A Realization of Multiple Circuit Transfer Functions without External Passive Elements

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Abstract : This paper introduces a way to realize biquadratic transfer functions using Operational Amplifiers (OAs) and Operational Transconductance Amplifiers (OTAs). The basic circuit configuration is constructed with two OAs and five OTAs. It is shown that low-pass, band-pass, high-pass, band-stop and all-pass transfer functions can be realized by suitably choosing the input terminals. And the circuit parameters can also be set by the transconductance gains of the OTAs independently.

An example is given together with simulated results by PSPICE.

1. Introduction

High performance active circuits have received much attention. The circuit designs employing active devices such as the OAs, the OTAs and second generation current conveyors (CCIIs) have been reported in the literature [1]-[7].

It is well known that active circuits with the finite and complex gain nature of internally compensated OAs are suitable for high-frequency operation. Also, the OTA provides highly linear electronic tunability and wide tunable range of its transconductance gain. Active circuit designs with such OA and OTA performances have been discussed in the past [2]-[7]. At present, there is a growing interest in designing active circuits that use only active devices. As such a circuit would facilitate its integrability and programmability, it is very attractive to circuit designers [8],[9].

This paper focuses on a way to realize the biquadratic transfer functions with two integrator loop structure [3] consisting of loss-less and lossy integrators. The basic circuit configuration is constructed with two OAs and five OTAs. It is shown that the low-pass, the band-pass, the high-pass, the band-stop and the all-pass transfer functions can be realized by suitably choosing the input terminals, and that the circuit parameters can be independently set and electronically tuned by the transconductance gains of the OTAs. Although the basic circuit configuration has been known, it seems that the feature for realizing their transfer functions makes the structure more attractive and useful.

An example is given together with simulated results by PSPICE.

2. Circuit configuration and analysis

Figure 1 shows a block diagram of the two integrator loop structure [3] with the loss-less and the lossy integrators. The characteristic equation $D_p(s)$ is given by

$$D_p(s) = s^2 + \left(\frac{\omega_p}{Q_p}\right)s + \omega_p^2 \qquad (1)$$

where the characteristic parameters ω_p and Q_p become, respectively

$$\omega_p = \sqrt{k_{f2}K_1K_2}, \quad Q_p = \frac{\sqrt{k_{f2}K_1K_2}}{k_{f1}K_3} \qquad (2)$$

It is found from (2) that ω_p and Q_p can be adjusted independently through the feedback coefficients k_{f1} and k_{f2}.

Figure 2 shows the active-only biquadratic circuit configuration derived from the block diagram of Fig.1.

In order to realize the biquadratic transfer functions, we consider three input terminals $V_{i1}(s)$, $V_{i2}(s)$ and $V_{i3}(s)$ in the

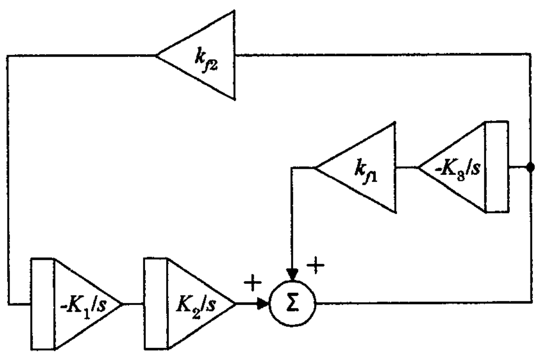


Figure 1 Two integrator loop structure.

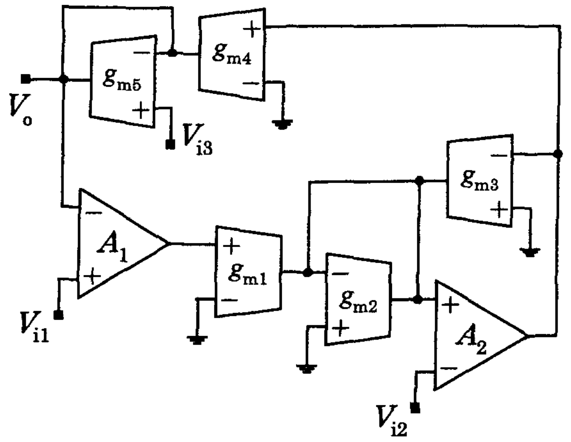


Figure 2 Active-only biquadratic circuit configuration.

original configuration.

Assuming the open-loop gain $A_i(s)$ of the OA to be of following form, where B_i is the gain-bandwidth product,

$$A_i(s) = \frac{B_i}{s} \quad (i = 1,2) \tag{3}$$

The routine analysis yields the output voltage $V_o(s)$ given by

$$\begin{aligned} V_o(s) = \{&k_1k_3B_1B_2V_{i1}(s) - k_3B_2sV_{i2}(s) \\ &+ s(s + k_2B_2)V_{i3}(s)\} / D(s) \end{aligned} \tag{4}$$

where

$$\left.\begin{aligned} &D(s) = s^2 + \left(\frac{\omega_0}{Q}\right)s + \omega_0^2 \\ &\omega_0 = \sqrt{k_1k_3B_1B_2}, \quad Q = \frac{1}{k_2}\sqrt{\frac{k_1k_3B_1}{B_2}} \\ &k_1 = \frac{g_{m1}}{g_{m2}}, \quad k_2 = \frac{g_{m3}}{g_{m2}}, \quad k_3 = \frac{g_{m4}}{g_{m5}} \end{aligned}\right\} \tag{5}$$

The equation (4) implies that the circuit in Fig.2 can offer a variety of circuit transfer functions with different input terminals. The low-pass (*LP*), the band-pass (*BP*), the high-pass (*HP*), the band-stop (*BS*) and the all-pass (*AP*) transfer functions can be realized as follows :

$$LP: \; T_{LP}(s) = \frac{V_o(s)}{V_{i1}(s)} = \frac{\omega_0^2}{D(s)} \tag{6}$$

$$BP: \; T_{BP}(s) = \frac{V_o(s)}{V_{i2}(s)} = -\frac{(\omega_0/Q)s}{D(s)} \tag{7}$$

$$HP: \; T_{HP}(s) = \frac{V_o(s)}{V_{i23}(s)} = \frac{s^2}{D(s)} \tag{8}$$

$$BS: \; T_{BS}(s) = \frac{V_o(s)}{V_{i123}(s)} = \frac{s^2 + \omega_0^2}{D(s)} \tag{9}$$

$$AP: \; T_{AP}(s) = \frac{V_o(s)}{V_{i123}(s)} = \frac{s^2 - (\omega_0/Q)s + \omega_0^2}{D(s)} \tag{10}$$

where the input voltages $V_{i23}(s)$ and $V_{i123}(s)$ imply $V_{i2}(s)= V_{i3}(s)$ and $V_{i1}(s)= V_{i2}(s)= V_{i3}(s)$, respectively.

In order to realize their transfer functions, the circuit conditions below are required :

$$\left.\begin{aligned} &BP: \; k_3 = k_2 \\ &HP: \; k_3 = k_2 \\ &BS: \; k_3 = k_2 \\ &AP: \; k_3 = 2k_2 \end{aligned}\right\} \tag{11}$$

Considering the circuit conditions above, the circuit parameters ω_0 and Q become, respectively

$$\left.\begin{aligned} &BP: \; \omega_0 = \sqrt{k_1k_2B_1B_2}, \quad Q = \sqrt{\frac{k_1B_1}{k_2B_2}} \\ &HP: \; \omega_0 = \sqrt{k_1k_2B_1B_2}, \quad Q = \sqrt{\frac{k_1B_1}{k_2B_2}} \\ &BS: \; \omega_0 = \sqrt{k_1k_2B_1B_2}, \quad Q = \sqrt{\frac{k_1B_1}{k_2B_2}} \\ &AP: \; \omega_0 = \sqrt{2k_1k_2B_1B_2}, \quad Q = \sqrt{\frac{2k_1B_1}{k_2B_2}} \end{aligned}\right\} \tag{12}$$

Equation (12) shows that the circuit parameter Q depends on ω_0. It is found that the circuit parameters ω_0 and Q can not be set independently. Therefore, the possible ranges of the circuit parameters are limited.

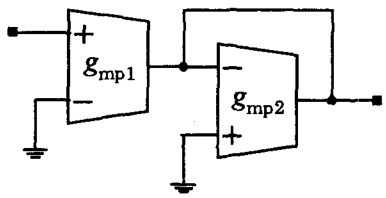


Figure 3 Proportional block with OTAs.

In order to overcome the issue above, we add the proportional block shown in Fig.3 at the input terminal $V_{i2}(s)$. The output voltages with the proportional block are given by

$$V_o(s) = -(k_3k_p - k_2)B_2sV_{i2}(s) / D(s) \tag{13}$$

$$V_o(s) = \{s^2 - (k_3 k_p - k_2)B_2 s\}V_{i23}(s) / D(s) \quad (14)$$

$$V_o(s) = \{s^2 - (k_3 k_p - k_2)B_2 s + k_1 k_3 B_1 B_2\}V_{i123}(s) / D(s) \quad (15)$$

where k_p (= g_{mp1}/g_{mp2}) denotes the gain of the proportional block.

The circuit conditions to realize their transfer functions are obtained from (13), (14) and (15) as :

$$\left.\begin{aligned} BP&: \; k_p = k_2/k_3 \\ HP&: \; k_p = k_2/k_3 \\ BS&: \; k_p = k_2/k_3 \\ AP&: \; k_p = 2k_2/k_3 \end{aligned}\right\} \quad (16)$$

Thus, the band-pass, the high-pass, the band-stop and the all-pass transfer functions can be realized setting the gain of the proportional block based on (16). In their transfer functions, the circuit parameters ω_0 and Q can be set on (5) independently.

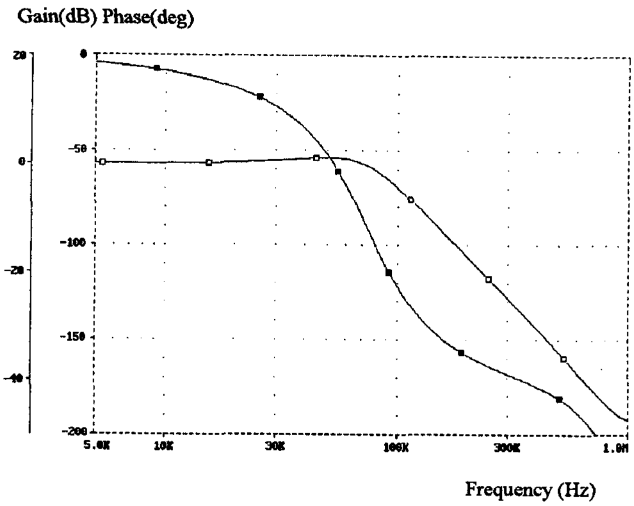
3. Design example and simulation results

As an example, consider a realization of the characteristic with the cut-off frequency f_0 (= $\omega_0 / 2\pi$)= $70kHz$, the quality factor Q= 1.0 and the gain constant H= 1.0. In the design example, LM741 OA with the gain-bandwidth product B_i= $2\pi(1.002)\times 10^6 rad/sec$($i$= 1,2) is used. Also, we have used CA8080 OTA with a macro model [5]. For proper circuit operation, we have inserted the proportional block shown in Fig.3 at the non-inverting terminal of A_2. The transconductance gains to realize the characteristic above are listed in Table 1. The transconductance gains g_{mpv1} and g_{mpv2} are then of the proportional block inserted at the input terminal of the OA. Based on (16), the transconductance gains of the proportional block to realize

Table 1 Transconductance gains.

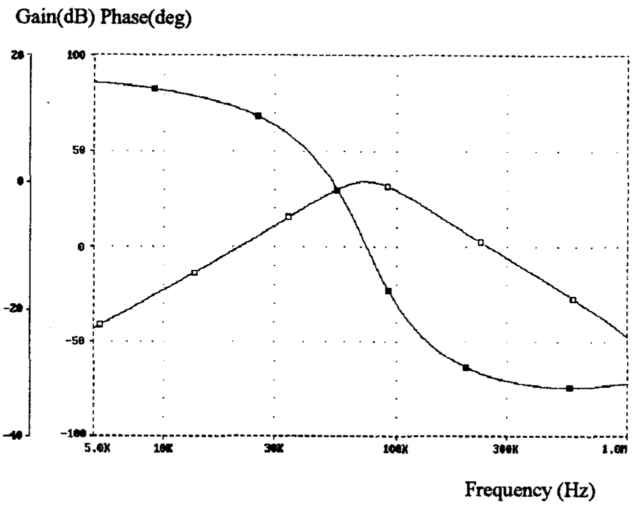
g_{mx}	value (mS)
g_{m1}	0.200
g_{m2}	0.200
g_{m3}	2.865
g_{m4}	2.000
g_{m5}	2.000
g_{mpv1}	2.437×10^{-2}
g_{mpv2}	5.000

the characteristic are as follows :



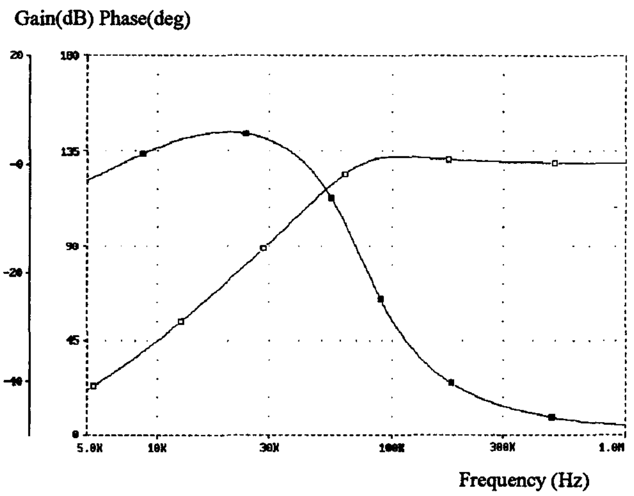
□: $|T_{LP}(j\omega)|$ ■: $\angle T_{LP}(j\omega)$

(a)



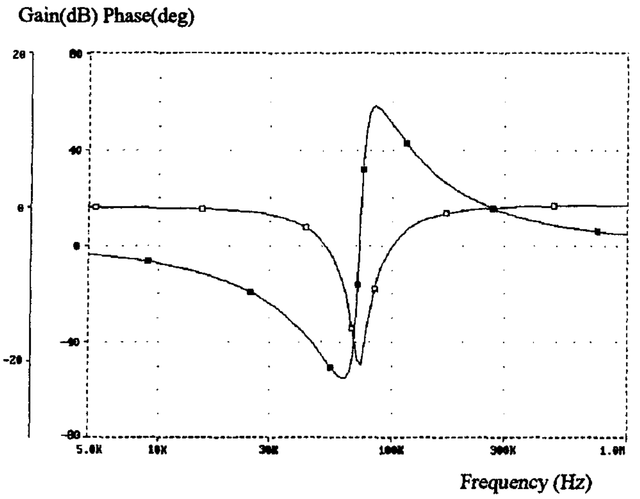
□: $|T_{BP}(j\omega)|$ ■: $\angle T_{BP}(j\omega)$

(b)



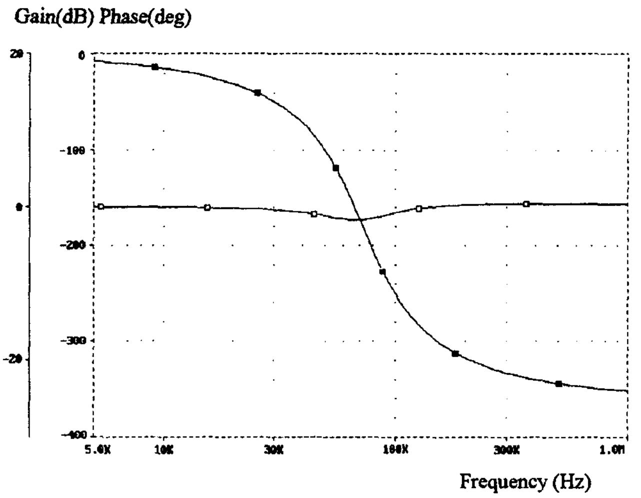
□: $|T_{HP}(j\omega)|$ ■: $\angle T_{HP}(j\omega)$

(c)



□: | $T_{BS}(j\omega)$ | ■: $\angle T_{BS}(j\omega)$

(d)



□: | $T_{AP}(j\omega)$ | ■: $\angle T_{AP}(j\omega)$

(e)

Figure 4 Simulation results ((a) low-pass, (b) band-pass, (c) high-pass, (d) band-stop, (e) all-pass characteristics).

$$\left.\begin{aligned} BP:&\ g_{mp1}=0.3491mS,\ \ g_{mp2}=5.000mS\\ HP:&\ g_{mp1}=0.3491mS,\ \ g_{mp2}=5.000mS\\ BS:&\ g_{mp1}=0.3491mS,\ \ g_{mp2}=5.000mS\\ AP:&\ g_{mp1}=0.6981mS,\ \ g_{mp2}=5.000mS \end{aligned}\right\} \quad (17)$$

Figure 4 shows the simulated frequency responses with PSPICE. They are favorable enough over a wide frequency range. In this simulation, we have used the LM741 OA macro model in PSPICE library.

4. Conclusions

A way to realize the biquadratic transfer functions using the OAs and the OTAs has been shown. It has been made clear that the low-pass, the band-pass, the high-pass, the band-stop and the all-pass transfer functions can be realized by suitably choosing the input terminals, and that the circuit parameters can be independently set and electronically tuned by adjusting the transconductance gains of the OTAs. Although the circuit configuration has been known, it seems that the feature for realizing their transfer functions makes the structure more attractive and useful.

The non-idealities of the OA and the OTA may affect the circuit characteristics. The solution on this will be presented in the near future.

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