Output Response Analysis of an 8th Order Active RC Band-Pass Filter Using Matlab

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Abstract- In this paper, an active eighth order band-pass filter is implemented. The filter has a center frequency of 15 kHz and roll-off rate of -80dB/decade. The architecture used is the Sallen-Key configuration. The filter parameters and values for the passive components were calculated and the gain magnitude and phase output response is then analyzed with MATLAB software. The simulation shows that the filter has high gain, a wide bandwidth and a good roll-off at the pass band.

Index Terms- Quality factor, centre frequency, Band-pass filter, MATLAB.

I. INTRODUCTION

In modern electronic circuits today, unwanted signals are a major challenge to contend with. This is due to interferences, in the form of noise and harmonics which these unwanted signals pose to certain specified wanted signal frequencies in a band in electronic systems [5-10]. In state-of-the-art RF receivers, high performance filters are required to remove undesired signals at different stages of the receiving process, such as noise from incoming signals the antenna receives, undesired signals at the image frequency, and the effects of harmonics after the mixing operation which attenuates the desired signal [3]. Active filters are used because of the following advantages:

- i. Active filters can generate a gain larger than one.
- ii. Higher order filters can easily be cascaded in the order of rising quality factor.

 filters are smaller in size as long as no inductors are used, which makes them very useful in integrated circuits.

The most common filter responses are the Butterworth, Chebyshev, and Bessel types. Among these responses, Butterworth type is used to get a 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 roll-off of 20dB/dec for every pole [1-4].

In this paper, an Eighth order active band pass filter is designed to meet the specifications of different quality factors using MATLAB.

II. DESIGN IMPLEMENTATION

In this paper, the architecture that has been used to implement the eighth (8th) order band-pass filter is the Sallen-Key Topology. This topology is chosen due to its simplicity compared to other known architectures such as multiple feedback and state variable.

The 8th order active band pass filter is achieved by cascading 4 identical 2nd order stages with different gains. The cascading is in the order of rising quality factor; this is done so as to reduce the filter saturation.

Table.1 illustrates the specifications for the desired bandpass filter. By using the following filter parameters, the required filter characteristic is simulated with MATLAB.

Table 1: Sallen key band pass Filter specifications

Centre frequency	15 kHz
Stop band attenuation	-80dB
Pass band ripple	0.1dB

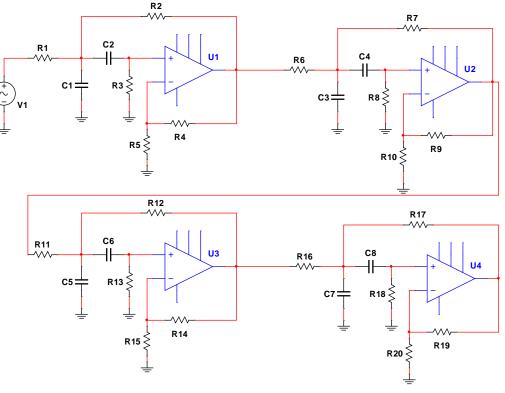


Fig. 2: Cascaded 8th order active band-pass filter

Individual 2nd order units are evaluated to obtain their transfer function as shown in equations (1-4) below:

$$C = 10 nF$$
, $R_3 = 10 k$, $R_4 = 10 k$, $f_o = 15 kHz$
 $R = 1/(2*\pi*15000*10 x 10^9) = 1.06k$

Bandwidth = $f_0/Q = 15$ kHz/ 1 = 15 kHz For the 1^{st} stage: $R_1 = R_2 = R$, $R_5 = 2R$, $C_1 = C_2 = C$, $\textbf{G_1} = \textbf{1} + \frac{R_4}{R_5}$

$$H_1(s) = \frac{sCRG_1}{s^2C^2R^2 + sCR(3-G_1) + 1} \tag{1}$$

where

$$Q_1 = \frac{1}{(3 - G_1)}$$

For the 2^{nd} stage: $R_6 = R_7 = R$, $R_8 = 2R$, $C_3 = C_4 = C$, $G_2 = 1 + \frac{R_{10}}{R_0}$

$$H_2(s) = \frac{sCRG_2}{s^2C^2R^2 + sCR(3-G_2)+1}$$
(2)

Where

$$Q_2 = \frac{1}{(3 - G_2)}$$

For the 3rd stage: $R_{11}=R_{12}=R,\,R_{13}=2R,\,C_5=C_6=C,\,$ $\textbf{G}_{3}=\textbf{1}+\frac{R_{15}}{R_{14}}$

$$H_2(s) = \frac{sCRG_2}{s^2C^2R^2 + sCR(2-G_2)+1}$$
(3)

where

$$Q_3 = \frac{1}{(3 - G_3)}$$

For the 4th stage:
$$R_{16} = R_{17} = R$$
, $R_{18} = 2R$, $C_7 = C_8 = C$, $G_4 = 1 + \frac{R_{20}}{R_{10}}$

$$\begin{split} H_4(s) &= \tfrac{s C R G_4}{s^2 C^2 R^2 + s C R (2 - G_4) + 1} \\ \text{where} \end{split} \tag{4}$$

$$Q_4 = \frac{1}{(3 - G_4)}$$

The transfer function for the cascaded Sallen-key 8th order active band pass filter is

$$H(s) = H_1(s) * H_2(s) * H_3(s) * H_4(s)$$

$$H(s) = s^4 C^4 R^4 G^4$$
 (5)

$$s^{8}\overline{C^{8}R^{8} + 4s^{7}C^{7}R^{7}(3-G) + 2s^{6}C^{6}R^{6}[3(3-G)^{2} + 2] + 4s^{5}C^{5}R^{5}(3-G)[\ (3-G)^{2} + 3] + s^{4}C^{4}R^{4}[(3-G)^{4} + 12(3-G)^{2} + 6\] + 4s^{3}C^{3}R^{3}[(3-G)^{3} + 3(3-G)] + 2s^{2}C^{2}R^{2}[3(3-G)^{2} + 2] + 4sCR(3-G) + 1$$

in standard form, the above transfer function can be written as

$$H(s) = A^4(\omega_o^4/Q^4) s^4$$
 (6

$$H(s) = \frac{A^{3}(\omega_{o}^{3}/Q^{3})s^{3}}{s^{8} + 4(\omega_{o}^{3}/Q^{3})[3Q^{2} + 1]s^{5} + (\omega_{o}^{4}/Q^{2})[4Q^{2} + 9]s^{4} + 4(\omega_{o}^{5}/Q^{3})[3Q + 1]s^{3} + 2(\omega_{o}^{6}/Q^{2})[2Q + 3]s^{2} + 4(\omega_{o}^{7}/Q)s + \omega_{o}^{8}}$$

$$(6)$$

$$s^{8} + 4(\omega_{o}/Q)s^{7} + 4(\omega_{o}^{2}/Q^{2})[1.5 + Q^{2}]s^{6} + 4(\omega_{o}^{3}/Q^{3})[3Q^{2} + 1]s^{5} + (\omega_{o}^{4}/Q^{2})[4Q^{2} + 9]s^{4} + 4(\omega_{o}^{5}/Q^{3})[3Q + 1]s^{3} + 2(\omega_{o}^{6}/Q^{2})[2Q + 3]s^{2} + 4(\omega_{o}^{7}/Q)s + \omega_{o}^{8}$$

III. RESULTS

The results of MATLAB simulation for the second order Active-RC band-pass filter is shown in Fig. 2 and 3 below

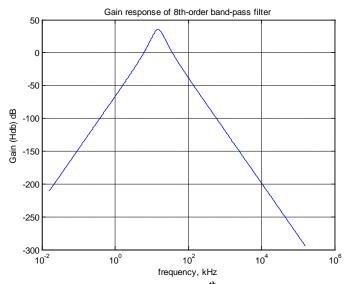


Fig. 2: Magnitude response of a 8th order band pass filter

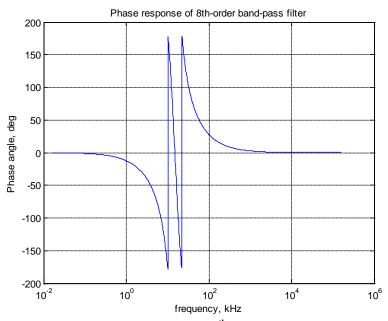


Fig. 3: Phase response of an 8th order band pass filter

TABLE 3: Characteristic values obtained from the simulation of the 8th order band-pass filter using MATLAB

Quality Factor (Q)	Maximum Gain	F _L at 3dB (kHz)	- F _H at 3dB (kHz)	- Bandwidth (kHz)	Center Freq. (kHz)
2.90	35.15	12.63	17.84	5.21	15.01

From Fig. 2 and Table 3, it is observed that, the filter has a maximum gain of 35.15 dB, at a centre frequency of 15.01 kHz, lower and upper cut-off frequencies of 12.63 kHz and 17.84 kHz respectively and a bandwidth of 5.21 kHz at an overall quality factor of 2.90.

It can also be noted from the graph of Fig. 3 that the Phase response is negative for $\omega < \omega_o$ and positive for $\omega > \omega_o$ (capacitive). The phase angle of the output signal is in phase with that of the input by $+0^\circ$ and starts lagging the input up to the centre or resonant frequency (ω_o) point were it becomes "-180°" degrees lagging the input signal and "out of-phase" and then changes to lead the input by $+180^\circ$ as the output frequency increases.

IV. CONCLUSION

An Eighth order active RC band-pass filter with equal stages cascade has been presented. It is characterized by high gain, a wide bandwidth and a good roll-off at the pass band as presented in results above. It also has very low quality factor and may not be suitable in high precision communications systems. The implemented 8th order active band-pass filter performed as expected with little dissatisfactions with point where maximum gain was obtained.

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