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Research notes

Conversion of a band-pass resonator to an all-pass or a notch filter

AHMED M. SOLIMAN†

A method is described for converting an active inverting band-pass resonator to an all-pass or a notch filter, without using any extra operational amplifier. An example based on the Sallen–Key resonator is included.

The realization of an all-pass characteristic having complex poles and zeros and using a single operational amplifier has received a great deal of attention recently (Holt and Gray 1967, Deliyannis 1969, Moschytz 1972, Soliman 1973 a, b).

It is well known that an all-pass or a notch filter can be realized from an inverting band-pass filter by using the circuit shown in Fig. 1 (Aikens and Brault 1969, Tobey *et al.* 1971). The tuning procedure for this circuit was recently discussed in detail (Roberts 1973). The above realization however requires an extra operational amplifier (OA).

The purpose of this research note is to provide a general configuration for converting an inverting active RC band-pass-resonator having its output obtained from the OA output terminal to an all-pass or a notch filter without using any extra OA.

The basic circuit is shown in Fig. 2. Terminal 2 is the output of the OA. The network N is an active RC band-pass filter having

$$T(s) \equiv \frac{V_2}{V_1} \equiv \frac{-K\omega_0 s}{s^2 + \frac{\omega_0}{Q} s + \omega_0^2} \tag{1}$$

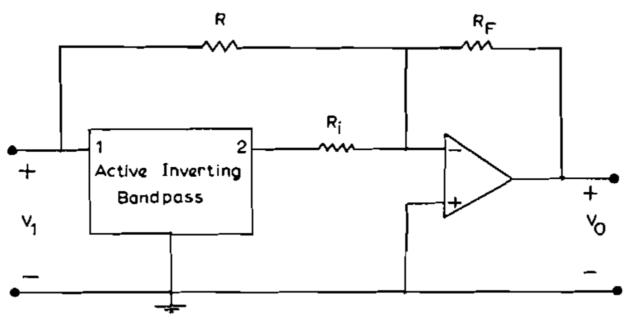

Figure 1. A well-known configuration.

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† Electronics and Communications Engineering Department, Faculty of Engineering, Cairo University, Cairo, Egypt.

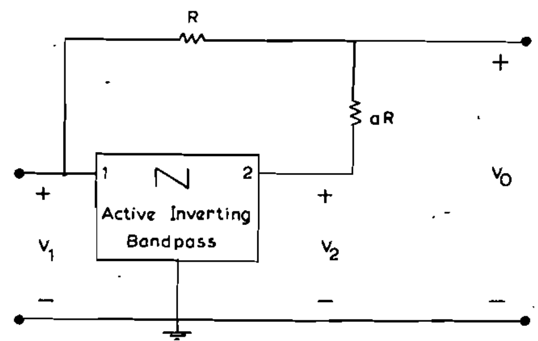

Figure 2. A new configuration.

By direct analysis, thus

$$G(s) \equiv \frac{V_0}{V_1} = \frac{a}{a+1}\left[\frac{s^2 - \omega_0 s\left(\frac{K}{a} - \frac{1}{Q}\right) + \omega_0^2}{s^2 + \frac{\omega_0}{Q}s + \omega_0^2}\right] \tag{2}$$

For an all-pass phase shifter, it is necessary that

$$a = \frac{KQ}{2} \tag{3}$$

and for a notch filter

$$a = KQ \tag{4}$$

It is seen that ω_0 and the pole Q of the non-minimum phase characteristics are the same as those of the band-pass filter.

Example

It is desirable to realize an all-pass phase shifter based on the well-known Sallen–Key resonator shown in Fig. 3 (a) (Geffe 1968) :

$$T(s) = \frac{-bsCR}{s^2C^2R^2(b+1) + 3sCR + 1} \tag{5}$$

$$KQ = \frac{b}{3} \tag{6}$$

$$\omega_0 = \frac{1}{CR\sqrt{(b+1)}} \tag{7}$$

$$Q = \frac{\sqrt{(b+1)}}{3} \tag{8}$$

For an all-pass

$$a = \frac{b}{6} = \frac{9Q^2 - 1}{6} \tag{9}$$

For a normalized value of $\omega_0 = 1$, the design equations are

$$R = 1, \quad C = \frac{1}{3Q}, \quad b = 9Q^2 - 1$$

The all-pass resonator is shown in Fig. 3 (*b*). This circuit belongs to the general configuration reported recently by the author (Soliman 1973 a).

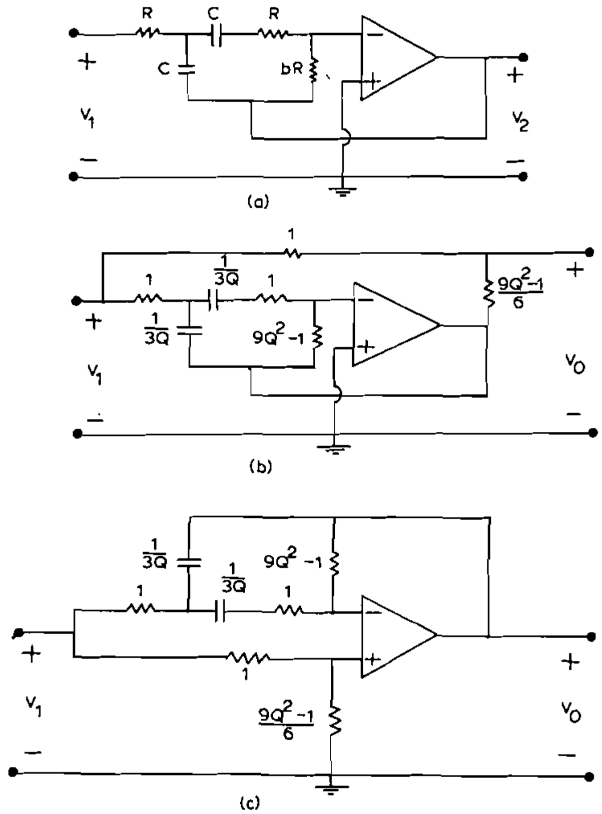

Figure 3. (*a*) Sallen–Key negative feedback band-pass resonator. (*b*) An all-pass phase shifter based on the Sallen–Key band-pass network. (*c*) An alternative all-pass phase shifter using a differential input OA.

It is very interesting to note that an identical all-pass resonator can be obtained from the circuit in Fig. 3 (*a*) by generating a voltage proportional to the input at the non-inverting terminal of the OA. The all-pass realization for $\omega_0 = 1$ is shown in Fig. 3 (*c*). The advantage of this realization is that it has a very low output impedance. Again this circuit belongs to the general structure given by the author (Soliman 1973 b).

From (8), it follows that

$$S_b^Q = \frac{dQ}{db}\frac{b}{Q} = \frac{1}{2} - \frac{1}{18Q^2}$$

The gain sensitivity product (Seeley 1972)

$$GS \equiv b \, . \, S_b^Q \cong 4 \cdot 5 Q^2 \quad \text{for } Q \gg 1$$

The above gain sensitivity is proportional to Q^2, thus it limits the use of the all-pass resonators to low-pole Q applications.

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