### Analysis and Simulation of Eighth-Order Active-R Band Pass Filter Using Biquadratic Topology

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#### Abstract

In this paper an Eight-order Active-R Band pass filter using Biquadratic topology at centre frequency of 284KHz and quality factor Q of 30 was designed and simulated using MULTISIM work bench (version 11.0). The simulated response characteristics show that the filter has a low mid band gain that decreases with each stage but recorded a positive gain at stage 3, with 13.87dB, while the Bandwidths monotonically decreased with each stage, with stage 1 having 10.82KHz, stage 2, 6.90KHz, stage 3, 5.41KHz and stage 4; 5.04KHz showing better selectivity at stage 4 (5.04KHz) at the edge of the pass band. The roll off rate of -215.16dB/decade even surpasses that of 160dB/decade for an ideal Eighth order filter indicating a very sharp roll-off exhibited by the filter. A shift in the centre frequency was observed but not out of range as it recorded 0.7% deviation from the actual centre frequency which is negligible. The filter therefore performed well and meets its specification.

### 1. Introduction

The operational amplifier (op. amp) is now accepted as the basic active component for an inductorless circuit. The circuit is realized using single pole (as “integrator”) behavior of an internally compensated operational amplifier<sup>1,2,3</sup> and <sup>4</sup>. The filter without the capacitor is called an Active-R filter<sup>5</sup>. This filter has received much attention due to its potential advantages in terms miniaturization, ease of design and has nevertheless been a challenge in view of many interrelated dependencies in the circuit parameters. In Band pass filter, quality factor (Q) and Gain of the filter are generally interrelated and thus do not give the independent control<sup>6</sup>. Always there has to be the same design tradeoff. In case of narrow band pass filter, the circuit stability poses difficult requirements. Generally, the narrow band pass filtering action is achieved by increasing the Q value of the normal Band pass filter. The higher Q value creates circuit instability oscillations and makes the circuit very sensitive to the circuit component tolerances. Certain application requires extremely stable narrow band pass filter with very high Q value with nominal gain. Such filters are used in the devices used to detect a particular frequency accurately. The filter performance very much depends on the filter topology chosen<sup>6</sup>. Hence the choice of the Biquad filters topology. The Biquad circuit is easily tunable using single resistor tuning. It can be configured to produce a Butterworth configuration. The Butterworth filter response is used to get maximally-flat response. Also, it exhibits a nearly flat pass band with no ripple. The roll-off is smooth and monotonic, with a low pass or high pass rolloff of 20dB/dec for every pole<sup>7</sup>. This paper shows an Eighth-order Active-R Band pass filter using Biquad circuit is designed to meet the specification of quality factor (Q) of 30 and centre frequency (f<sub>o</sub>) of 284KHz, using MULTISIM work bench version 11.0 software.

### 2. Methods

#### 2.1 Design Specification

The architecture that has been used to implement the Eighth-order Band pass filter is the Biquad pole configuration because of its advantages of low-pass, high-pass, band-pass and second-order Band pass filter is shown in fig. 1. Table 1 illustrates specifications for the desired band pass filter. Using the following filter parameters, the required filter can be designed and simulated with MULTISIM work bench version 11.0 software.

#### 2.2 Design Implementation

Fig. 1 shows the second-order Band pass R-filter used in this work to design eight-order Band pass configuration presented by <sup>8</sup> has a voltage transfer function:

\[
V_2 = \frac{\alpha - \beta}{s^2 + (\omega_1 + \omega_2)s + (1 + K)\omega_1\omega_2}
\]

(1)

\[
V_1 = \frac{(\alpha - \beta)s + (\gamma - \delta)}{s^2 + (\omega_1 + \omega_2)s + (1 + K)\omega_1\omega_2}
\]

(2)

Where: S=J<sub>o</sub>

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\[ \frac{R_5}{R_4} = \left(1 - \eta \right) \frac{2\omega_0}{\omega_p} G B_2 - 1 \] (17)

And:
\[ \frac{R_{1b}}{R_{1a} + R_{1b}} = \left(1 - \eta \right) \frac{2\omega_0}{\omega_p} \] (18)

Using, \( \gamma = \frac{R_{1a} R_5}{R_{1b} R_4} \omega_0 \omega_2 \), \( \delta = (\beta - \alpha) \) together with equation 4 and 5, we have:
\[ R_{1b} = R_{1a} + R_{1b} \frac{R_6}{R_5} \] (19)
\[ R_{1a} = \frac{R_5}{R_4} \] (20)

where, \( 0 < \eta < 1 \) (21)

Given the pole parameters and the Gain Bandwidth product of the operational amplifiers GB₁ and GB₂, we determine the resistance ratios from the equations above for a chosen \( \eta \). For \( 4Q^2 \gg 1 \), it can be seen from equation 18 that the since tuning of the pole frequency \( \omega_p \) is attainable by \( R_{1a} R_5 \), while the pole frequency \( \omega_Q \) is tuned by \( R_4 \).

First, we consider the design of second-order band pass R filter (stage 1) with resonant frequency \( \omega_0 \) of 284 KHz, \( Q=30 \) and \( GB_1=GB_2=10\times10^4 \text{Hz} \). Choosing \( R_{1a}=1.0 \Omega \), \( R_4=40 \Omega \) form equation 15 we have \( R_{1b}=18.94 \Omega \) (choose 18.94Ω). From equation 16 choose \( \eta=0.1 \) and taking the value of \( R_3=40 \text{K} \Omega \), yield \( R_5=189.33 \Omega \) (choose 10KΩ).

Also from equation 17, \( R_s=40 \text{K} \Omega \), \( R=21.10 \Omega \). From equation 19, the ratio of the resistors \( R_{1a}=1.98 \text{K} \Omega \) (choose 40KΩ) and \( R_{1b}=135.25 \text{K} \Omega \) (14.62Ω). Finally, using equation 19, the ratio of the resistors \( R_{1a}=1.98 \text{K} \Omega \) (choose 40KΩ) and \( R_{1b}=135.25 \text{K} \Omega \) (14.62Ω). Finally, using equation 18, the ratios are \( R_5=1.70 \text{K} \Omega \) (1.90KΩ) and \( R_4=1.90 \text{K} \Omega \).

The value of the filter Gain calculated from equation 10 is -1.6dB for the second-order and -6.60dB for the Eighth-order. All calculated component values were presented in table 1. The exponential values also used to realize the band pass filter are also presented in table 1.
Table 1 Resistor Values

<table>
<thead>
<tr>
<th>S/N</th>
<th>Qual</th>
<th>calculated values of Resistor (Ω)</th>
<th>Experimental Resistor Values (Ω)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>R1 a</td>
<td>R1 b</td>
</tr>
<tr>
<td>1</td>
<td>30</td>
<td>1.0</td>
<td>18.</td>
</tr>
<tr>
<td>M</td>
<td>94</td>
<td>00k</td>
<td>33k</td>
</tr>
</tbody>
</table>

Fig. 2 - Eighth-order Active-R Biquadratic filter

Fig. 3 - Simulated result of Magnitude response of Eight-order Active-R Band pass filter

3. Results and Discussion

Fig. 3 shows the magnitude verses frequency response plot obtained from the output of the four cascading sections (stage 1, 2, 3, and 4) of the Eight-order Band pass R-filter with Q=30. The plot shows a gradual decrease in the mid band gain from stage 1 to 2 with the highest mid band gain as recorded at stage 3 and further decrease to stage 4. The roll-off of R-filter network obtained from the output of the first cascading section (stage 1) to the fourth section (stage 4) increases considerably. The Bandwidth was however found to decrease monotonically with each additional section in accordance with [9] and [10]. From
the result, of the roll-off, presented in table 2 it seems each cascading section is providing a double pole roll-off of \( \approx 40 \text{dB/decade} \).

Thus, for the four cascading stages (fig 2), \( n=4 \) and the result in table 2 shows consistency with the above argument because the roll-off values (Table 2) approach that of the ideal Eight-order network given by \( \approx 160 \text{dB/dec} \) [11] and even surpass it as supported by [6].

The centre frequency is slightly shifted but not out of range as it is 0.7\% of the original centre frequency.

**Table 2.** Filter sections response characteristics

<table>
<thead>
<tr>
<th>Stage</th>
<th>Bandwidth(Hz)</th>
<th>Mid Band Gain(dB)</th>
<th>Roll-off (dB/decade)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10.82k</td>
<td>-1.76</td>
<td>-53.77</td>
</tr>
<tr>
<td>2</td>
<td>6.90k</td>
<td>-2.51</td>
<td>-107.57</td>
</tr>
<tr>
<td>3</td>
<td>5.42k</td>
<td>13.87</td>
<td>-144.26</td>
</tr>
<tr>
<td>4</td>
<td>5.04k</td>
<td>-4.01</td>
<td>-215.16</td>
</tr>
</tbody>
</table>

4. Conclusions

We have successfully designed and simulated the Eighth-order Active-R Band pass filter using Biquadratic topology, and found that in addition to the advantages of miniaturization, ease of design and high frequency performance, the R-filter network provides better selectivity, greater stop band attenuation and steeper cut-off at the edge of the pass band. Therefore the filter can be said to meet its specification outlined above.

**References**


[9]. Chavan, U.N. and Shinde, G.N. Synthesis of Third Order Active-R Multifunction Filter Using Feed Forward,