Active-C Realization of nth-order Current-Mode Allpole Lowpass Filters Using CFTAs

Worapong Tangsrirat, *Member, IAENG*

***Abstract*— In this paper, a general synthesis procedure of using the signal flow graph technique to realize an nth-order allpole lowpass current transfer function with current follower transconductance amplifiers (CFTAs) has been presented. The proposed circuit, in general, contains at most *n* CFTAs and *n* grounded capacitors, without needing external passive resistors. It has been also shown that the design procedure given here is simple structure, convenient tunability, and suitable for integration. Furthermore, the circuit has low sensitivity. PSPICE simulation results which agree very well with the theoretical analysis are also included.**

***Index Terms*— Current Follower Transconductance Amplifier (CFTA), Signal Flow Graph (SFG), lowpass filter.**

I. Introduction

RECENTLY, the conception of the current follower transconductance amplifier (CFTA) has been introduced in [1]. The CFTA is slightly modified from the conventional current differencing transconductance amplifier (CDTA) [2] by replacing the current differencing unit with a current follower and complementing the circuit with a simple current mirror for copying the z-terminal current. Thus, the CFTA element is a combination of the current follower, the current mirror and the multi-output operational transconductance amplifier. Consequently, there are several structures for realizing current-mode active filters using CFTAs [3]-[7]. However, little work has been studied in the synthesis of general nth-order allpole lowpass transfer function. Although an interesting circuit realization of an nth-order lowpass filter using current conveyors can be found in [8], the circuit has too many grounded resistors, i.e. n+1 current conveyors, n grounded resistors and n grounded capacitors.

Therefore, this work largely focuses on presenting a general synthesis procedure for the realization of an nth-order allpole lowpass transfer function. The proposed method is based on drawing a signal flow graph directly from the given transfer function and then obtaining, from the graph, the active-C filter involving CFTAs. The resulting circuit uses a minimum number of n CFTAs and n grounded capacitors, which makes the circuit especially suitable for monolithic implementation. It is shown that the design procedure proposed here is general and simple. Simulation results from PSPICE program illustrate the properties of the proposed design procedure.

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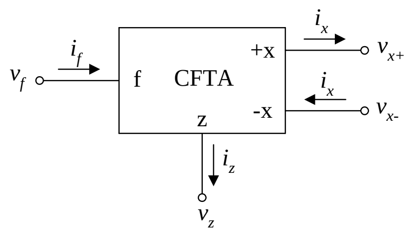
W. Tangsrirat is with the Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang (KMITL), Chalongkrung road, Ladkrabang, Bangkok 10520, Thailand (phone: +662-326-4205; fax: +662-326-4205; e-mail : drworapong@yahoo.com).

II. Current Follower Transconductance Amplifier (CFTA)

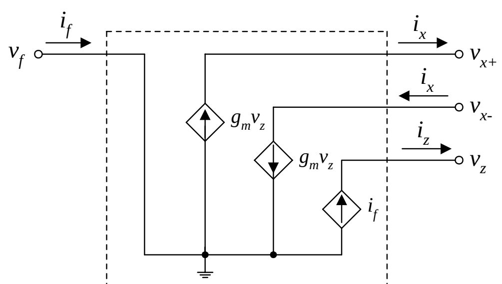
The symbolic representation of the CFTA and its behavior model are shown in Fig.1. Assuming the standard notation, the terminal defining relations of this device can be characterized by the following set of equations [3]-[6].

$$v_f = 0 \ , \quad i_z = i_f \quad \text{and} \quad i_x = g_m v_Z = g_m Z_Z i_Z \tag{1}$$

where g_m is the transconductance gain of the CFTA and Z_z is an external impedance connected to the z-terminal. The CFTA consists essentially of the current follower at the input part and the multi-output trnascondcutance amplifier at the output part. According to equation (1) and Fig.1, the f-terminal forms the current input terminal at ground potential (v_f = 0) and the output current at the z-terminal (i_z) follows the current (i_f) through the f-terminal. The voltage drop at the z-terminal (v_z) is then converted to a current at the x-terminal (i_x) by a g_m-parameter. In general, the g_m-value is adjustable over several decades by a supplied bias current/voltage, which lends electronic controllability to design circuit parameters.



(a)



(b)

Fig. 1 The CFTA
(a) schematic symbol (b) behavioral model

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III. Realization Procedure

The general form of an nth-order lowpass current transfer function can be expressed by the following formula :

$$\frac{I_o(s)}{I_{in}(s)} = \frac{1}{b_n s^n + b_{n-1}s^{n-1} + ... + b_1 s + 1} \quad . \qquad (2)$$

The above expression can be represented by the signal flow graph (SFG) as shown in Fig.2. It clearly seen that the graph consists of two basic operations, which are current summation and current lossless integrator, as redraw in Figs.3(a) and 3(c), respectively. Using the current and voltage relations of the CFTA given in eq.(1), we easily find that these two sub-graphs can be realized using CFTA by the sub-circuits shown in Figs.3(b) and 3(d), respectively. For the CFTA-based realization, it can readily obtain the CFTA-C circuit by interconnecting the corresponding subcircuits of Figs.3(b) and 3(d) according to the overall signal flow representation of Fig.2. Therefore, the CFTA-C circuit realizing any nth-order lowpass current transfer function is shown in Fig.4. For this realization, it has to be noted that the proposed filter configuration contains *n* CFTAs as active elements and *n* capacitors as passive elements for general nth-order filter function. Also note that the circuit realization uses only grounded capacitors that are suitable for the integrated circuit point of view [9]-[10], and also provides low-impedance input and high-output impedance terminals that are desirable for cascading in current-mode operation [11].

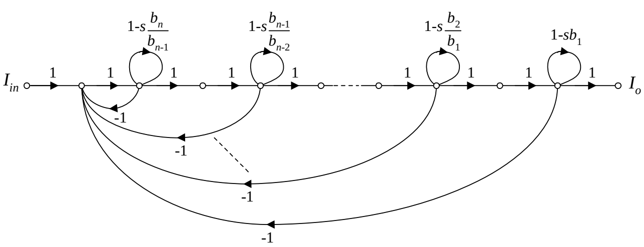

Fig.2 : Signal flow graph representing equation (2).

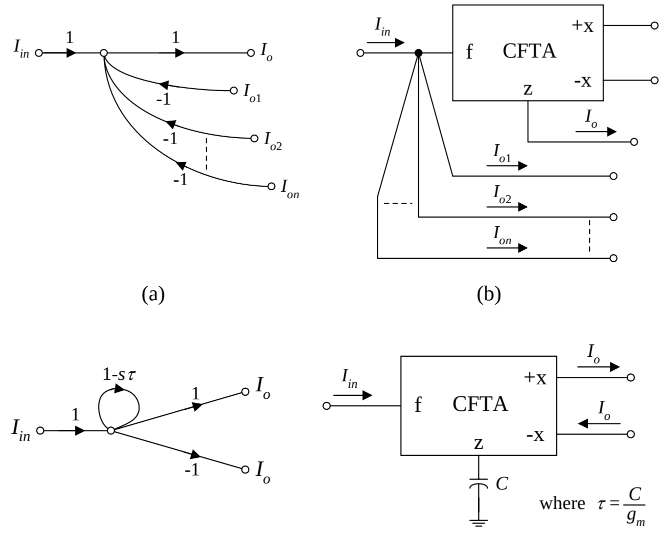

Fig.3 : Sub-graphs and their corresponding active-*C* sub-circuits involving CFTAs.

From the realization of Fig.4, the design equations can be obtained through comparing Fig.2 with Fig.4. The results are summarized as follows :

$$\frac{b_n}{b_{n-1}} = \frac{C_1}{g_{m1}}$$

$$\frac{b_{n-1}}{b_{n-2}} = \frac{C_2}{g_{m2}}$$

$$\vdots$$

$$\frac{b_2}{b_1} = \frac{C_{n-1}}{g_{mn-1}}$$

and

$$b_1 = \frac{C_n}{g_{mn}} \qquad (4)$$

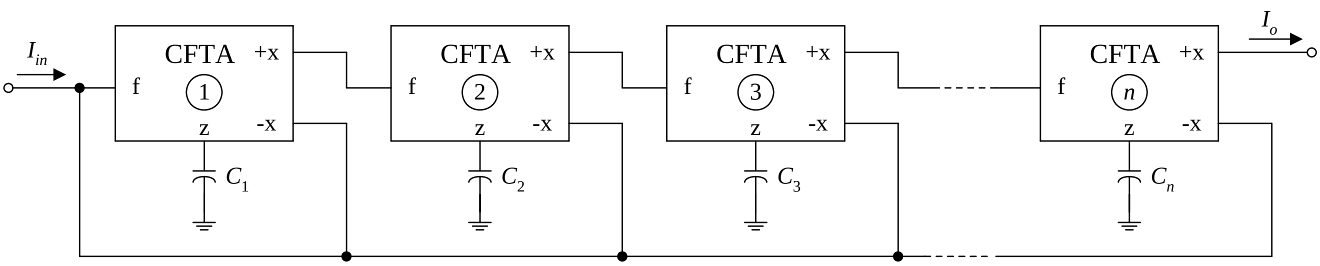

Fig.4 : CFTA-based realization of nth-order current-mode lowpass filter, corresponding to the SFG given in Fig.2.

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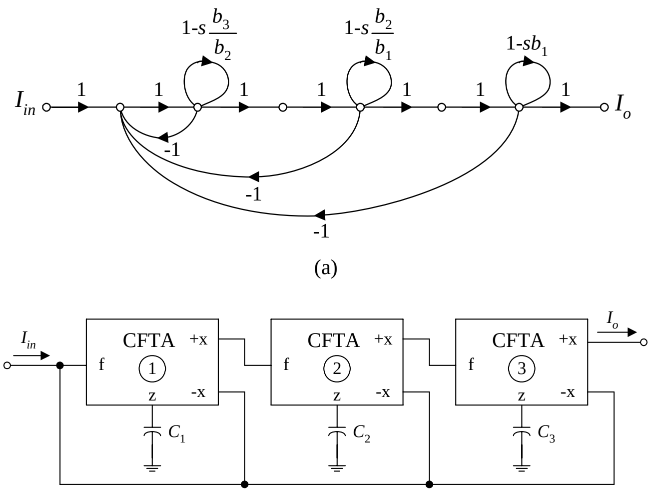
IV. Application Example

To demonstrate the useful application of the proposed design procedure, the third-order lowpass transfer function is considered. Generally, the current transfer function of the normalized third -order Butterworth lowpass filter is defined as :

$$\frac{I_o(s)}{I_{in}(s)} = \frac{1}{b_3 s^3 + b_2 s^2 + b_1 s + 1} = \frac{1}{s^3 + 2s^2 + 2s + 1} \tag{5}$$

It can easily shown that this transfer function can be represented by the signal flow graph shown in Fig.5(a), and the corresponding circuit realization of this graph is thus shown in Fig.5(b).



(a)

(b)

Fig.5 : Third-order lowpass transfer function of equation (5)
(a) signal flow graph representation (b) circuit realization.

In this case, the design equations of the circuit are found as :

$$\frac{b_3}{b_2} = \frac{C_1}{g_{m1}} = \frac{1}{2}$$

$$\frac{b_2}{b_1} = \frac{C_2}{g_{m2}} = 1$$

and

$$b_1 = \frac{C_3}{g_{m3}} = 2 \tag{6}$$

Thus, the normalized component value are obtained as : $C_1 = C_2 = C_3 = 1$ F, $g_{m1} = 2$ A/V, $g_{m2} = 1$ A/V, and $g_{m3} = 1/2$ A/V. Routine circuit analysis of Fig.5(b) yields the current transfer function as :

$$\frac{I_o(s)}{I_{in}(s)} = \frac{\left(\frac{g_{m1}g_{m2}g_{m3}}{C_1C_2C_3}\right)}{s^3 + \left(\frac{g_{m1}}{C_1}\right)s^2 + \left(\frac{g_{m1}g_{m2}}{C_1C_2}\right)s + \left(\frac{g_{m1}g_{m2}g_{m3}}{C_1C_2C_3}\right)} \tag{7}$$

The active and passive sensitivities of the natural angular frequency (ω_0) and quality factor (Q) are calculated using relations given in [12]. The results of active and passive sensitivity analysis of various parameters for the proposed filter are given in Table 1. It is clearly seen from Table 1 that all the sensitivities are low and within unity in magnitude.

Table 1 : Sensitivities for the circuit parameters in Fig.5.

	g_{m1}	g_{m2}	g_{m3}	C_1	C_2	C_3
b_0	1	1	1	-1	-1	-1
b_1	1	1	0	-1	-1	0
b_2	1	0	0	-1	0	0
ω_0	0	1	0	0	-1	0
Q	-1	0	1	1	0	-1

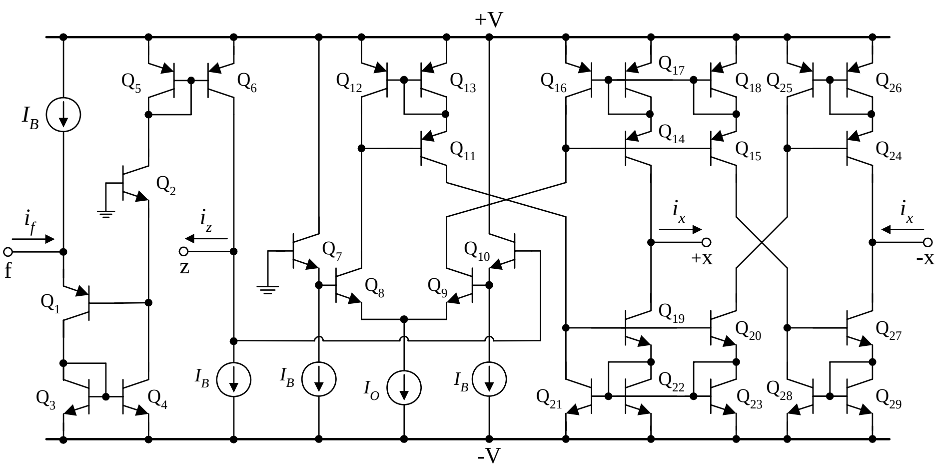


Fig.6 : Bipolar implementation of the CFTA used for simulations.

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V. SIMULATION RESULTS

To verify the theoretical analysis, the proposed circuit given in Fig.2 has been simulated with PSPICE simulation program. To implement the CFTA active device in simulations, the bipolar technology structure depicted in Fig.3 has been used [6]-[7]. The PNP and NPN transistors in CFTA implementation were simulated using the typical parameters of bipolar transistor model PR100N (PNP) and NP100N (NPN) [13]. The DC supply voltages and bias currents were respectively selected as : +V = -V = 3V and I_B = 100 μA. In this case, the transconductance gain (g_m) of the CFTA is directly proportional to the external bias current I_O, which is approximately equal to :

$$g_m = \frac{I_O}{2V_T} \tag{8}$$

and $V_T \cong 26$ mV at 27°C.

As an example, the illustrative current-mode third-order lowpass filter of Fig.5(b) was designed with $\omega_o = 10^6$ rad/sec. For this purpose, the de-normalized component value were chosen as : $C_1 = C_2 = C_3 = 1$ nF, $g_{m1} = 2$ mA/V ($I_{O1} \cong 104$ μA), $g_{m2} = 1$ mA/V ($I_{O2} \cong 52$ μA), and $g_{m3} = 1/2$ mA/V ($I_{O3} \cong 26$ μA). The simulated responses comparing with the theoretical values are shown in Fig.7. From the results, it can be observed that the simulation results agree very well with theoretical predictions.

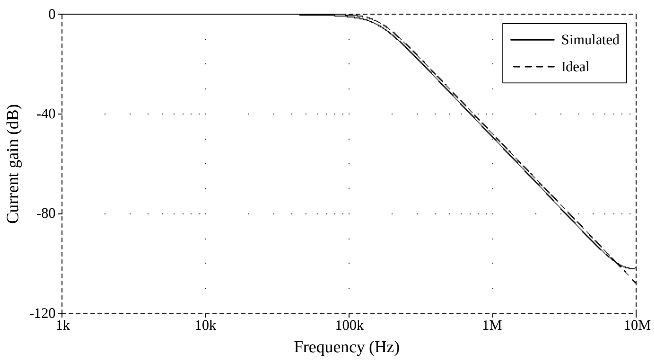

Fig.7 : Simulated and ideal lowpass current responses of the filter in Fig.5(b).

VI. CONCLUSION

This work presents a synthesis procedure for realizing the n^{th}-order allpole lowpass current transfer function by a resistor-less (active-C) circuit. By using the signal flow graph representation, any n^{th}-order lowpass filter can be realized employing n CFTAs and n grounded capacitors. The resulting circuit obtained from the presented method is a canonical structure and especially suitable for integration. It has low-input and high-output impedances, and also convenient electronic controllability through the g_m-value of the CFTA.

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