CIRCUIT THEORY AND APPLICATIONS, VOL. 6, 153-157 (1978)

A UNIVERSAL ACTIVE *R* BIQUAD

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SUMMARY

A universal active *R* biquad structure is presented which uses only resistors and two operational amplifiers. The network provides general biquadratic, band-pass and low-pass characteristics and is suitable for high-frequency applications at medium pole *Q* values. When the network is adjusted to realize a high-pass characteristic it becomes a special case from Schaumann's circuit N. The biquad circuit is recommended for monolithic integration.

1. INTRODUCTION

Active *R* design using internally compensated operational amplifiers has recently received considerable attention. In addition to their improved high-frequency performance active *R* circuits are characterized by very low sensitivities to both active and passive circuit parameters.

Most of the literature[1-3] was mainly concerned with the realization and investigation of active *R* band-pass and low-pass filters.

Recently the realization of any second-order transfer function was considered by Schaumann[4,5] and Srinivasan.[6] The former gave a general state variable circuit which includes most of the active *R* filters published[1-3] as special cases.

In this paper an active *R* biquad is given. Inverting band-pass and low-pass transfer characteristics can be obtained at two different output terminals. At a third output terminal, a general biquadratic transfer characteristic is obtained, namely, an equalizer, a nonminimum phase, an all-pass, a universal notch or a high-pass transfer function. In the special case when the network is tuned to realize a high-pass transfer function it belongs to Schaumann's Circuit N.[5] Sensitivities to all active and passive circuit parameters are discussed.

2. THE NETWORK

For the circuit of Figure 1, assuming

$$A_i = \frac{GB_i}{s} \qquad (i = 1, 2) \tag{1}$$

where *GB* is the gain–bandwidth product of the operational amplifier, and by direct analysis thus:

$$\frac{V_2}{V_1} = K \cdot \frac{s^2 \pm (\omega_z/Q_z)s + \omega_z^2}{s^2 + (\omega_p/Q_p)s + \omega_p^2} \tag{2}$$

0098-9886/78/0206-0153$01.00

Received 19 November 1976
Revised 2 March 1977

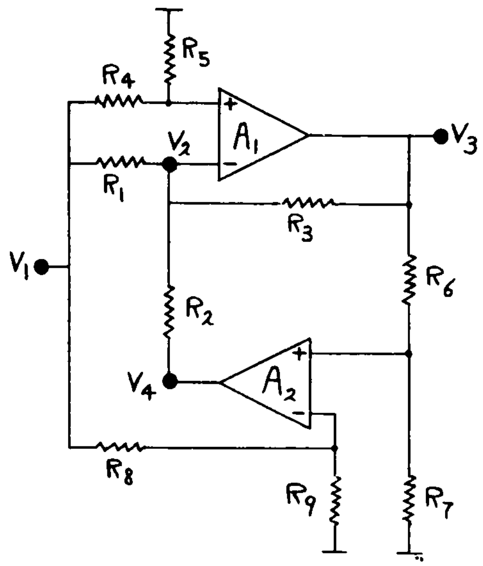

Figure 1. Universal biquad

where

$$K = a/b \tag{3}$$

$$a = R_2/R_1, \qquad b = 1 + a + R_2/R_3 \tag{4}$$

$$\omega_z^2 = m \,.\, n \,.\, GB_1 \,.\, GB_2/a \tag{5}$$

$$Q_z = \frac{\omega_z}{\pm Y} \tag{6}$$

$$Y = n \,.\, GB_1 \,.\, \frac{R_1}{R_3} - p \,.\, GB_2 \,.\, \frac{R_1}{R_2} \tag{7}$$

$$\omega_p^2 = m \,.\, GB_1 \,.\, GB_2/b \tag{8}$$

$$Q_p = \frac{\sqrt{m \,.\, b \,.\, GB_2/GB_1}}{b - a - 1} \tag{9}$$

with:

$$n = \frac{R_5}{R_4 + R_5}, \qquad m = \frac{R_7}{R_6 + R_7}, \qquad p = \frac{R_9}{R_8 + R_9} \tag{10}$$

Equation (2) comprises:

(I) *Equalizer*:
which is obtained if:

$$Y > 0 \tag{11}$$

(II) *Nonminimum phase*:
which is obtained if:

$$Y < 0 \tag{12}$$

Different transfer functions can be derived as special cases from the nonminimum phase; as follows:

Case 1: All–pass transfer function:

$$Y=-GB_1\,.\,\frac{R_2/R_3}{b}=-GB_1\,.\,\frac{b-a-1}{b} \tag{13}$$

Case 2: Universal notch filter:

$$E=1 \tag{14}$$

where

$$E=\frac{n}{p}\cdot\frac{GB_1}{GB_2}\cdot\frac{R_2}{R_3} \tag{15}$$

All types of notch characteristics can be obtained depending on the value of n:

(i) $n=K$ (notch filter) (16)

(ii) $n>K$ (low-pass notch) (17)

(iii) $n<K$ (high-pass notch) (18)

Case 3: High-pass filter:
Equation (2) represents a high-pass filter if:

$$p=0 \quad (\text{i.e. } R_9=0,\ R_8=\infty) \tag{19}$$

$$n=0 \quad (\text{i.e. } R_5=0,\ R_4=\infty) \tag{20}$$

It is worthy to mention that the circuit in this case is similar to circuit N_1 of Schaumann[4,5] with the addition of the potential divider R_6, R_7. The introduction of this divider increases the degrees of freedom so as to be able to separately specify all the parameters of the filter. Also, it helps obtaining better tuning capability and independent control.

It is a fact that active R biquadratic transfer functions can never be obtained at the output terminal of an operational amplifier. For this reason, the output resistance of the biquad is not small, thus limiting its practical capability. A solution to this problem is to use an extra operational amplifier acting as a buffer stage at the output terminal V_2. In addition to acting as a buffer stage with a non-load-dependent output voltage, it is more or less a voltage follower provided that $\omega \ll GB$.

It is obvious that when (V_2/V_1) represents a high-pass filter, then (V_3/V_1) represents a band-pass filter with midband gain given by:

$$G_0=-R_3/R_1 \tag{21}$$

Also, (V_4/V_1) represents a low-pass filter with low-pass gain given by:

$$G_L=-R_2/R_1 \tag{22}$$

It is to be noted that the gains described by equations (21) and (22) are limited only by the DC open-loop gain. In fact these gains should be much less than the DC open-loop gain of the operational amplifier in order that active parameter sensitivity to these should become small.

3. SENSITIVITIES

The critical dependence of ω_p of an active network on GB_i $(i=1,2)$ was discussed by Schaumann.[4,5] It can be easily shown that

$$S^{\omega_p}_{GB_1}=S^{\omega_p}_{GB_2}=0{\cdot}5.$$

It can also be proved that by course estimation

$$|S^{\omega_p}_x|\leqslant 0{\cdot}5,\qquad |S^{\omega_z}_x|\leqslant 0{\cdot}5,\qquad |S^{Q_p}_x|\leqslant 1$$

where x stands for any active or passive circuit element, which means very small sensitivities.

Depending on whether $Y > 0$ or $Y < 0$ it is clear that:

$$S_x^{Q_z} = S_x^{\omega_z} \mp S_x^Y \tag{23}$$

where

$$S_{GB_1}^Y = \frac{E}{(E-1)}$$

$$S_{GB_2}^Y = \frac{-1}{(E-1)}$$

$$S_{R_1}^Y = 1$$

$$S_{R_2}^Y = \frac{1}{(E-1)}$$

$$S_{R_3}^Y = \frac{-E}{(E-1)}$$

$$S_{R_4}^Y = -S_{R_5}^Y = -\frac{(1-n)E}{(E-1)}$$

$$S_{R_6}^Y = S_{R_7}^Y = 0$$

$$S_{R_8}^Y = -S_{R_9}^Y = \frac{1-p}{(E-1)}$$

It seems that

$$|S_x^{Q_z}| \quad \text{can be} \gg 1.$$

This is in fact due to the term Y being a difference of two quantities.

In ideal notch filters it is required that $E = 1$. This clearly places the zeros of transmission directly on the imaginary axis and is equivalent to infinite attenuation. The fulfillment of this condition depends on the tracking capability of the network since GB varies from unit to unit, and changes with variations in temperature and supply voltage. Also, since there are differences in resistor tolerances, tracking is too difficult for the discrete component circuit. The one way to avoid this problem is to fabricate a monolithic integrated circuit, where the tolerances in resistor ratios are minimum, and the effect of temperature or supply voltage variations is unique. Of course, a universal filter with three operational amplifiers has not this tracking problem at the expense of using one extra operational amplifier.

4. CONCLUSION

A universal active R biquad has been described which uses the operational amplifier roll-off characteristics and eliminates completely the need for external capacitors. The circuit is recommended to be monolithically integrated. Work should be devoted to improve the output resistance of the biquad without degrading the gain of the network.

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