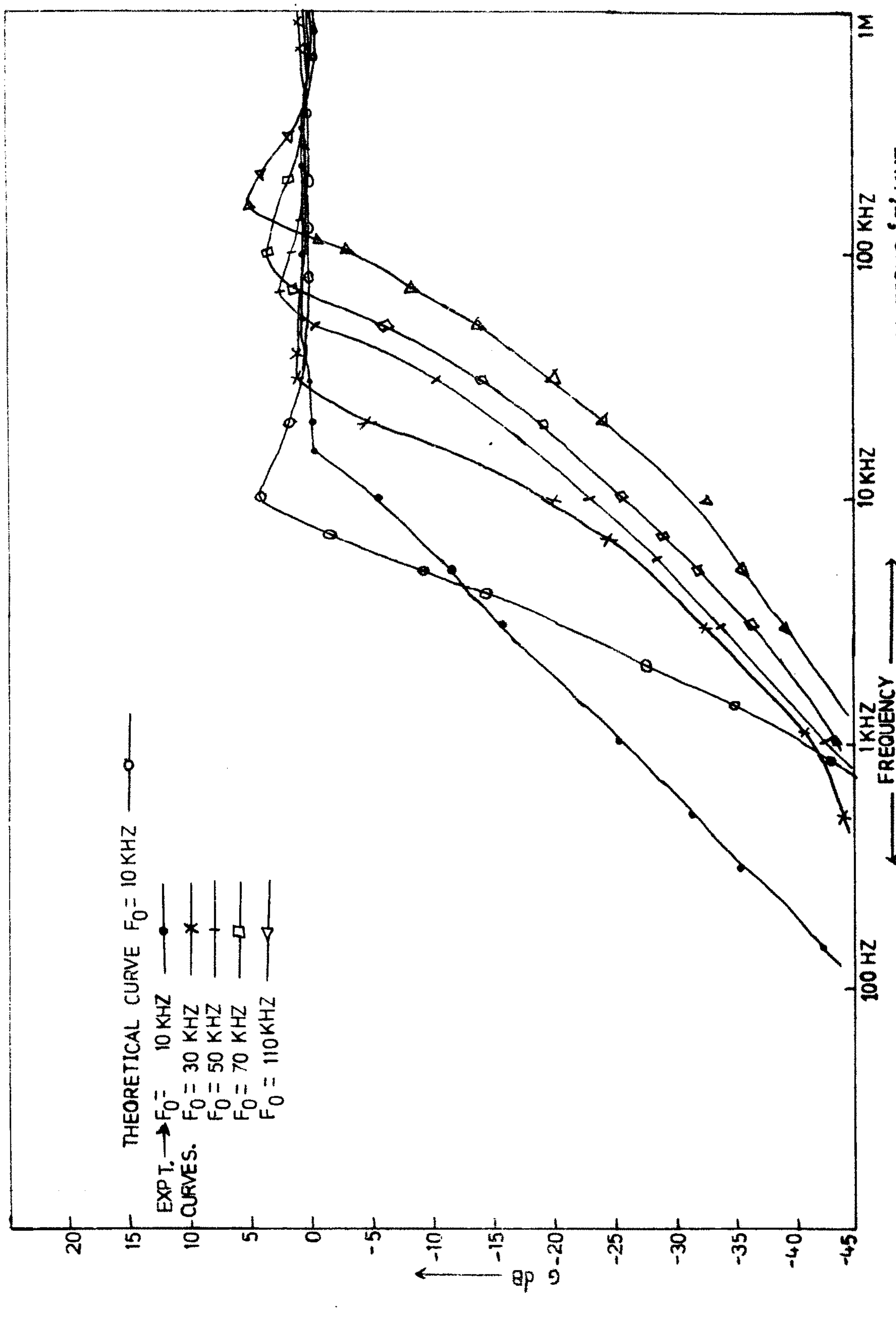

FIG.(3·3): HIGH PASS RESPONSE FOR Q=1, R=33 OHMS AND VARIOUS 'F_0' KHZ.

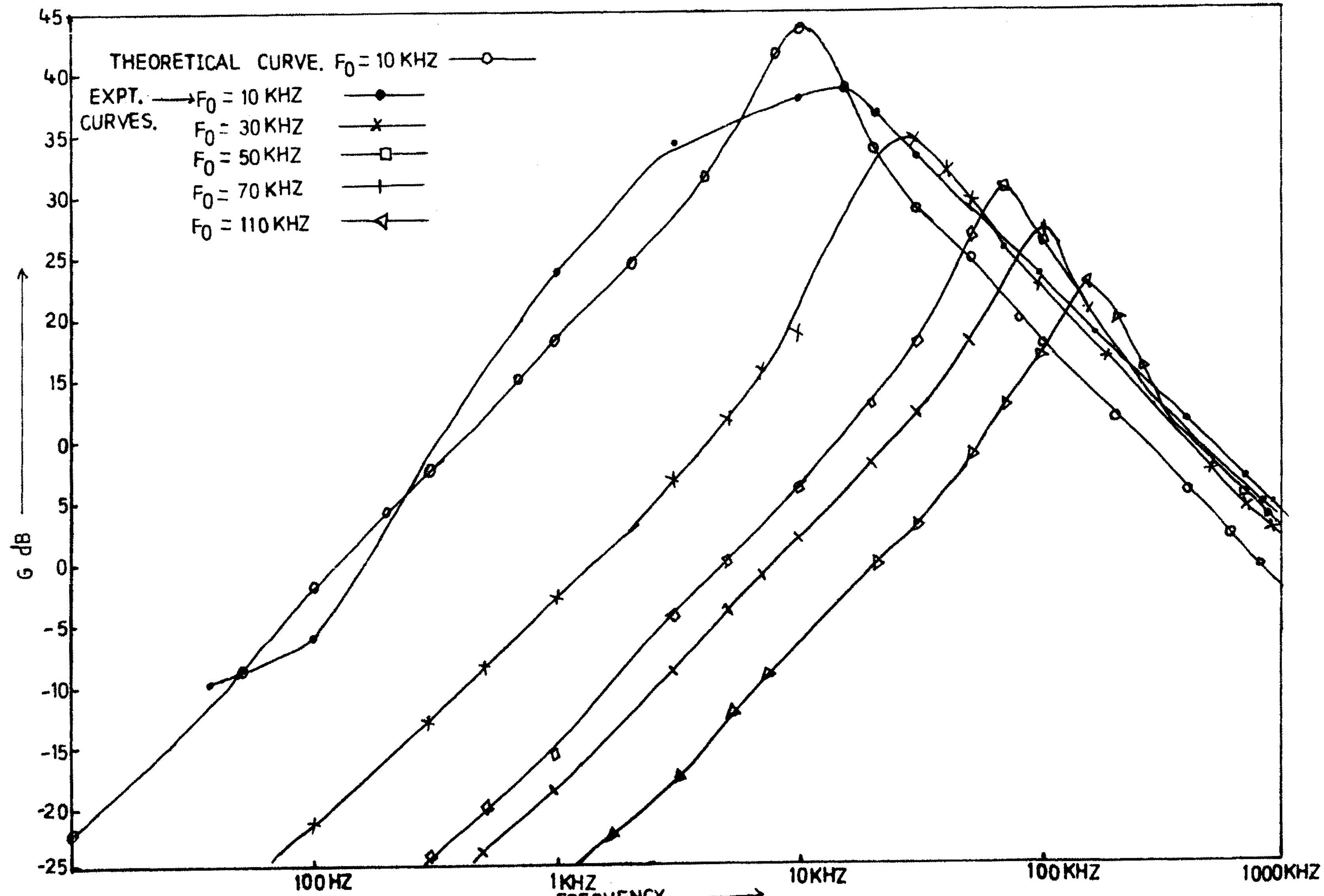

FIG.(3·4): BAND PASS RESPONSE FOR Q=1, R=33 OHMS AND VARIOUS 'F_0' KHZ.

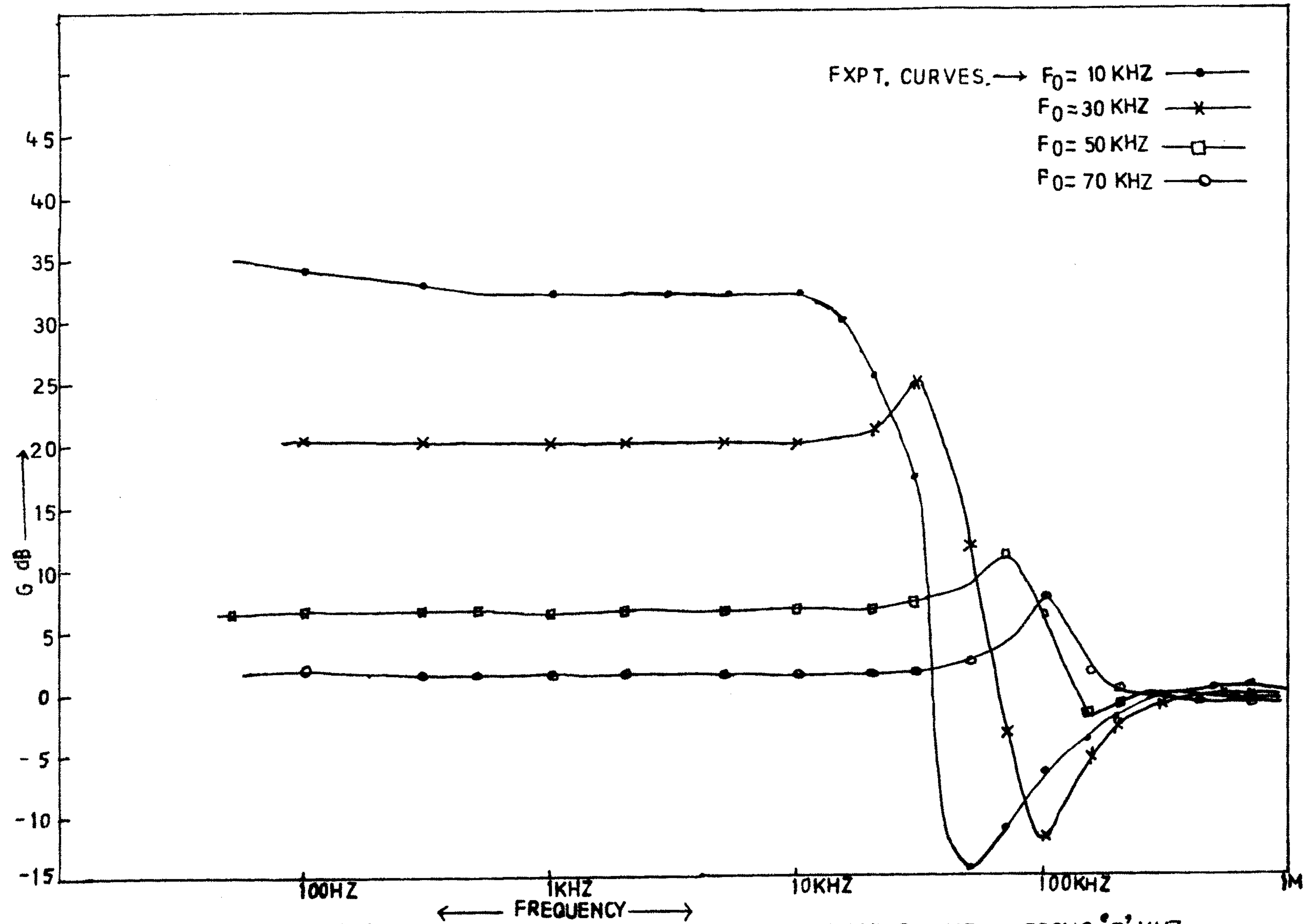

FIG.(3.5): BAND STOP RESPONSE FOR Q=1, R=33OHMS AND VARIOUS 'F_0' KHZ.

KHz, the observed response remains almost constant upto 1000 KHz.

(2) HIGH PASS RESPONSE

The high pass response is shown in Fig.(3.3). It is seen that overall response is very satisfactory and design value of F_o matches with the observed value. In this case also slight peaking is observed for F_o = 50 KHz onwards. A theoretical curve is also included for F_o = 10 KHz for comparison. It is observed that in the pass band, there is good agreement between theoretical and observed responses. However, theoretical curve shows slight peaking near F_o = 10 KHz and shows higher rejection below 10 KHz.

(3) BAND PASS RESPONSE

The band pass response is shown in Fig.(3.4). It is observed that the response is similar to response of a resonant circuit with low 'Q' values. The peaks are observed at frequencies equal to the design F_o values for F_o = 10 KHz and 30 KHz. For values of F_o, there is a shift in the observed values. The theoretical curve for F_o = 10 KHz almost coincide with the observed curve. It is found that as central frequency (F_o) increases, the gain in passband region decreases. The overall response is quite satisfactory.

(4) BAND STOP RESPONSE

The band stop response is shown in Fig.(3.5). It is seen that band stop response is similar to low pass response. However, a pronounced deep is observed in the high frequency region. For low values of F_o, the response decreases very rapidly.

As F_o increases, the deep becomes less and less pronounced. Above 200 KHz all the curves coincide. From the curves, it is seen that as F_o increases, the frequency of rejection point increases and gain decreases. The central frequency F_o does not match with designed value. The response is not that satisfactory.

3.9 CONCLUSIONS

The new Active-R circuit is quite satisfactory as far as low pass, high pass and band pass responses are concerned. In case of low pass filter, the gain decreases in passband as design frequency (F_o) increases. In high pass response, the theoretical curve shows slight peaking near F_o = 10 KHz. Band pass response shows peaks at frequencies equal to the design values of F_o. There is good agreement between theoretical and observed results for LP, HP and BP functions. The performance is not satisfactory in case of band stop response.

The transfer functions show that for $R = \infty$, the circuit does oscillate. In practice, such oscillations are observed but observed frequency does not match with the theoretical results. Also, it is observed that frequency of oscillations depends on the value of $R_1 \parallel R_2$. The circuit is studied upto 1 MHz. Finally, the circuit is studied for low 'Q' with satisfactory performance for low pass, high pass, band pass and band reject filter.

Table (3.2) : The designed and experimental values of resistances.

F_o (KHz)	Tapping point (A)	Q	Designed Values			Experimental Values		
			R_3	R_2	R_1	R_3	R_2	R_1
10	0.5	1	101 Ω	911.8 KΩ	15.46 KΩ	100 Ω	911.2 KΩ	15.30 KΩ
30	0.5	1	104 Ω	102.2 KΩ	10.26 KΩ	100 Ω	102.2 KΩ	11.20 KΩ
50	0.5	1	107 Ω	37.13 KΩ	2.98 KΩ	100 Ω	37 KΩ	3 KΩ
70	0.5	1	110 Ω	19.12 KΩ	2.08 KΩ	100 Ω	20 KΩ	2 KΩ
110	0.5	1	119 Ω	7.9 KΩ	1.28 KΩ	116 Ω	8.2 KΩ	1.32 KΩ

Table (3.3) : Comparison of designed and experimental values of F_o, Q and GB.

F_o (KHz)		Q		Gain-Bandwidth product ($2\pi \times 10^5$ rad/sec)	
Designed values	Experi-mental values	Designed values	Experi-mental values	Designed values	Experi-mental values
10	15	1	1.09	7.8	5.30
30	30	1	1.05	7.8	5.00
50	70	1	1.30	7.8	10.70
70	100	1	1.18	7.8	13.90
110	150	1	0.90	7.8	15.92