A Realization of High-pass, Band-stop and All-pass Transfer Functions with OTA-C Integrator Loop Structure

Takao Tsukutani+, Masami Higashimura+, Yasutomo Kinugasa+, Yasuaki Sumi++ and Yutaka Fukui+++

+ Matsue National College of Technology.
Tel & Fax : +81-852-36-5204; E-mail : tsukutani@matsue-ct.ac.jp
++ Tottori University of Environmental Studies. +++ Tottori University.

Abstract : This paper introduces a way to realize high-pass, band-stop and all-pass transfer functions using Operational Transconductance Amplifiers (OTAs) and grounded capacitors. The basic circuit configuration is constructed with five OTAs and two grounded capacitors. In the circuit with the proportional block, it is shown that the circuit parameters can be independently set and electronically tuned by the transconductance gains. Although the circuit configuration has been known, it seems that the feature for realizing the high-pass, the band-pass and the all-pass transfer functions makes the structure more attractive and useful. 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 operational amplifiers (OAs), OTAs and second generation current conveyors (CCIIs) have been reported in the literature [1]-[6].

It is well known that the OTA provides highly linear electronic tunability and wide tunable range of its transconductance gain. Also, the OTA-based circuits require no resistors, hence they are more suitable for integration than the OA-based and the CCII-based ones. These features are very attractive to circuit designers. The circuit designs with the OTA performances have been discussed in the past [1],[3],[6]-[8].

This paper focuses on a way to realize the high-pass, the band-stop and the all-pass transfer functions with two integrator loop structure [1] consisting of loss-less and lossy integrators. The basic circuit configuration is constructed with five OTAs and two grounded capacitors. In the circuit with the proportional block, it is shown that the circuit parameters can be independently set and electronically tuned by the transconductance gains. Although the circuit configuration has been known, it seems that the feature for realizing the high-pass, the band-pass and the all-pass 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 with the loss-less and the lossy integrators. The characteristic equation $D_p(s)$ is given by

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

where the characteristic parameters ω_p and Q_p become, respectively

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

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

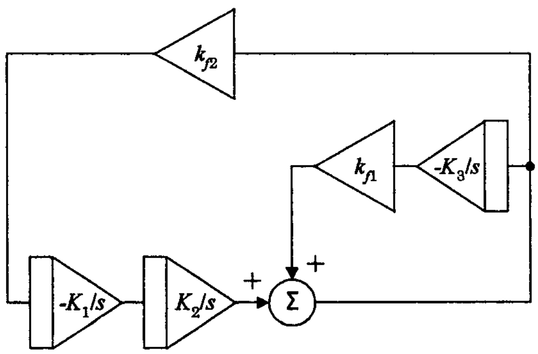

Figure 1 Two integrator loop structure.

Figure 2 shows the symbol of the OTA. The current output I_o is given by

$$I_o = g_m(V_+ - V_-) \tag{3}$$

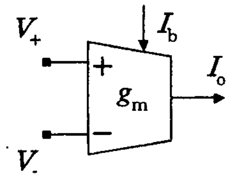

Figure 2 Symbol of OTA.

where g_m denotes the transconductance gain of the OTA. The transconductance gain for the OTA with bipolar transistors is given by, where I_b is the bias current,

$$g_m = k_b I_b \tag{4}$$

Also, the transconductance gain for the OTA with MOS transistors is given by

$$g_m = k_m \sqrt{I_b} \tag{5}$$

Figure 3 shows the OTA-C circuit configuration derived from the block diagram of Fig.1. The basic circuit configuration has already been shown in reference [1]. In order to realize the high-pass, the band-stop and the all-pass transfer functions, we consider three input terminals $V_{i1}(s)$, $V_{i2}(s)$ and $V_{i3}(s)$ in the original configuration.

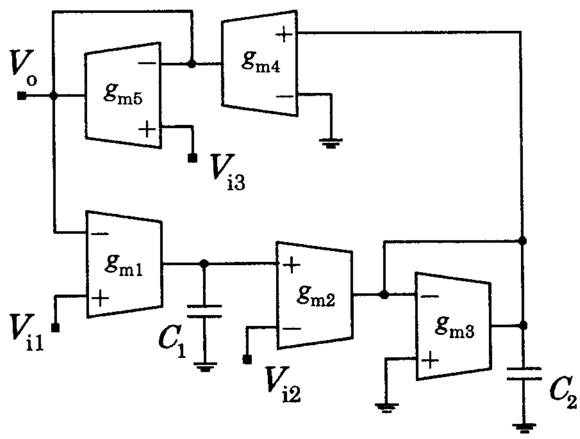

Figure 3 OTA-C circuit configuration.

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

$$V_o(s) = \{\frac{g_{m1}g_{m2}g_{m4}}{g_{m5}C_1C_2}V_{i1}(s) - \frac{g_{m2}g_{m4}}{g_{m5}C_2}sV_{i2}(s) + s(s+\frac{g_{m3}}{C_2})V_{i3}(s)\}/D(s) \tag{6}$$

where

$$\left.\begin{aligned} D(s) &= s^2 + \left(\frac{\omega_0}{Q}\right)s + \omega_0^2 \\ \omega_0 &= \sqrt{\frac{g_{m1}g_{m2}g_{m4}}{g_{m5}C_1C_2}} \\ Q &= \frac{1}{g_{m3}}\sqrt{\frac{g_{m1}g_{m2}g_{m4}C_2}{g_{m5}C_1}} \end{aligned}\right\} \tag{7}$$

The equation (6) implies that the circuit in Fig.3 can offer a variety of circuit transfer functions with different input terminals.

The high-pass (HP), the band-stop (BS) and the all-pass (AP) transfer functions can be realized as follows :

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

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

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

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 :

$$\left.\begin{aligned} HP&:\ g_{m2}g_{m4} = g_{m3}g_{m5} \\ BS&:\ g_{m2}g_{m4} = g_{m3}g_{m5} \\ AP&:\ g_{m2}g_{m4} = 2g_{m3}g_{m5} \end{aligned}\right\} \tag{11}$$

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

$$\left.\begin{aligned} HP&:\ \omega_0 = \sqrt{\frac{g_{m1}g_{m3}}{C_1C_2}},\quad Q = \sqrt{\frac{g_{m1}C_2}{g_{m3}C_1}} \\ BS&:\ \omega_0 = \sqrt{\frac{g_{m1}g_{m3}}{C_1C_2}},\quad Q = \sqrt{\frac{g_{m1}C_2}{g_{m3}C_1}} \\ AP&:\ \omega_0 = \sqrt{\frac{2g_{m1}g_{m3}}{C_1C_2}},\quad Q = \sqrt{\frac{2g_{m1}C_2}{g_{m3}C_1}} \end{aligned}\right\} \tag{12}$$

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.

In order to overcome the issue above, we add the proportional block shown in Fig.4 at the input terminal $V_{i2}(s)$. The output voltages with the proportional block are

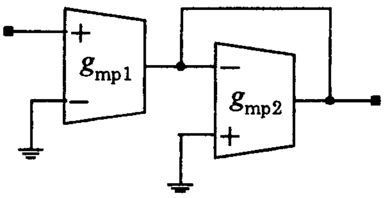

Figure 4 Proportional block.

given by, respectively

$$V_o(s) = \{s^2 - \frac{(g_{m2}g_{m4}k_p - g_{m3}g_{m5})s}{g_{m5}C_2}\}V_{i23}(s)/D(s) \quad (13)$$

$$V_o(s) = \{s^2 - \frac{(g_{m2}g_{m4}k_p - g_{m3}g_{m5})s}{g_{m5}C_2} + \frac{g_{m1}g_{m2}g_{m4}}{g_{m5}C_1C_2}\} \times V_{i123}(s)/D(s) \quad (14)$$

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) and (14) as :

$$\left.\begin{aligned} HP:\ & k_p = \frac{g_{m3}g_{m5}}{g_{m2}g_{m4}} \\ BS:\ & k_p = \frac{g_{m3}g_{m5}}{g_{m2}g_{m4}} \\ AP:\ & k_p = \frac{2g_{m3}g_{m5}}{g_{m2}g_{m4}} \end{aligned}\right\} \quad (15)$$

Thus, the high-pass, the band-stop and the all-pass transfer functions can be realized setting the gain of the proportional block based on (15). In their transfer functions, the circuit parameters ω_0 and Q can be set on (7) independently.

In Fig.3, low-pass (LP) and band-pass (BP) transfer functions can also be realized as follows :

$$LP:\ T_{LP}(s) = \frac{V_o(s)}{V_{i1}(s)} = \frac{\omega_0^2}{D(s)} \quad (16)$$

$$BP:\ T_{BP}(s) = \frac{V_o(s)}{V_{i2}(s)} = -\frac{(\omega_0/Q)s}{D(s)} \quad (17)$$

3. Design example and simulation results

As an example, consider a realization of the characteristic with the cut-off frequency f_0 (= $\omega_0/2\pi$)= $50kHz$, the quality factor Q= 1.0 and the gain constant H= 1.0. In the design example, we have used a LM13600 OTA.

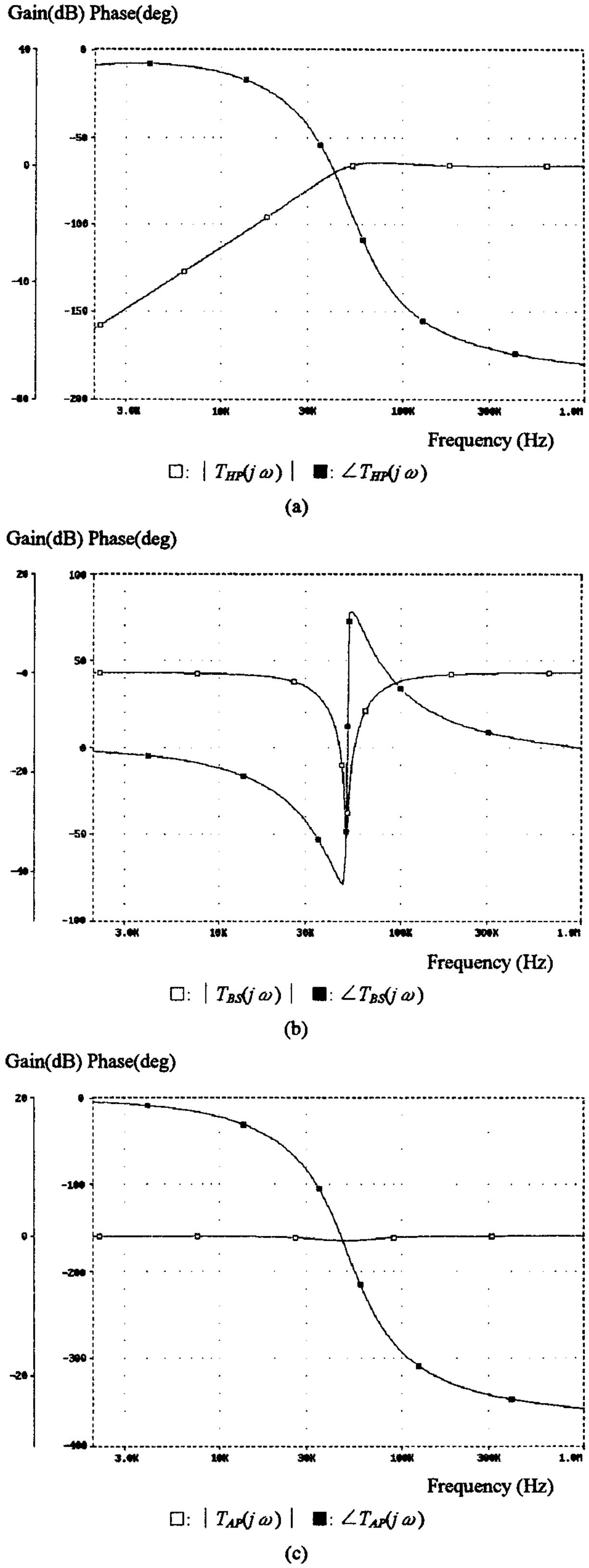

Figure 5 Simulation results ((a) high-pass, (b) band-stop, (c) all-pass characteristics).

The transconductance gain g_m for the *LM*13600 OTA is given by

$$g_m \cong 19.2 I_b \tag{18}$$

To realize the characteristic above, we have determined that the transconductance gains g_{mi} (i=1, 2, 3, 4, 5)= 2.576mS (I_b= 134.2 μA) and the grounded capacitors C_1= C_2= 8200pF. The gains of the proportional block take the values of 1.0 (i.e. g_{mp1}= g_{mp2}= 2.576mS), 1.0 (i.e. g_{mp1}= g_{mp2}= 2.576mS) and 2.0 (i.e. g_{mp1}= 2.576mS and g_{mp2}= 5.134mS (I_b= 268.4 μA)) on (15), respectively.

Figure 5 shows the simulated frequency responses with PSPICE. They are favorable enough over a wide frequency range. In this simulation, we have used the *LM*13600 OTA macro model in PSPICE library.

The low-pass and band-pass responses on (16) and (17) are also shown in Fig.6.

4. Conclusions

A way to realize the high-pass, the band-stop and the all-pass transfer functions using the OTAs and the grounded capacitors has been shown. In the circuit with the proportional block, it has been made clear that the circuit parameters can be independently set and electronically tuned by adjusting the transconductance gains. Although the circuit configuration has already been known, it seems that the feature for realizing their transfer functions makes the structure more attractive and useful.

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

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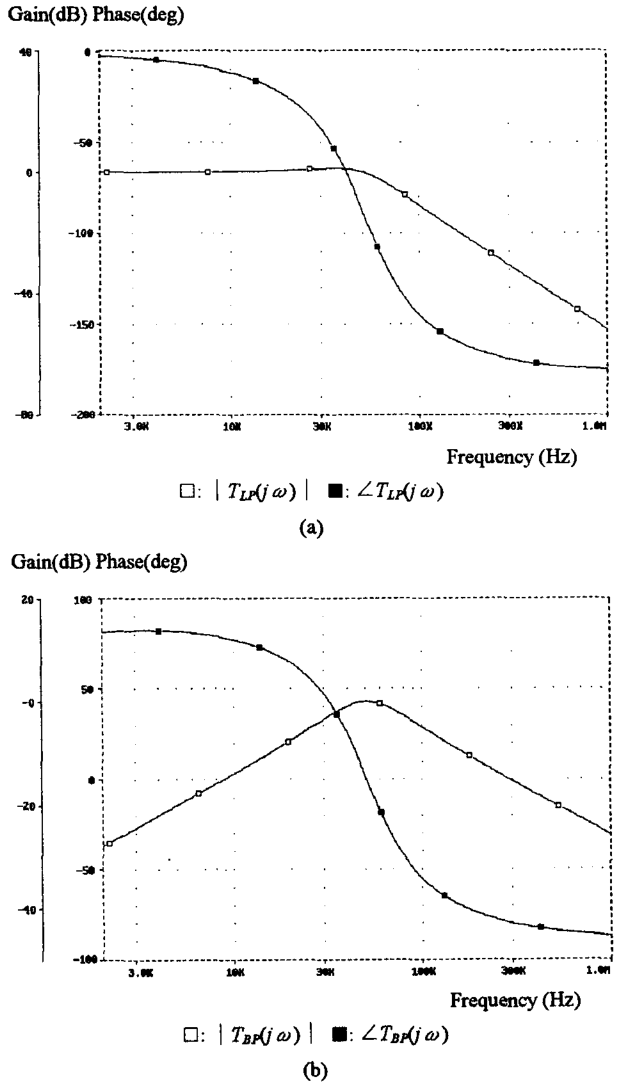

Figure 6 Simulation results ((a) low-pass, (b) band-pass characteristics).