STUDY OF THIRD ORDER ACTIVE-R FILTER WITH MULTIPLE FEEDBACK AND FEEDFORWARD INPUT SIGNAL FOR DIFFERENT TAPPING POINT

6.1 Introduction:

A third order active-R filter with variation in tapping ratio with positive feedback is proposed and studied. This circuit having feed forwarding input signal at inverting terminal of third op. amp. In the low pass response the pass band gain is same for all tapping ratio. The circuit is studied for different tapping ratio \( A \) (\( A = 0.1, 0.3, 0.5, 0.7 \) and 0.9), for center frequency \( F_0=20 \text{ KHz} \), circuit merit factor \( Q=10 \) and the positive feedback resistor \( R = 470\Omega \) which taps \( R_3 \). The circuit gives low pass, high pass and band stop response at corresponding output terminals. The designed circuit uses op-amp \( \mu \text{A 741IC} \). It is an internally compensated and represented by "integrator" model [1-13]. Various authors have proposed third order active-R filter.

In this chapter a third order active-R filter with variation in positive feedback is proposed and studied (with feedback resistor \( R \)). This circuit having feed forwarding input signal at inverting terminal of third op. amp., which provides low pass, high pass & band stop filter at three different terminals. The circuit is designed for various values of tapping point with center frequency \( F_0=20 \text{ KHz} \), circuit merit factor \( Q=10 \) and the positive feedback resistor 470\( \Omega \). Variation of tapping point varies feedback. So this filter has been studied for different values of tapping point. The response of the circuit shows that there is similar pass band gain in low pass response as tapping point varies.
In the third order active-R filter uses positive feedback, negative feedback and feed forward the input signal.

6.2 Circuit configuration:-

The proposed filter circuit is designed and studied with multiple feedback and feedforward input signal using operational amplifier and resistor as shown in figure (6.1). The filter circuit gives three filter functions: low pass, high pass and band stop at distinct terminals. This filter circuit is useful for high value of Q with high passband gain. In the designed circuit three op-amps are used and fourth op-amp is used for band stop response, it is simply summing amplifier. Negative feedback resistance $R_3$ is tapped at center by positive feedback resistance $R$ and is connected to non-inverting terminal of third op-amp. The negative feedback is incorporated by resistance $R_1$, $R_2$ and $R_3$. The resistor $R$, which in turn is connected to non-inverting terminal of the third op-amp to constitute positive feedback which is depends upon the value of resistor $R$. The tapping point of $R_3$ by $R$ is changed i.e, $A$ varies (A=0.1, 0.3, 0.5, 0.7 and 0.9).

The op-amps are coupled such that output of first op-amp is connected to non-inverting input of second op-amp and output of second op-amp is connected to non-inverting input of third op-amp. Non-inverting terminal of first op-amp is grounded. The input is applied to inverting input of first op-amp through $R_4$. Inverting of first op-amp is connected to inverting input terminal of third op-amp for feedforwarding input signal.

The circuit has been designed using coefficient-matching techniques with general third order transfer function [14-19].
The value of GB=GB₁=GB₂=GB₃= 2 π (5.6) x10⁵ rad /sec. The general operating frequency range of this filter circuit is 10 Hz to 1MHz, as the operating frequency range of op-amp µA741 is 10 Hz to 1.2 MHz.

The circuit is studied by varying circuit merit factor Q.

6.3 Circuit analysis and Design equations:-

The transfer function shows op. amp. as an 'integrator' model [2-5]. It is represented by single pole model and leads to complex gain

\[ A(s) = \frac{A₀ \omega₀}{s + \omega₀} \]  

where,

\[ A₀ = \text{open loop d. c. gain} \]

\[ \omega₀ = \text{open loop 3dB bandwidth of the op. amp} = 2 \pi F₀ \]

\[ GB = A₀ \omega₀ = \text{gain bandwidth product of the op. amp} \]

For \( S >> \omega₀ \)

\[ A(S) = \frac{A₀ \omega₀}{S} = \frac{GB}{S} \]  

The figure (6.1) shows the third order active-R filter circuit where the feedback resistance \( R₃ \) is tapped at the center and resistance \( R \) is connected with multiple feedback.

The transfer functions for various outputs are

\[ T_{LP}(s) = \frac{-\left(\frac{1}{R₄}\right)(GB₁GB₂GB₃)}{s^³X₁ + s^²X₂ + sX₃ + X₄} \]  

(3)

\[ T_{HP}(s) = \frac{\left(\frac{1}{R₄}\right)s³}{s^³X₁ + s^²X₂ + sX₃ + X₄} \]  

(4)
where,

\[ X_1 = \left( \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_4} + \frac{1}{AR_3} - \frac{(1-A)RN}{A} \right) \]

\[ X_2 = \left( \frac{GB_1}{R_1} \right) + GB_3 (RN) = \omega_0 \left( \frac{1}{Q} + 1 \right) \]

\[ X_3 = (GB_1 GB_2) \left( \frac{1}{R_2} + [(1-A)R_3N] \right) = \omega_0^2 \left( \frac{1}{Q} + 1 \right) \]

\[ X_4 = GB_1 GB_2 GB_3 (RN) = \omega_0^3 \]

The circuit has been designed using coefficient-matching technique with general third order filter transfer functions [ ]

\[ T(S) = \frac{H_3S^3 + H_2S^2 + HS + H_0}{S^3 + S^2\omega_0 \left[ \frac{1}{Q} + 1 \right] + S\omega_0^2 \left[ \frac{1}{Q} + 1 \right] + \omega_0^3} \]  \hspace{1cm} (5)

we get design equation by comparing (3), (4) with (5).

\[ X_1 = \left( \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_4} + \frac{1}{AR_3} - \frac{(1-A)RN}{A} \right) = 1 \]  \hspace{1cm} (6)

\[ X_2 = \left( \frac{GB_1}{R_1} \right) + GB_3 (RN) = \omega_0 \left( \frac{1}{Q} + 1 \right) \]  \hspace{1cm} (7)

\[ X_3 = (GB_1 GB_2) \left( \frac{1}{R_2} + [(1-A)R_3N] \right) = \omega_0^2 \left( \frac{1}{Q} + 1 \right) \]  \hspace{1cm} (8)

\[ X_4 = GB_1 GB_2 GB_3 (RN) = \omega_0^3 \]  \hspace{1cm} (9)

\[ N = \frac{1}{RR_3 + (1-A)R_3^2} \]

Values of \( R_1, R_2, R_3, \) and \( R_4 \) can be calculated using these equation for different values \( F_0 \) with \( Q = 10, R = 470\Omega \). For practical realization the value of resistance must be positive and are impedance scaled up by 100.

The values of \( R_1, R_2, R_3, \) and \( R_4 \) are shown in Table No.6.1.
<table>
<thead>
<tr>
<th>A</th>
<th>Design value</th>
<th></th>
<th>Experimental value</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R₁</td>
<td>R₂</td>
<td>AR₃</td>
<td>(1-A)R₃</td>
</tr>
<tr>
<td>0.1</td>
<td>2.548k</td>
<td>149.36k</td>
<td>84.096k</td>
<td>756.869k</td>
</tr>
<tr>
<td>0.3</td>
<td>2.548k</td>
<td>100.26k</td>
<td>179.904k</td>
<td>418.53</td>
</tr>
<tr>
<td>0.5</td>
<td>2.548k</td>
<td>88.18k</td>
<td>277.628</td>
<td>277.628</td>
</tr>
<tr>
<td>0.7</td>
<td>2.548k</td>
<td>81.35k</td>
<td>418.53</td>
<td>179.904k</td>
</tr>
<tr>
<td>0.9</td>
<td>2.548k</td>
<td>75.66k</td>
<td>756.869k</td>
<td>84.096k</td>
</tr>
</tbody>
</table>

Table No 6.1 Resistance value: Designed value and experimental value
6.4 Experimental Observation:-

A third order active-R filter is studied for variation in different tapping point with positive feedback resistor R= 470Ω, F0=20 KHz and Q=10 and using operational amplifier μA741. The operational amplifiers are having identical GB values. The value of GB=GB1=GB2=GB3 is $2\pi (5.6)10^5$ rad/sec. The general range of these frequency responses for this active-R filter is from 10 Hz to 1 MHz as operating range of this op. amp. is 10 Hz to 1.2 MHz. Following observation are studied at three different terminals; low pass, high pass, band stop function for different tapping point A.

6.5 Result and discussion:-

(a) Low pass response

Low pass responses for different values of tapping point A is shown in figure (6.2). The passband gain is almost constant. There is no overshoot any where in the response. The response shows as tapping ratio is increased the gain roll-off per octave increases and as tapping point moves towards extreme point, the gain roll-off improves per octave and so for tapping ratio A=0.3 shows better gain roll-off per octave about 17dB for octave 20 kHz to 40 kHz. For instance A=0.7 the gain roll-off per octave for octave 20 kHz to 40 kHz is 22 dB. The graph analysis is shown in table 7.2.

(b) High pass response

High pass responses for different values of tapping point A are shown in fig. (6.3). The designed center frequency is shifted and the shift is almost constant. The gain roll-off in the transient part of the response is almost constant for all values of A. For A=0.1; the gain roll-off is about
10 dB / octave for octave 65 kHz to 130 kHz, for A=0.5; the gain roll-off is about 12 dB / octave for octave 65 kHz to 130 kHz, for A=0.7; the gain roll-off is about 10 dB / octave for octave 65 kHz to 130 kHz and for A=0.9; the gain roll-off is about 8.5 dB / octave for octave 65 kHz to 130 kHz. The overshoot occurs for A=0.3, 0.5. The better high pass response of the circuit is for A=0.3, 0.5. The better high pass response of the circuit is for A=0.1, 0.7 and 0.9. The curves for the extreme values of A (=0.1, 0.7 and 0.9) are almost same.

The graph analysis is shown in table 7.3.

The better high pass response of the circuit is for A=0.1, 0.7 and 0.9 with no overshoot and 0 dB passband gain.

(c) Band stop response

The band stop response for different values of tapping point A as shown in fig. (6.4). For A=0.7 the response slightly decreases up to 2.5 dB at 50 kHz and again increases up to 3 dB at 90 kHz and above 90 kHz response is flat. A slight rejection is observed. The deep rejection may be improved by applying more positive feedback.

6.6 Conclusion:-

A third order active-R filter with variation in tapping ratio with positive feedback introduced through resistance R and feed forward input signal to inverting input of third op. amp. Circuit designed for various tapping point i.e. positive feedback for constant center frequencies F_0. The circuit gives three filter functions; low pass, high pass and band stop response.

The low pass response of the designed circuit shows that the high passband gain. For tapping ratio A=0.3 shows better gain roll-off per octave about 17dB for octave 20 kHz to 40 kHz.

The better high pass response of the circuit is for A=0.1 and 0.9. The
designed circuit shows good response for low pass & high pass. The overshoot occurs for $A=0.3, 0.5$ and $0.7$. A slight deep rejection is observed in the band stop response for $A=0.7$.

The circuit may be used in instrumentation, communication, medical instruments, the digitations of telephone, entertainment electronics, and PLL etc.

**Overall performance:-**

A new third order active-R filter circuit is designed and studied for different center frequency, different circuit merit factor $Q$ and different tapping point $A$. the circuit gives three filter functions; low pass response, high pass response and band stop response. The circuit is useful for high value of $Q$ with lower limit is $Q > 0.0.384$. The gain roll-off is almost same for all $Q$. For lower $Q$ passband gain is very low i.e., -16.3 dB. In high pass band designed center frequency is disturbed. In high pass response; for $Q=50$; the ideal high pass response is observed. In band stop response minimum passband gain is observed. The circuit shows better response for $Q=10$.

While study of this filter circuit for different center frequency; with constant $Q=10$ and feedback resistor $R= 470 \Omega$, a better gain roll-off per octave is observed for $F_0=20$ kHz. The circuit is suitable for $10$ kHz $\leq F_0 \leq 322$ kHz. The band stop response shows deep rejection for $F_0=60$ kHz. In the band stop response, minimum passband gain is of -13 dB observed for $F_0=200$ kHz. The overall better response of this filter shows for $F_0=20$kHz.
The performance of circuit is also studied for different tapping ratio i.e., positive feedback. The response shows better gain roll off for center tap.
Figure 6.1 Third order active-R filter with multiple feedback and feedforward input signal for different tapping point.
Figure (6.2) Third order active-R filter low pass response for different tapping point.
### Graph Analysis

**Third Order Active-R Filter for Different Tapping Point**

**Low Pass Response**

<table>
<thead>
<tr>
<th>Sr.No.</th>
<th>A</th>
<th>Max. Pass Band Gain (dB)</th>
<th>$F_{OL}$ (kHz)</th>
<th>$F_0$-$F_{OL}$ (kHz)</th>
<th>% Change in $F_{OL}$</th>
<th>Gain Roll-off / Octave/Decade in the stop band</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>dB/Octave</td>
</tr>
<tr>
<td>1</td>
<td>0.1</td>
<td>67</td>
<td>10</td>
<td>10</td>
<td>100</td>
<td>15</td>
</tr>
<tr>
<td>2</td>
<td>0.3</td>
<td>67</td>
<td>10</td>
<td>10</td>
<td>100</td>
<td>17</td>
</tr>
<tr>
<td>3</td>
<td>0.5</td>
<td>67</td>
<td>10</td>
<td>10</td>
<td>100</td>
<td>15.5</td>
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<tr>
<td>4</td>
<td>0.7</td>
<td>67</td>
<td>10</td>
<td>10</td>
<td>100</td>
<td>22</td>
</tr>
<tr>
<td>5</td>
<td>0.9</td>
<td>67</td>
<td>10</td>
<td>10</td>
<td>100</td>
<td>51.5</td>
</tr>
</tbody>
</table>

$F_{OSL}$: Frequency at which Overshoot occurs

Table No. 6.2 Data sheet for low pass response.
Fig. (6.3) Third order active-R filter high pass response for different tapping point.
### GRAPH ANALYSIS

**THIRD ORDER ACTIVE-R FILTER FOR DIFFERENT TAPPING POINT**  
**HIGH PASS RESPONSE**

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>A (kHz)</th>
<th>$F_{OH}$ (kHz)</th>
<th>$F_{OH} - F_{O}$ (kHz)</th>
<th>% Change in $F_{OH}$</th>
<th>Gain Roll-off / Octave/Decade in the stop band</th>
<th>Gain Stabilization at passband</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$\text{dB/Octave}$</td>
<td>Octave starting at $F_{OH}$ (kHz)</td>
<td>$\text{dB}$</td>
</tr>
<tr>
<td>1</td>
<td>0.1</td>
<td>30</td>
<td>10</td>
<td>33.33</td>
<td>10</td>
<td>15</td>
<td>-0.18</td>
</tr>
<tr>
<td>2</td>
<td>0.3</td>
<td>35</td>
<td>15</td>
<td>42.85</td>
<td>9</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0.5</td>
<td>35</td>
<td>15</td>
<td>42.85</td>
<td>12</td>
<td>15</td>
<td>-0.175</td>
</tr>
<tr>
<td>4</td>
<td>0.7</td>
<td>32</td>
<td>12</td>
<td>37.5</td>
<td>10</td>
<td>15</td>
<td>-0.17</td>
</tr>
<tr>
<td>5</td>
<td>0.9</td>
<td>30</td>
<td>10</td>
<td>33.33</td>
<td>8.5</td>
<td>15</td>
<td>-0.175</td>
</tr>
</tbody>
</table>

$F_{OSL}$: Frequency at which Overshoot occurs  
$F_{OSH}$: -3dB Frequency  
$P$: Peak gain of overshoot  
$F_{S}$: Frequency at Which gain is stabilized

Table No. 6.3 Datasheet for high pass response.
Figure (6.4) Third order active-R filter low pass response for different taping point.
References:


