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Biquad Fiters with RC Feed Back & its Effect Over The Stability on the Poles of the Amplifiers: A New Dimensional Study

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Abstract: ***Wide variety of networks and active filters has acknowledged concentration in active resistor-capacitor networks (RC networks). Few of limitations in the linear filters, a unique combination of resistor (R), Inductor (I) and capacitors (C) and are not dependent on any external supply or in other words passive filters is entirely removed in active filters those are composed of active component such as an external amplifier to adjust the required gain. The current investigation to reduce the circuit by means of enhances the package density and the trustworthiness of the circuit as an important objective in the present study. It was almost impossible not to integrate the inductor with the experimental readings of inductance and reasonable Q factors. As RC filters can be realized with a Q value 0.5 and with this value it's almost impossible to fabricate a lofty selectivity filter.***

Keywords: Biquad Fiters, RC Feed Back, Amplifiers, Resistor, Inductor and Capacitors

1. Background

The effect of feedback on the stability of 2 poles of single stage in successively studied at two options of the values of C. The observation explains the objective of the study in respect of 3dB frequencies and stable characterization of the high pass filters. The results observed on the said structures clearly explain the stability of the system with respect to 2 poles in single stage or more than 2 poles in cascade. The validation of experimental results is checked against the SPICE observations their by explanation for the objective of the present [1].

The theory relevant to Biquad type 1 can view as basic concept in identifying the stability of the poles from the calculation of transfer function. The theory is considered as a relevant material of the proposed work.

R2 = 1KΩ,
C1 = C2 = 0.001µF = 1nF

Controlled sources are classified in four different ways. They are (a) Current-controlled current source (CCT), (b)Voltage- controlled current source(VCT), (c) Voltage-controlled voltage source(VVT) and (d) Current- controlled voltage source(CVT). The symbols are represented in the below figure 1.

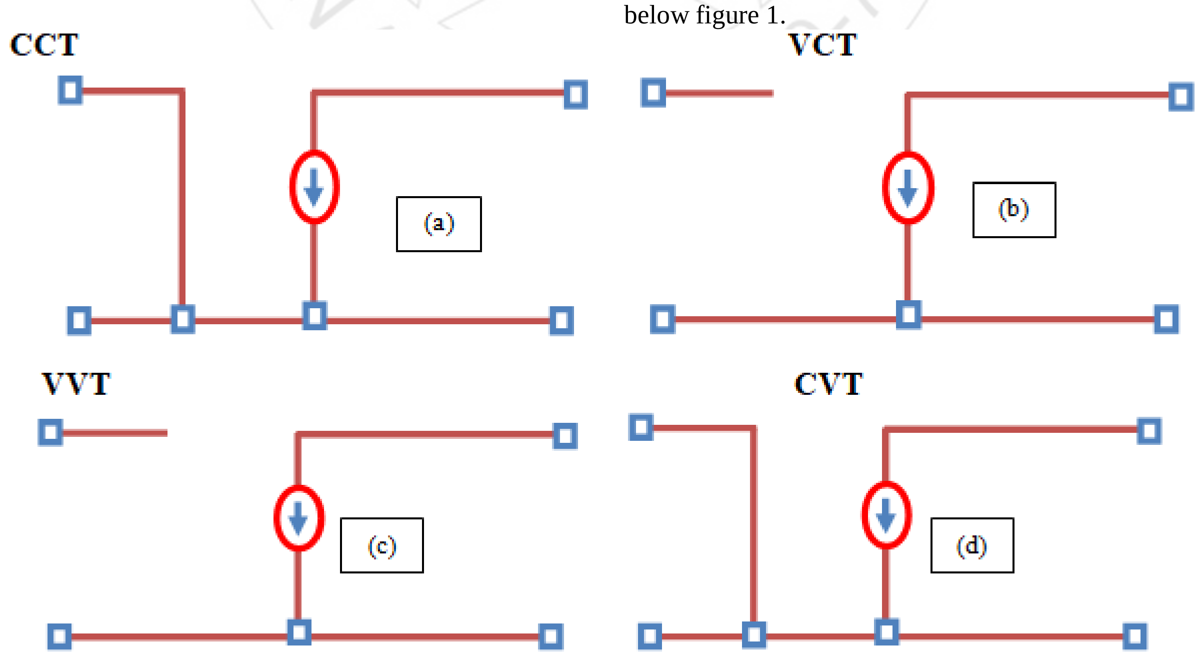

Figure 1: Classified controlled sources.

An operational amplifier is a high gain differential input DC amplifier. Ideally it is considered as a dual input infinite gain VVT. The symbol and the equivalent circuit of Operational amplifier are shown in the fig.2. The output voltage is given by, [2]

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

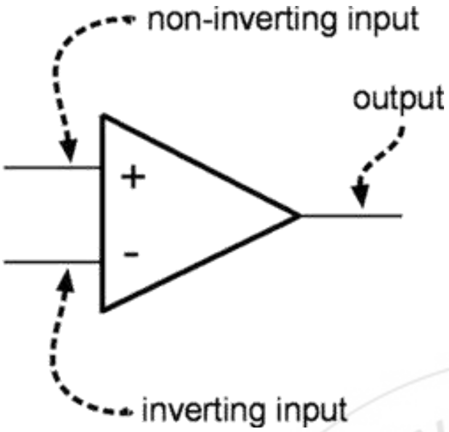

Figure 2: The output voltage schematics

In an ideal operational amplifier A is considered to be infinite and the amplifier is imagined to have infinite bandwidth and the input impedance and the output admittance are assumed to be infinity as well. The reason is of infinite gain A, the differential voltage V is zero if one of the terminal of operational amplifier (i.e either 1 or 2) in feedback configuration is grounded and other is virtual ground. It is also assumed that an operational amplifier has zero offset setting i.e. output voltage V_o is zero when the differential input is made zero. The current drawn by the two input terminal of an operational amplifier is zero as the impedance is assumed to be infinity [3].

Operational amplifiers are rarely operated in open mode. Some of the feedback mode operations and the corresponding terminal relations are shown in figure 3.

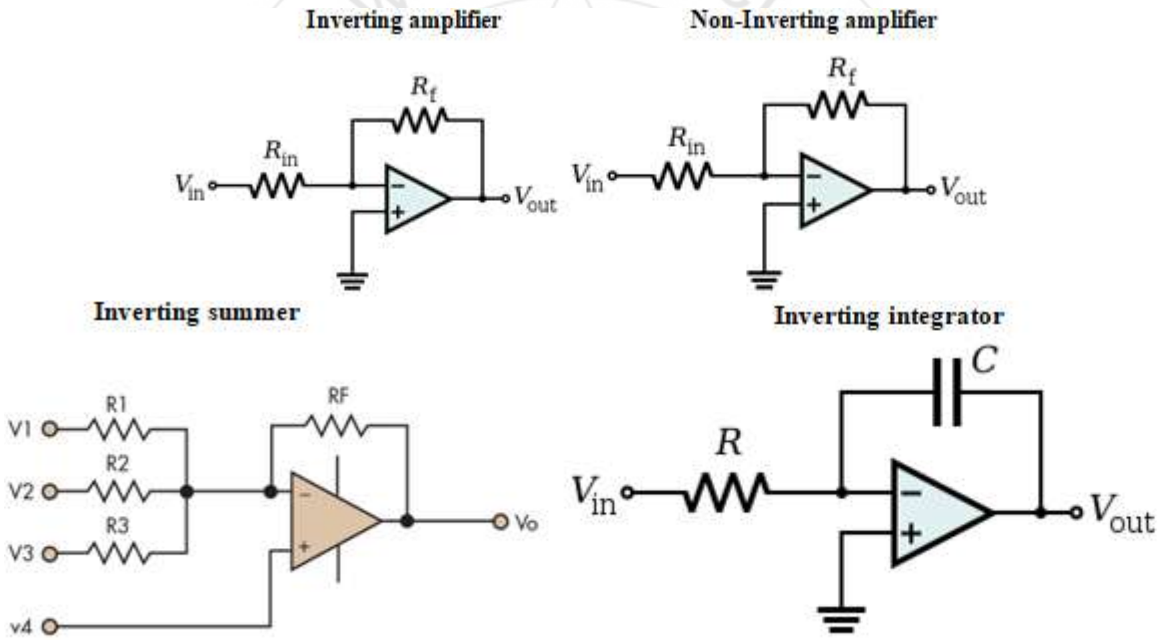

Figure 3: The feedback mode operations and the corresponding terminal relations

Negative Impedance Converter

A negative impedance converter (NIC) is a two port device whose input impedance when terminated in impedance Z_L, is $-kZ_L$ where k is conversion ratio. From figure 4

$Z_{in} = V_1/I_1$

$Z_L = V_2/I_2$

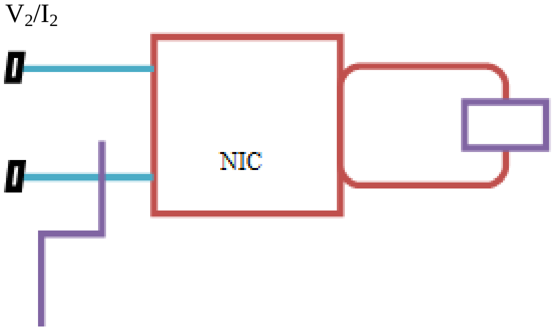

Figure 4: K conversion ratio circuit diagram

A NIC is characterized by the relation $V_1/I_1 = k(V_2/I_2)$

To see the usefulness of NICs apart from being able to generate negative valued components, consider the network as shown in the figure. The input impedance of the network is

$Zi_n = 1\text{-}1/s\text{+}1 = s/s\text{+}1$

And hence a NIC can be used to simulate the effect of an inductance.

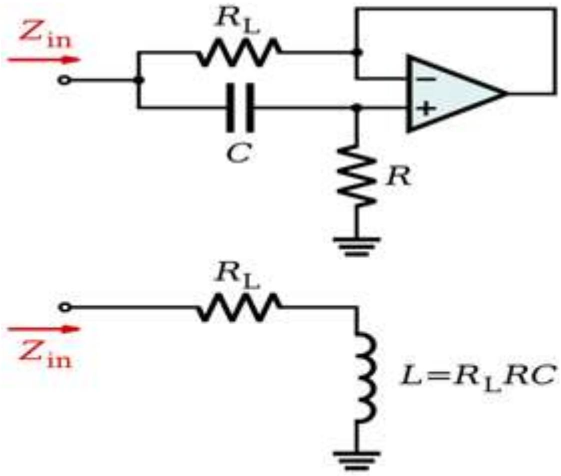

Figure 5: NIC simulated effect of an inductance

NICs can be realized by using controlled sources as shown in figure 6. Opposed amplifier realization of a CNIC and a VNIC. (Observe that in the circuit 2 the output is grounded.

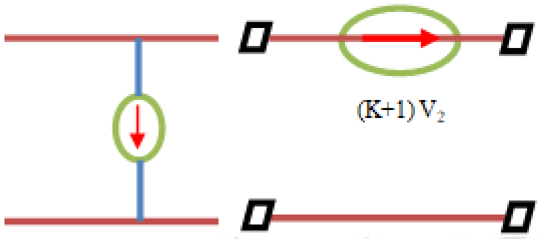

Figure 6: Opposed amplifier realization of a CNIC and a VNIC.

NICs are nonreciprocal devices and are potentially unstable networks.

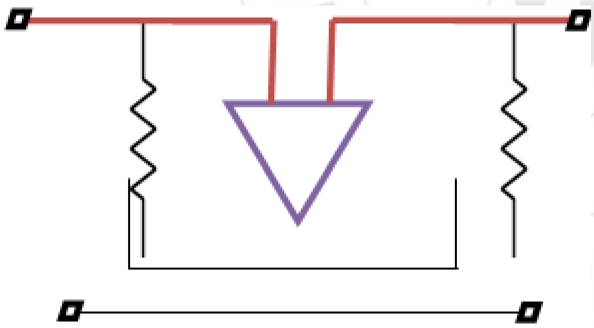

Figure 7: NIC as a unstable network

2. Gyrators

A two port device which is becoming an integral part of active filter design and inductor simulation is gyrator. A gyrator is characterized by terminal relationships.

$V_1 = -r_1 I_2$
$V_2 = r_2 I_1$

And its symbolic representation is shown in the figure 8. The total power delivered to the gyrator is [4]

$V_1 I_1 + V_2 I_2 = (r_1 - r2)I_1 I_2$

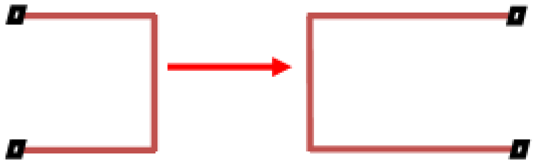

Figure 8: $V_1 I_1 + V_2 I_2 = (r_1 - r2)I_1 I_2$

IF r1 = r2, the power delivered to the gyrator is zero. Such a device is a passive lossless one and is called an ideal gyrator. If r1 = r2, the power can be made negative and then the device is called an active gyrator. The two port parameters of gyrator are [5],

$$= \begin{matrix} 0 & -r_1 \\ r_2 & 0 \end{matrix}, \quad Y = \begin{matrix} 0 & g_2 \\ -g_1 & 0 \end{matrix}, \quad T = \begin{matrix} 0 & r_2 \\ g_2 & 0 \end{matrix}$$

where $g_i = 1/ r_i$ It can be seen from above equation that a gyrator is a nonreciprocal device.

If gyrator is terminated in an impedance Z_L then the input impedance is

$Z_{in} = V_1/I_1 = - r_1 I_2/(V_2/r_2) = r_1r_2(-I_2/V_2)$

i.e $Zi_n = k/Z_L$ where $k = r_1r_2$

A gyrator can thus be considered as an impedance inverter. If the load is a capacitance, i.e. $Z_L = 1/sC$, then Z_{in} assuming $r_1 = r_2$ is sr^2C. Hence a capacitance terminated gyrator is equivalent to an inductor of value r^2C(figure 9)

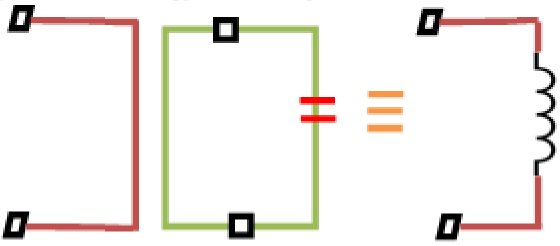

Figure 9: A circuit diagram of capacitance terminated gyrator is equivalent to an inductor of value r^2C.

A realization of an ideal gyrator using two controlled sources and the gyration ratio is r = 1/G. The circuit is commonly known as “ANTONIOU GYRATOR” [6]. In which the capacitor C_4 is being gyrated into an inductance.

3. Generalised Impedance Convertor

Let a two port network be terminated in an impedance Z_L . If the input impedance of the terminated two port is [4-7],

$Z_{in} = K(s)Z1^n$, n±1

Where K(s) is rational function of s, then the two port is called a generalized impedance converter(GIC). K(s) may also be a constant.

If n=1 it is called a converter and n=-1 it is an impedance inverter. If K(s)=-1 and n=1, then the GIC is already familiar NIC and thus can be realized by a single op. amp. If K(s)=k and n=-1, then GIC is a gyrator. On the other hand if K(s)=-k and n=-1 then GIC acts like a negative impedance inverter. Realization of a two amplifier GIC is ahown in figure 9. The input impedance of this network is

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$Z_{in}=Z_1Z_3Z_5/Z_2Z_4$

If we select Z_i,(i=1,2,3,5) as resister and Z_4 as capacitor we obtain the familiar Antoniou gyrator. We can also generate a second two amplifier gyrator circuit by selecting Z_2 as a capacitor and rest of the impedance as resistors.

If Z_1 and Z_2 are capacitors and Z_2, Z_3, Z_4 resistors then the input impedance is
$Z_{in}(s) = (R_3/R_2R_4)(1/s^2C_1C_5) = 1/Ds^2$
Where $D = R_2R_4\,C_1C_5/R_3$
Then $Z_{in}(jw) = -1/Dw^2$

Hence the input impedance behaves like a frequency dependent negative resistance (FDNR). The circuit realizing FDNR is known as Bruton's FDNR. We can have two more FDNR circuits by selecting Z_1, Z_3, or Z_3, Z_5 as capacitors and rest of impedance as resistors. FDNRs are becoming popular active components in the design of active filters.

We have, $Z_{in}(s) = Bs^2$ or $Z_{in}(jw) = -Bw^2$

Where $B = R_1R_2R_5C_2C_4$ this component is called a frequency dependent negative conductance (FDNC). The basic topology of the two amplifier GIC two gyrators, three FDNRs and an FDNC can be generated. We cannot generate an NIC and NIV from this topology.

4. Sensitvity

In most of the design the values of R, L and C are considered to be constant. The values of the components depend upon no of parameters such as temperature, humidity and ageing. And hence we cannot consider them as constants. This deviation of the parameter introduces variation in response due to incremental change in the values of the elements [8].

Classically the sensitivity of the network function F(s) with respect to parameter x is defined as
$S_x^{F(s)} = \partial \ln F(s)/\partial \ln x = (x/F)(\partial F/\partial x)$

Let the transfer function (open circuit voltage transfer ratio) of the network N be T(s) = p(s)/q(s). Then the sensitivity of T(s) with respect to the parameter x can be shown to be

$$S^T_x = S^p_x - S^q_x$$
$$= x[(1/p)\,\partial p/\partial x - ((1/q)\,\partial q/\partial x]$$

An active filter offers the following advantages over a passive filter.

1. Gain and frequency adjustment flexibility:-
The op. amp is capable of providing a gain, the input signal which is not attenuated as in case of passive filter. Another advantage of the filter is the tuning arrangement.

2. No loading problem:
Because of high input resistance and low output resistance of op. amp the active filter does not cause loading.

3. The cost of active filters is more economical than the passive filters
Active filters which have extensive applications in the field of communication and signal processing are employed in one form or another in most of the electronic systems such as radio, television, telephone, cell phone, RADAR, biochemical equipments etc. In most of the active filter designs IC 741 works satisfactorily through it has limitations over its slew rates and higher unity band width. Hence in the present study IC 741 is taken as an active device in the design of different structure of Butter Worth structures.

5. Theory

The general 2nd order biquad transfer function can be represented in the form of equation of transfer function [9-10].

$$T(S) = \frac{n_2s^2+n_1\,s+n_0}{s^2+s[\frac{w0}{Q}+w_0{}^2]}$$

Here w_0 and Q are the parameters that determine the location of poles shown in the fig 10.

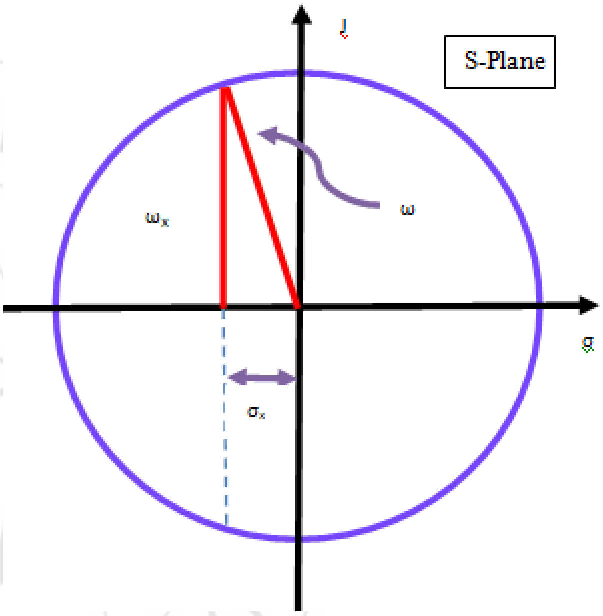

Figure 10: S-Plane with the Q parameters.

The figure illustriates pair of complex conjugate poles as shown with pole frequency equal to w_0, The pole frequency is the radial distance of poles from the origin. The Q factor determined from the poles is from jw axis. Hence pole location represented by [11]

$$P1p2 = \frac{w_0}{2\theta} \pm jw_0\sqrt{1-\frac{1}{4Q^2}}$$

The values less than 0.5 means the –ve locations of the poles define the response the filter either High pass or low pass. The low pass filters are defined by the transformations [12],

$$T(S) = \frac{n_2s^2}{s^2+s[\frac{w0}{Q}+w_0{}^2]}$$

The effect of values Q is similar which have assumed slope of 45^0

In respect of the above theory the simplest realization of the 2nd order filter utilizes single loop op. amp biquads.
SAB: Two step approaches is used in the design by quadratic filters.
1) Synthesis of feedback loop realizes a pair of complex conjugate poles characterized by frequency w_0 and Q factor.

2) Injecting the input signal in a way that realizes the desired transmission of zeros.

The figure consists of two port RC network placed in –ve feed back path of an op. amp except for having finite gain, an op. amp is an ideal & we shall realize transfer function by open circuit is given [13],

$$\mathrm{T(s)} = \frac{N(s)}{\mathrm{D(s)}}$$

The roots of N(s) are the transmission of zeros of RC network and the roots of D(s) are the poles. Study of network theory shows that the poles of RC network are restricted to lie on the ⁻ve real axis and zeros can live at any location in X plane [14-16].

If A is finite gain then

$$\mathrm{L(s)} = AT(s) = \frac{AN(s)}{\mathrm{D(s)}}$$

Substituting for L(s) in the character equation 1+L(s) = 0

These results the poles of closed loop circuits obtained as a solution of the equation,

$$\mathrm{T(s)} = -\frac{1}{\mathrm{A}}$$

And in ideal case A=∞ the poles are obtained from N (s_p)=0

That is Poles are identical to zeros o RC network.

$$\mathrm{T(s)} = \frac{\mathrm{S}^2 + \frac{\mathrm{s}\left[\frac{1}{\mathrm{c1}} + \frac{1}{\mathrm{c2}}\right]1}{\mathrm{R}_3} + \frac{1}{\mathrm{c1c2R3R4}}}{\mathrm{S}^2 + \mathrm{s}\left[\frac{1}{\mathrm{c1R3}} + \frac{1}{\mathrm{c2R3}} + \frac{1}{\mathrm{c1R4}}\right] + \frac{1}{\mathrm{c1c2R3R4}}}$$

$$\mathrm{T(s)} = \frac{\mathrm{S}^2 + \frac{\mathrm{s}\left[\frac{1}{\mathrm{R}_1} + \frac{1}{\mathrm{R}_2}\right]1}{\mathrm{R}_3\,\mathrm{c4}} + \frac{1}{\mathrm{c3c4R1R2}}}{\mathrm{S}^2 + \mathrm{s}\left[\frac{1}{\mathrm{c4R1}} + \frac{1}{\mathrm{c4R2}} + \frac{1}{\mathrm{c3R2}}\right] + \frac{1}{\mathrm{c3c4R1R2}}}$$

The values of

$$w_0 = \frac{1}{\sqrt{c1c2R3R4}}$$

$$Q = \left[\frac{\sqrt{c1c2R3R4}}{R3}\ \mathrm{X}\left[\frac{1}{\mathrm{c1}} + \frac{1}{\mathrm{c2}}\right]\right]^{-1}$$

Experimental

Butter worth structures is one of the practical structures that approximate ideal response. The main characteristic of this filter is that it has a flat pass band as well as stop band. Hence it is also known as flat filter. Similarly Chebysheve filter has ripple pass bands and flat stop band, and the cauver has ripple pass band and a ripple stop band. Since Butter worth structure is more advantageous in the design of speech filters it is considered as the selected structure for the present study. The experimental investigations of these filters are reported in the present study.

Using IC 741 general purpose op amp the 2nd order biquad with RC feedback is arranged as shown in circuit diagram. The input is injected in the filter at junction of C1, C2 and the resistance R3. The circuit functions as high pass structures explaining the transmission of zeros. The output is measured across the terminal number 6 of the op. amp and the ground.

The graph of Frequency Versus Gain is plotted in order to obtain the analysis on the performance of filter.

6. Results and Discussion

Graph for the above records for Frequency Versus Gain

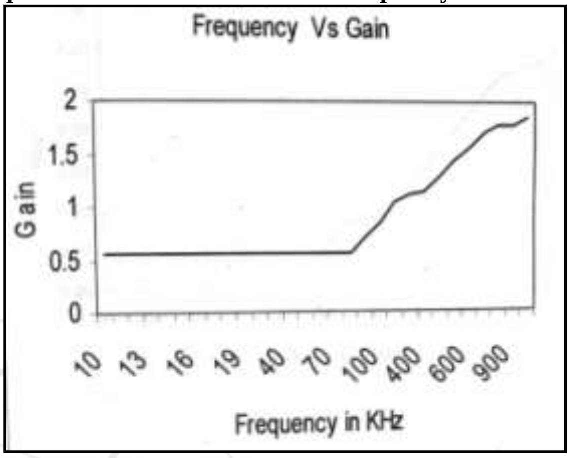

Figure 11: Graph for the above records for Frequency Versus Gain.

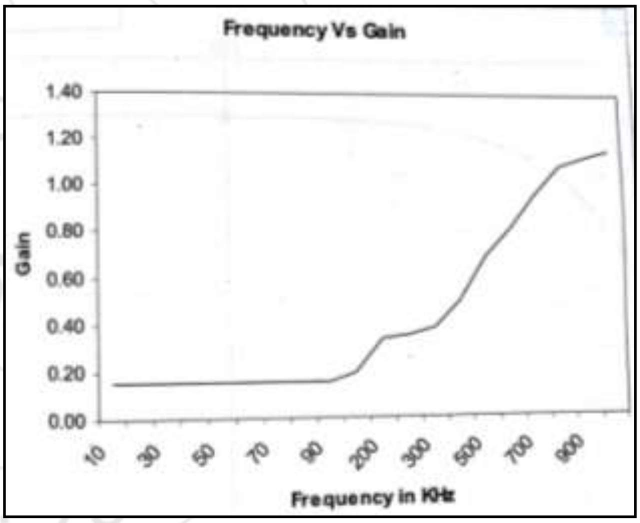

Figure 12: SPICE RESPONSE for the above circuit

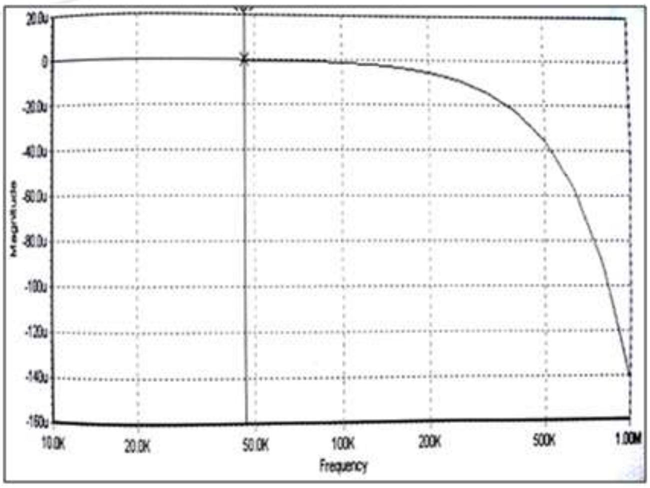

Figure 13: SPICE RESPONSE for the above circuit

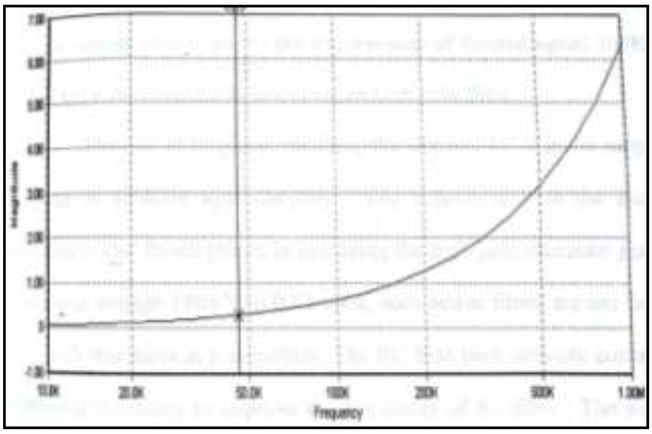

Figure 14

The experimental analysis of the filter is obtained from the frequency response on 2nd stage Biquad. The performance of the filter clearly shows the response as high pass structure. The unwanted frequencies up to 80 KHz are attenuated up to 90 KHz. The signal transmission from the studied circuits clearly shows the transmission of desired signal 100 KHz to 1 MHz. i.e the structure is functional asn high pass filter.

The role of frequency defining the slope of 45^o is in range of 90 KHz to 400 KHz approximately. The improvement in the studied response is the development in executing the high pass character just by increasing voltage 140 mV to 0.52 volts; such active filters are useful in high pass structures in transmitters. The RC feedback network contained additional flexibility to improve the sensitivity of the filter. The simple operational amplifier with capacitor explains how the sensitivity can be increased.

7. Conclusions

Nearly all of the Operational amplifiers in RC network realized by active filters in a feedback configuration which provides a high Q. To best fit in the objective of the project, commonly employed active elements are used in active filter fabrication. The impression of sensitivity which plays crucial function in active filter design in several single amplifiers and few multi amplifiers are discussed in the present study. Inductance and ladder simulation is also reported in this report with its applications to higher order filters. Of many active elements used in filters the most important one is the operational amplifier. Several active elements like gyrators, generalized impedance converter are becoming an integral part of active filters. However a controlled source may be considered as the basic active element.

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