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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 Biquadrtic 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 Eight 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.

1.0 Introduction

The operational amplifier (op. amp) is now accepted as the basic active component for an inductorless filter. The circuit is realized using single pole (as "integrator") behavior of an internally compensated operational amplifier[1],[2],[3] and [4]. The filter without the capacitor is called an Active-R filter [5]. This filter has received much attention due to its potential advantages in terms miniaturization, ease of design 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 [6].

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 [6]. Hence the choice of the Biquadratic filters topology. The Biquadratic topology is a useful circuit for producing band pass and low-pass filter responses which require high

Q-factor values not achievement with voltage with voltage supply. Voltage supply (VSVS) and IGMF circuit configuration.

The Biquad and the state variable filter circuit configuration can have Q-factor values 400, or greater. This Biquadratic 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,

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with a low pass or high pass roll-off of 20dB/dec for every pole [7]. This paper shows an Eight-order Active-R Band pass filter using Biquadratic topology is designed to meet the specification of quality factor (Q) of 30 and centre frequency (f0) of 284KHz, using MULTISIM work bench version 11.0 software.

2.0 Methods

2.1 Design specification

The architecture that has been used to implement the Eighth-order Band pass filter is the Biquadratic topology because of its advantages of in terms of mid-frequency stability, high-Q factor, independent gain and Q values, high-roll-off and second-order Band pass filter is shown in fig. 1. Table 1 illustrates specifications for the desired band pass filter. By 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 [8] has a voltage transfer function;
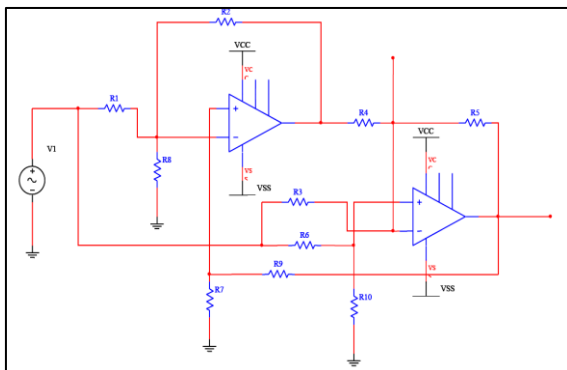
$$\frac{V_2}{V_1} = \frac{(\alpha - \beta)s + (\gamma - \delta)}{s^2 + (\omega_1 + \omega_2)s + (1 + K)\omega_1\omega_2} \quad (1)$$

The band-pass function is obtained with $\gamma = \delta$, giving the transfer function from equation 1 to be:

$$\frac{V_2}{V_1} = \frac{(\alpha - \beta)s}{s^2 + (\omega_1 + \omega_2)s + (1 + K)\omega_1\omega_2} \quad (2)$$

Where; $S = J\omega$ (3)

Fig 1: Second-order Active Biquadratic Filter

$$\alpha = \frac{R_{6b}}{R_{6a} + R_{6b}}\left(1 + \frac{R_5}{R_4} + \frac{R_5}{R_3}\right)\omega_2 \quad (4)$$

$$2\omega_1 = \frac{\omega_Q}{\omega_p} = 2\omega_2 \quad (6)$$

$$\omega_p = \text{pole frequency} = \sqrt{(1 + k)\omega_1\omega_2} \quad (7)$$

$$Q_p = \text{pole quality} = \frac{\sqrt{(1+k)\omega_1\omega_2}}{\omega_1 + \omega_2} \quad (8)$$

$\omega_1 = frquency\ of\ first\ op - amp$
$\omega_2 = frquency\ of\ second\ op - amp$

The alternator, k of the filter is given as;

$$k = \left(1 + \frac{R_2}{R_{1a}//R_{1b}}\right)\frac{R_5}{R_4}\frac{R_{7b}}{R_{7a} + R_{7b}} \quad (9)$$

The Gain (G) of the filter is;

$$\text{Gain (G)} = \frac{\alpha - \beta}{\omega_1 + \omega_2} \quad (10)$$

For convenience, he assumed $\omega_1 = \omega_2$ in the equation:

$$\omega_1 = GB_1 / \left(1 + \frac{R_2}{R_{1a}//R_{1b}}\right) \quad (11)$$

$$\omega_2 = GB_2 / \left(1 + \frac{R_5}{R_4} + \frac{R_5}{R_3}\right) \quad (12)$$

And then identify equation 6 together with equation 11 for ω_1 yields;

$$1 + \frac{R_2}{R_{1a}//R_{1b}} = \frac{2\omega_Q}{\omega_p} = 2GB_2 \quad (13)$$

where the values of the resistors are determined by ratios. Similarly, using equation 12 for equation 6 for ω_2, then substituting:

$$1 + \frac{R_5}{R_4} + \frac{R_5}{R_3} = 2\frac{Q_p}{\omega_p} = GB_2 \quad (14\text{-}a)$$

and

$$\beta = \frac{R_5}{R_3}\omega_2 \quad (14\text{-}b)$$

using $\omega_p^2 = (1 + k)\omega_1\omega_2$, we express resistance ratios as;

$$\frac{R_2}{R_{1a}//R_{1b}} = \frac{2\omega_Q}{\omega_p}GB_2 - 1 \quad (15)$$

$$\frac{R_5}{R_3} = \eta\frac{2\omega_Q}{\omega_p}GB_2 \quad (16)$$

$$\frac{R_5}{R_4} = (1-\eta)\frac{2\omega_Q}{\omega_p}GB_2 - 1 \qquad (17)$$

And:

$$\frac{R_{7b}}{R_{7a}+R_{7b}} = \frac{2Q_p\frac{\omega_p}{GB_1}\left(1-\frac{1}{Q_p^2}\right)}{(1-\eta)\frac{2Q_2}{\omega_p}GB_2-1} \qquad (18)$$

Using, $\gamma = \frac{R_2 R_5}{R_{1a}R_4}\omega_1\omega_2$, $\delta = (\beta-\alpha)\omega_1$ together with equation 4 and 5, we have;

$$\frac{R_{6a}}{R_{6b}} = \frac{1+2\frac{R_5}{R_2}+\frac{R_5}{R_4}\left(1+\frac{R_2}{R_{1a}}\right)}{\frac{R_5}{R_4}\frac{R_2}{R_{1a}}\frac{R_5}{R_2}} \qquad (19)$$

$$R_{1a} \geq \frac{R_2 R_2}{R_4} \qquad (20)$$

where, $\quad 0<\eta<1 \qquad (21)$

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 η. For 4Q2>>1, it can be seen from equation 18 that the since tuning of the pole frequency (ω_p) is attainable by R7b/R7a, while the pole frequency (Qp) is tuned by R4.

First, we consider the design of second-order band pass R filter (stage 1) with resonant frequency (ω_p) of 284 KHz, Q=30 and GB1=GB2=10×10⁶Hz. Choosing R1a=1.0MΩ, R2=40KΩ form equation 15 we have R1b=18.94Ω (choose 18.94Ω). From equation 16 choose η=0.1 and taking the value of R5=40KM, yield R4=189.33Ω (choose 10KΩ). Also from equation 17, R5=40KΩ, R4=21.10Ω. from equation 19, the ratio of the resistors R6a=1.98KΩ (choose 40KΩ) and R6b=135.25Ω (14.62Ω). Finally, using equation 19, the ratio of the resistors R6a=1.98KΩ (choose 40KΩ) and R6b=135.25Ω (14.62Ω). Finally, using equation 18, the ratios are R7a=1.70KΩ (1.90KΩ) and R1b=1.90KΩ.

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

S/N	Quality Factor (Q)	calculated values of Resistor (Ω)										Experimental Resistor Values (Ω)								
		R1a	R1b	R2	R3	R4	R5	R6a	R6b	R7a	R7b	R1a	R1b	R2	R3	R4	R5	R6a	R6b	R7a	R7b
1	30	1.0M	18.94	40.00k	189.33k	21.10	40.00k	1.98k	135.251	1.70k	1.90k	1.0M	18.94	40.00k	10.0k	21.10	40kΩ	40kΩ	14.62	248kΩ	1.90

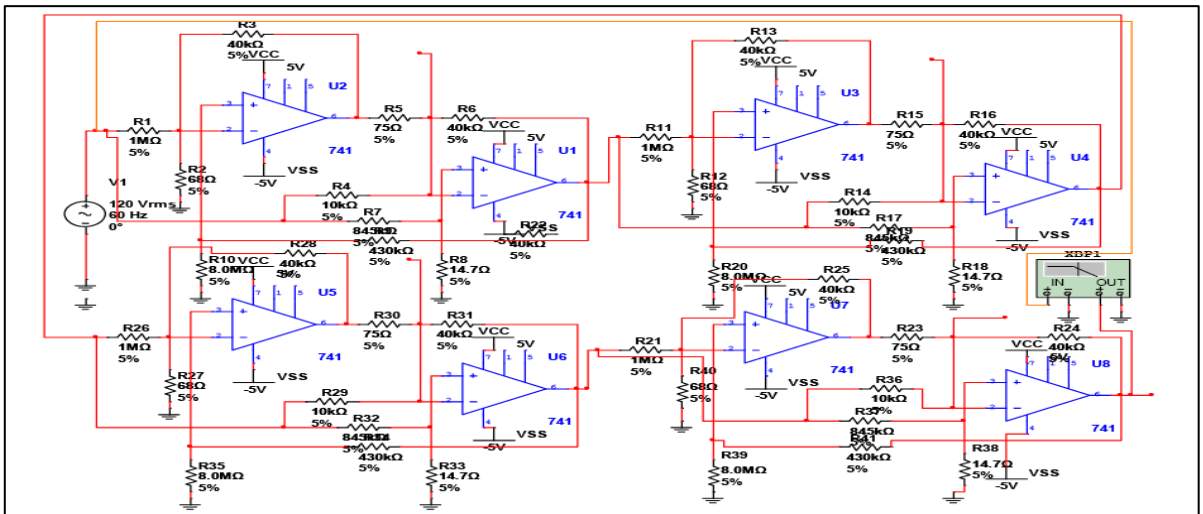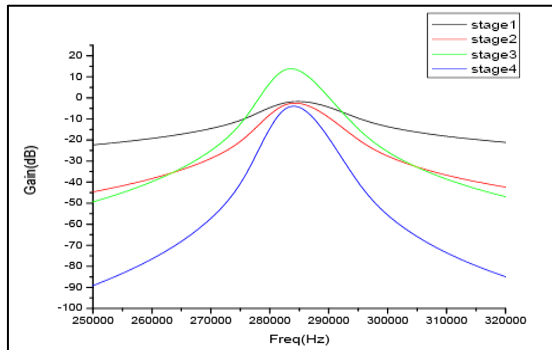**Fig 2: Eighth-order Active-R Biquadratic Filte**

Fig 3: Simulated Result of Magnitude Response of Eight-Order Active-R Band Pass Filter

3.0 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 $\approx$ 40dB/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 $\approx$ 160dB/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

Stage	Bandwidth(Hz)	Mid Band Gain(dB)	Roll-off (dB/decade)
1	10.82k	-1.76	-53.77
2	6.90k	-2.51	-107.57
3	5.42k	13.87	-144.26
4	5.04k	-4.01	-215.16

4.0 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.

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