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A NEW SINGLE OPERATIONAL AMPLIFIER ACTIVE RC BANDPASS NETWORK WITH REDUCED SENSITIVITY TO AMPLIFIER GAIN-BANDWIDTH PRODUCT

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SUMMARY

A new configuration for realizing a low sensitivity active RC bandpass filter suitable for hybrid integrated realization is given. The network consists of a single operational amplifier (OA) and two identical passive RC bandpass building blocks. The active element sensitivities are given. The frequency limitation equations of the filter based on the one-pole rolloff model of the OA are derived. It is found that the choice of the element ratios of the passive RC networks plays an important role in the overall performance of the active resonator. Two cases are discussed in detail: one has the advantage of having better element ratios, and the other has the advantage of having lower sensitivities. The given network is less sensitive to the amplifier gain-bandwidth product than other low sensitivity active RC bandpass networks using two operational amplifiers.

1. INTRODUCTION

The design of active RC filters by activating passive RC building blocks usually leads to very low active sensitivities.[1–6] Recently a bandpass positive feedback circuit based on this idea was given[7] which does not provide any gain at resonance. The present paper gives a novel, low sensitivity active RC bandpass network, using a single OA, and two identical passive RC bandpass building blocks, which provides gain at resonance.

2. THE GENERAL CONFIGURATION

Figure 1 represents the proposed configuration which consists of two passive RC networks (N_1, N_2) and a single OA. This is different from the circuit of Wolff[8] and Hamilton and Sedra[9] in that the common terminal of N_1 is activated by the output voltage rather than being grounded, and the OA polarity is reversed. Also if terminals 1 and 3 of N_1 are interchanged, the configuration will be identical to the type 2 basic configuration given recently by Novak and Hruby.[10]

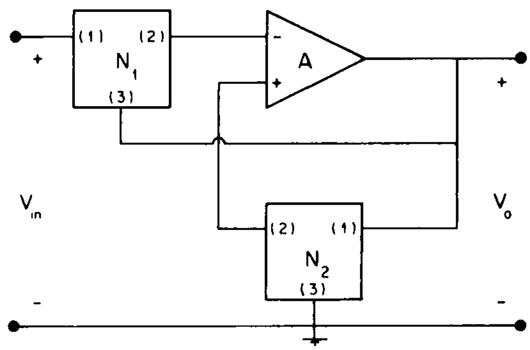

Figure 1. The general filter configuration

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Assuming that the OA has infinite input impedance at both input terminals and gain A, analysis leads to:

$$G(s) \equiv \frac{V_o}{V_{in}} = \frac{-T_1}{1 - T_1 - T_2 + 1/A} \tag{1}$$

where T_1 and T_2 are the open-circuit voltage transfer functions of N_1 and N_2, respectively.

3. BANDPASS FILTER REALIZATION

If two identical second-order passive RC bandpass networks are used for N_1 and N_2, then

$$T_1(s) = T_2(s) = \frac{K\omega_p s}{s^2 + \frac{\omega_p}{q_p}s + \omega_p^2} \tag{2}$$

where q_p is the selectivity factor of the passive network, $0 < q_p < 0{\cdot}5$ and $Kq_p < 1$.
Substituting (2) in (1) gives:

$$G(s) = \frac{-K\omega_p s}{s^2\left(1 + \frac{1}{A}\right) + \left[\frac{\omega_p}{q_p}\left(1 + \frac{1}{A}\right) - 2K\omega_p\right]s + \omega_p^2\left(1 + \frac{1}{A}\right)} \tag{3}$$

As $A \to \infty$, the above equation reduces to the form:

$$G(s) = \frac{-H(\omega_o/Q)s}{s^2 + \frac{s\omega_o}{Q} + \omega_o^2} \tag{4}$$

where Q is the selectivity factor of the active network, assuming an idea l OA:

$$Q = \frac{q_p}{1 - 2Kq_p} \tag{5}$$

$$\omega_o = \omega_p \tag{6}$$

$$H = |\text{Gain}|_{\omega_o} = KQ \tag{7}$$

It is clear that the passive networks must be designed such that $Kq_p < 0.5$ to ensure the stability of the active resonator.

4. ACTIVE ELEMENT SENSITIVITY

First the effect of the finite gain of the OA is considered. If $A \simeq A_o$, then

$$G(s) = \frac{1}{\left(1 + \frac{1}{A_o}\right)} \cdot \frac{-K\omega_p s}{s^2 + \omega_p\left(\frac{1}{q_p} - \frac{2K}{1 + (1/A_o)}\right)s + \omega_p^2} \tag{8}$$

It is seen that

$$\omega_{oa} = \omega_o \tag{9}$$

and

$$S_{A_o}^{\omega_{oa}} = 0 \tag{10}$$

The actual selectivity factor of the active network is given by:

$$Q_a = \frac{Q\left(1+\frac{1}{A_o}\right)}{1+\frac{Q}{q_p A_o}} \simeq \frac{Q}{1+\frac{Q}{q_p A_o}} \qquad \text{for } \frac{Q}{q_p} \gg 1 \tag{11}$$

and

$$S_{A_o}^{Q_a} \simeq \frac{Q}{q_p A_o} \qquad \text{for } A_o \gg \frac{Q}{q_p} \gg 1 \tag{12}$$

It is clear that for minimum active sensitivity, the passive q_p should be approaching its maximum value of 0·5.

5. EFFECT OF THE ROLLOFF OF THE OA GAIN

The actual gain of the OA is given by

$$A = \frac{A_o \omega_1}{s+\omega_1} \simeq \frac{GB}{s} \tag{13}$$

where

A_o is the open-loop DC gain of the OA,

ω_1 is the open-loop 3-dB bandwidth,

and

$GB = A_o \omega_1$ is the gain–bandwidth product.

Following the Budak–Petrela analysis,[11] the fractional shifts in ω_o and Q are obtained as

$$\frac{\Delta\omega_o}{\omega_o} = -\frac{\omega_o}{2GB}\left(\frac{1}{q_p} - \frac{1}{Q}\right) \tag{14}$$

$$\frac{\Delta Q}{Q} = \frac{\omega_o}{2GB}\left(\frac{1}{q_p} - \frac{1}{Q}\right) \tag{15}$$

It is clear that to minimize the fractional shifts in ω_o and Q, the passive RC networks should have a value of q_p close to 0·5, as was observed before from equation (12).

6. THE PASSIVE RC NETWORK

Figure 2 represents a canonic realization for the passive RC network N. To ensure stability of the active structure, the passive parameters should be chosen such that

$$\frac{C_2}{C_1} + 1 > \frac{R_1}{R_2} \tag{16}$$

Two cases are considered here; the first has the advantage of having better element ratios, the second has lower active sensitivities. Table I summarizes the results for the two cases.

Notice that the Q sensitivities to all passive circuit components are high, as is the case with other good high-frequency performance networks.[12, 13] In common with all such realizations, the present network will perform satisfactorily only when realized in hybrid integrated circuit technology for which it is intended.

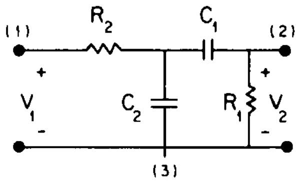

Figure 2. The passive RC networks N_1 and N_2

Table I

	Circuit parameters	q_p	K	$\omega_p=\omega_o$	Q	H	Design equations
Case 1	$C_1=C_2=C$ $R_2=R$ $R_1=aR$	$\frac{\sqrt{a}}{2+a}$	$\sqrt{a}$	$\frac{1}{CR\sqrt{a}}$	$\frac{\sqrt{a}}{2-a}$	$\frac{a}{2-a}$	$a\simeq 2-\frac{\sqrt{2}}{Q}$ $CR=\frac{1}{\sqrt{(2)}\omega_o}$
Case 2	$R_2=R$ $C_2=C$ $C_1=bC$ $R_1=\frac{R}{b}$	$\frac{1}{2+b}$	1	$\frac{1}{CR}$	$\frac{1}{b}$	$\frac{1}{b}$	$b=\frac{1}{Q}$ $CR=\frac{1}{\omega_o}$

7. EXPERIMENTAL RESULTS

The circuit was constructed in the laboratory using an operational amplifier type LM 741 (National Semiconductors Corp.) and with discrete circuit components (precise resistors and ±5 per cent capacitors are used), to realize a bandpass response having $f_o=1{\cdot}88$ kHz and $Q=10$. The circuit components taken for a typical Case 2 design are:

$$R_1=18\ \mathrm{k\Omega},\qquad R_2=1{\cdot}8\ \mathrm{k\Omega}$$

$$C_1=4{\cdot}7\ \mathrm{nF},\qquad C_2=47\ \mathrm{nF}$$

Figure 3 represents the experimental results obtained. Next the effect of the variation of the response due to a change in a circuit parameter is examined. The circuit was designed for the same specifications listed above and it is found experimentally that when R_1 (in the two passive networks N_1, N_2) is increased by 1 per cent from its nominal value, the frequency f_0 is almost unaffected, whereas the pole Q is increased by 5·5 per cent from its nominal value.

For comparison purposes the well-known Deliyannis[14] bandpass circuit (which also belongs to the same general configuration[10]) was constructed in the laboratory to realize a bandpass response having $f_o=1{\cdot}88$ kHz and $Q=10$ using an operational amplifier type LM 741. The element values taken are:

$$C_1=C_2=4{\cdot}7\ \mathrm{nF}$$

$$R_a=9\ \mathrm{k\Omega},\qquad R_b=20\ \mathrm{k\Omega}$$

$$R_1=9\ \mathrm{k\Omega},\qquad R_2=36\ \mathrm{k\Omega}$$

(The symbols are the same as in the Deliyannis circuit.[14])

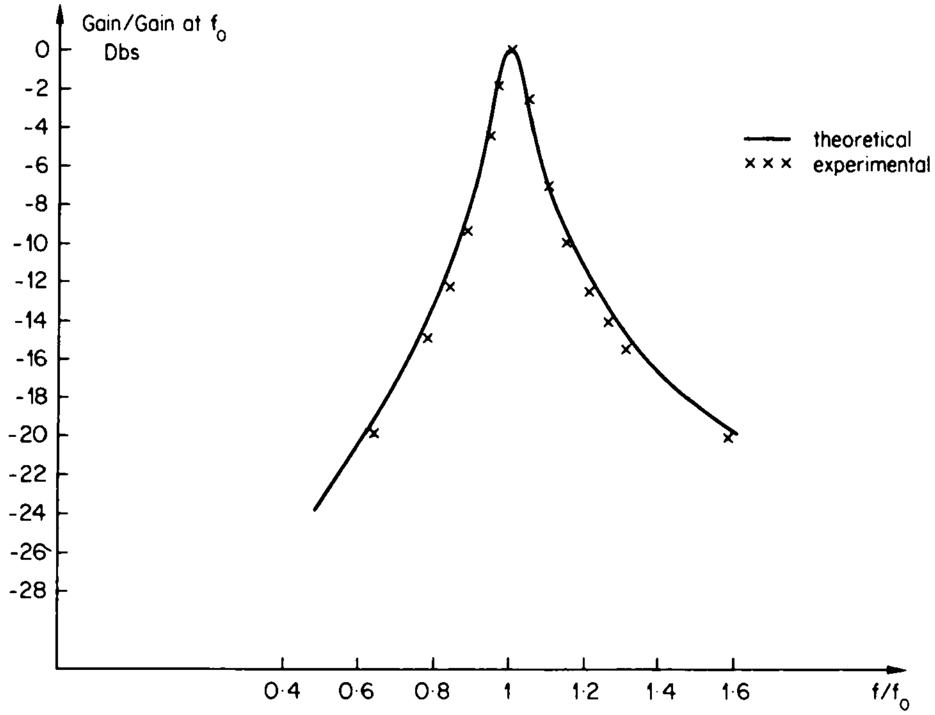

Figure 3. Bandpass frequency response for Case 2 ($f_o = 1{\cdot}88$ kHz and $Q = 10$), $C_1 = 4{\cdot}7$ nF, $C_2 = 47$ nF, $R_1 = 18$ kΩ, $R_2 = 1.8$ kΩ. The operational amplifier used is National Semiconductor type LM 741

Table II

Bandpass network type		Circuit components			Fractional shifts in ω_o and Q	
		OA	R	C	$\frac{\Delta\omega_o}{\omega_o}$	$\frac{\Delta Q}{Q}$
Hamilton–Sedra single OA circuit[9]		1	6	5	$-\frac{2\omega_o}{GB}$	$\frac{2\omega_o}{GB}$
Wilson–Bedri–Bowron circuit[7]		2	5	3	$-\frac{4\omega_o}{GB}$	$\frac{4\omega_o}{GB}$
Soliman canonic circuit[13]		2	4	2	$-\frac{3\omega_o}{GB}$	$\frac{3\omega_o}{GB}$
New circuit	Case 1	1	4	4	$-\frac{1{\cdot}4\omega_o}{GB}$	$\frac{1{\cdot}4\omega_o}{GB}$
	Case 2	1	4	4	$-\frac{\omega_o}{GB}$	$\frac{\omega_o}{GB}$

It is found that when R_2 (the feedback resistor connected between the output of the OA and its inverting terminal) is increased by 1 per cent from its nominal value, $\Delta f_o/f_o = -0{\cdot}78\%$ and $\Delta Q/Q = 8{\cdot}1\%$.

8. CONCLUSION

A novel configuration for realizing a low sensitivity active RC bandpass network using a single OA is given. The network is suitable for hybrid integrated realization and uses two identical passive RC bandpass building blocks. It is less sensitive to the amplifier gain–bandwidth product than other low sensitivity active RC bandpass networks using a single OA[9] or two OA's[7,13] as can be seen from Table II.

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REFERENCES

1. G. S. Moschytz, 'A universal low Q active filter building block suitable for hybrid integrated circuit implementation', *IEEE Trans. Cir. Syst.* **CAS-20**, 37–47 (1973).
2. A. M. Soliman, 'A new active RC configuration for realizing a medium selectivity notch filter', *Electron. Lett.* **21**, 522–524 (1972).
3. A. M. Soliman, 'Active RC low-pass filter suitable for integration', *Int. J. Electron.* **36**, 799–803 (1974).
4. A. M. Soliman, 'Two active RC configurations for realizing nonminimum phase transfer functions', *Int. J. Cir. Theor. Appl.* **1**, 293–299 (1973).
5. A. M. Soliman, 'A new active RC configuration for realizing nonminimum phase transfer functions', *Int. J. Cir. Theor. Appl.* **2**, 307–315 (1974).
6. A. M. Soliman, 'A new single operational amplifier medium selectivity nonminimum phase network', *Arch. Elektron. Übertragungstech.* **28**, 511–513 (1974).
7. G. Wilson, Y. Bedri and P. Bowron, 'RC active networks with reduced sensitivity to amplifier gain–bandwidth product', *IEEE Trans. Cir. Syst.* **CAS-21**, 618–626 (1974).
8. D. Wolff, 'Two structures to minimize sensitivity in active RC filters', *Electron. Lett.* **2**, 152–153 (1966).
9. T. A. Hamilton and A. S. Sedra, 'Some new configurations for active filters', *IEEE Trans. Cir. Theor.* **CT-19**, 25–33 (1972).
10. M. Novak and J. Hruby, 'Optimized design of cascaded active RC bandpass filters, *Int. J. Cir. Theor. Appl.* **3**, 113–121 (1975).
11. A Budak and D. M. Petrela, 'Frequency limitations of active filters using operational amplifiers', *IEEE Trans. Cir. Theor.* **CT-19**, 322–328 (1972).
12. E. A. Faulkner and J. M. Grimbleby, 'The effect of amplifier gain–bandwidth product on the performance of active filters', *Radio Electron. Eng.* **43**, 547–552 (1973).
13. A. M. Soliman, 'A novel canonic active RC bandpass network with reduced sensitivity to amplifier gain–bandwidth product', *Proc. IEEE International Symposium on Circuits and Systems*, 493–496 (1976).
14. T. Deliyannis, 'High Q factor circuit with reduced sensitivity', *Electron. Lett.* **4**, 577–579 (1968).