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Active RC high selectivity notch filter

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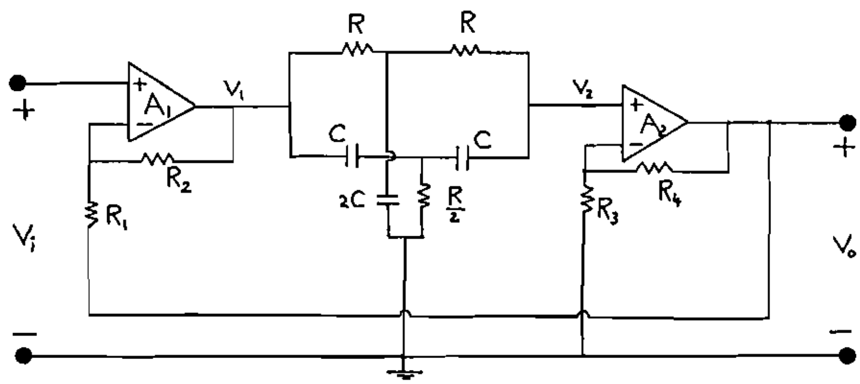
A general configuration for realizing a high Q notch filter is given. The circuit has a very high input impedance and a very low output impedance. The frequency limitation equations based on the one-pole roll-off model of the operational amplifier are given.

1. Introduction

Active filters are being classified now based on the selectivity that can be achieved by the circuit (Moschytz 1970). The Q range is divided into three decades, low Q (0·5 to 5), medium Q (5 to 50) and high Q (50 to 500). Recently a general configuration for realizing a medium selectivity notch filter was given (Soliman 1972). The purpose of this paper is to modify the previous circuit to make it capable of realizing a high Q notch characteristics.

2. Basic configuration



The circuit is shown in the figure. The open circuit voltage transfer function is given by :

$$G(s) \equiv \frac{V_0}{V_i} = \frac{T(s)}{\left(\frac{1}{K_1}+\frac{1}{A_1}\right)\left(\frac{1}{K_2}+\frac{1}{A_2}\right)+\left(\frac{K_1-1}{K_1}\right)T(s)} \tag{1}$$

where

$$K_1 = 1+\frac{R_2}{R_1}, \quad K_2 = 1+\frac{R_4}{R_3} \tag{2}$$

and

$$T(s)=\frac{V_2}{V_1}=\frac{s^2+\left(\frac{1}{CR}\right)^2}{s^2+\left(\frac{4}{CR}\right)s+\left(\frac{1}{CR}\right)^2} \tag{3}$$

From (3) in (1), hence

$$G(s)=\frac{s^2+\left(\frac{1}{CR}\right)^2}{\left[\left(\frac{1}{K_1}+\frac{1}{A_1}\right)\left(\frac{1}{K_2}+\frac{1}{A_2}\right)+\frac{K_1-1}{K_1}\right]\times\left[s^2+\frac{4}{CR}\,\frac{1}{1+\frac{K_1-1}{K_1\left(\frac{1}{K_1}+\frac{1}{A_2}\right)\left(\frac{1}{K_2}+\frac{1}{A_2}\right)}}\,s+\left(\frac{1}{CR}\right)^2\right]} \tag{4}$$

For A_1 and A_2 approaching infinity, the above transfer function reduces to

$$G(s)\simeq\frac{K_1K_2\left[s^2+\left(\frac{1}{CR}\right)^2\right]}{[K_2(K_1-1)+1]\left[s^2+\frac{4}{CR(1+K_2(K_1-1))}\,s+\left(\frac{1}{CR}\right)^2\right]} \tag{5}$$

which realizes a notch characteristics having

$$\omega_0=\frac{1}{CR} \tag{6}$$

$$Q=\frac{K_2(K_1-1)+1}{4}\simeq\frac{K_1K_2}{4} \quad \text{for} \quad K_1, K_2 \gg 1 \tag{7}$$

$$H\equiv|G(0)|\equiv|G(\infty)|=\frac{K_1K_2}{K_2(K_1-1)+1}\simeq 1 \quad \text{for} \quad K_1, K_2 \gg 1 \tag{8}$$

Equations (6) and (7) are the design equations of the filter. It is seen that C and R control ω_0 without affecting Q of the circuit, on the other hand the selectivity of the filter is adjusted by K_1 and K_2 without changing the notch frequency.

3. Active sensitivities

The effect of the finite gain of the operational amplifiers is discussed next. Assuming a real gain of the operational amplifiers, i.e. $A_1=A_2=A_0$, and for the case of interest namely $K_1=K_2$ and $Q\gg 1$, the actual values of ω_0 and Q are given by

$$\omega_{0a}=\omega_0 \tag{9}$$

$$Q_a\simeq\frac{Q}{\left(1+\frac{2\sqrt{Q}}{A_0}\right)^2} \tag{10}$$

Thus

$$\overset{\omega_{o0}}{\underset{A_0}{S}} = 0 \tag{11}$$

$$\overset{Q_0}{\underset{A_0}{S}} \simeq \frac{\dfrac{4\sqrt{Q}}{A_0}}{1+\dfrac{2\sqrt{Q}}{A_0}} \simeq \frac{4\sqrt{Q}}{A_0} \quad \text{for} \quad Q \ll A_0 \tag{12}$$

which is proportional to the square root of Q rather than Q as in the medium selectivity circuit (Soliman 1972).

4. Frequency limitation equations

The frequency limitation equations of this network are obtained from (4) by setting,

$$A_1 = A_2 = \frac{A_0}{1+\dfrac{s}{\omega_1}} \simeq \frac{GB}{s} \tag{13}$$

where

A_0 is the open loop d.c. gain of the operational amplifier,
ω_1 is the open loop 3 dB bandwidth in radians per second,

and

$$GB = A_0\omega_1$$

and following Budak–Petrela analysis (1972), hence ;

$$\frac{\Delta\omega_0}{\omega_0} \simeq -\frac{2\omega_0}{\sqrt{Q}\,.\,GB} \tag{14}$$

$$\frac{\Delta Q}{Q} = \frac{2\omega_0}{\sqrt{Q}\,.\,GB} \tag{15}$$

where it is assumed that $Q \gg 1$ and $K_1 = K_2$.

As an example, for the μA 741 operational amplifier having $A_0 = 10^5$, $f_1 = 10$ Hz, if the maximum allowable change in ω_0 and Q is not to exceed 2% and for $Q = 100$, the maximum notch frequency that can be realized using this circuit is 100 kHz.

5. Conclusions

A general circuit for realizing a high Q notch characteristics is given. The circuit has a very high input impedance and a very low output impedance. The frequency limitation equations based on the one pole rolloff model of the operational amplifier are given.

References

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