LETTER

A Reduction of the Number of Components Included in Direct Simulation Type Active Complex Filter

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SUMMARY In this paper, a reduction of the number of components included in direct simulation type active complex filter is proposed. The proposed method is achieved by sharing NIC's (Negative Impedance Converters) which satisfy some conditions. Compared with the conventional method, the proposed one has wide generality. As an example, a third-order complex elliptic filter is designed. The validity of the proposed method is confirmed through experiment.
key words: *complex, active, filter, NIC*

1. Introduction

In recent years, many techniques concerned with the complex signal processing have been presented, not only in the field of digital circuits but also in the field of analog circuits. The complex filters are important for the Low-IF radio systems [1], [2], SSB (Single Side Band) communication systems [3] and so on.

It is known that the direct simulation method [4]–[6] offers the advantage of a simple design. The authors have proposed a complex filter using NIV's (Negative Immittance Inverters) [4]. Compared with the conventional circuits [5], the complex filter using NIV's can be realized with fewer active components. However, it is difficult to apply this technique [4] to the complex filters with finite transmission zeros.

In this paper, a reduction of the number of components included in direct simulation type active complex filter is proposed. The proposed method is achieved by sharing NIC's (Negative Impedance Converters). As an example, a third-order complex elliptic filter is designed. The validity of the proposed method is confirmed through experiment. The number of the required components of the proposed circuit is compared with that of the conventional one.

2. Proposed Method

In many cases, complex prototype filters include not only resistors and capacitors but also imaginary resistors and inductors. The imaginary resistors and inductors can be realized by using gyrators. Therefore, the complex filters can be realized by using resistors, capacitors and gyrators. When the complex filter is realized directly by using operational amplifiers, gyrators are realized by using NIC's [5]. Except for special case [7], complex filters composed of resistors, capacitors, and gyrators are realized as circuits including two or more NIC's connected to the same nodes.

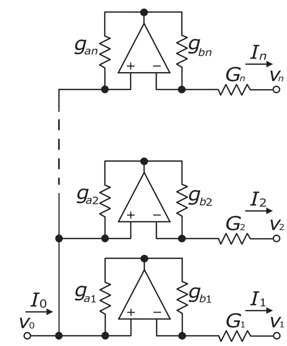

Fig. 1 Several NIC's connected to the same node.

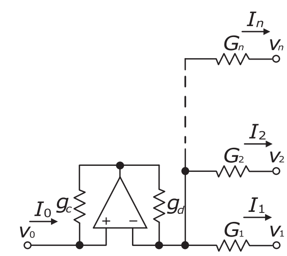

Fig. 2 An NIC and resistors.

In this section, a method for sharing NIC's is proposed. First, when $(I_0, I_1, \cdots I_n)^t = \mathbf{Y_a}(V_0, V_1, \cdots, V_n)^t$, a Y-matrix of the circuit shown in Fig. 1 has the following form.

$$\mathbf{Y_a} = \begin{pmatrix} Y_{a0} & (g_{a1}G_1)/g_{b1} & (g_{a2}G_2)/g_{b2} & \cdots & (g_{an}G_n)/g_{bn} \\ -G_1 & G_1 & 0 & \cdots & 0 \\ -G_2 & 0 & G_2 & \cdots & \vdots \\ \vdots & \vdots & \ddots & \ddots & 0 \\ -G_n & 0 & \cdots & 0 & G_n \end{pmatrix}, \quad (1)$$

where $Y_{a0} = -\{(g_{a1}G_1)/g_{b1} + (g_{a2}G_2)/g_{b2} + \cdots + (g_{an}G_n)/g_{bn}\}$.

Secondly, the Y-matrix of the circuit shown in Fig. 2 becomes as follows. When $(I_0, I_1, \cdots, I_n)^t = \mathbf{Y_b}(V_0, V_1, \cdots, V_n)^t$.

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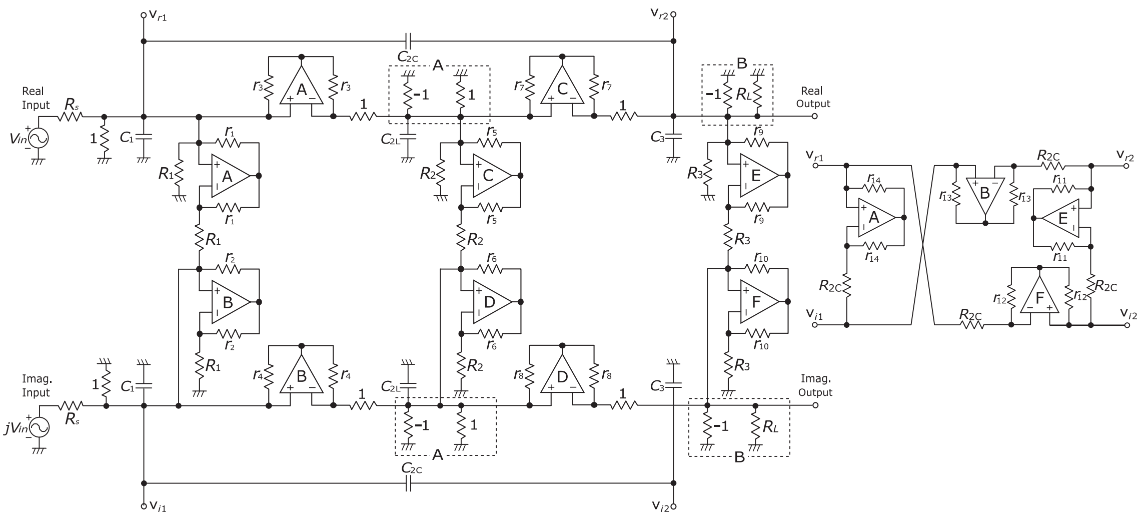

Fig. 3 Conventional circuit (n = 3) [4], [5].

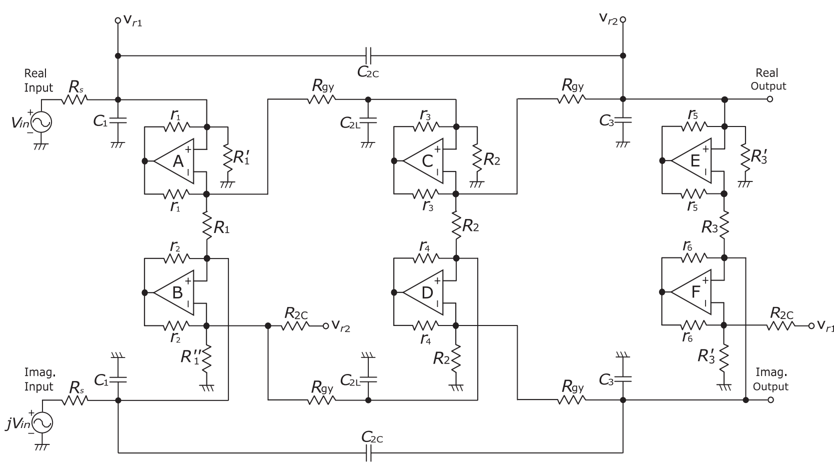

Fig. 4 Proposed circuit (n = 3).

$$\mathbf{Y_b} = \begin{pmatrix} Y_{b0} & (g_c G_1)/g_d & (g_c G_2)/g_d & \cdots & (g_c G_n)/g_d \\ -G_1 & G_1 & 0 & \cdots & 0 \\ -G_2 & 0 & G_2 & \cdots & \vdots \\ \vdots & \vdots & \ddots & \ddots & 0 \\ -G_n & 0 & \cdots & 0 & G_n \end{pmatrix}, \tag{2}$$

where $Y_{b0} = -(g_c/g_d)(G_1 + G_2 + \cdots + G_n)$. By comparing Eq. (1) and Eq. (2), it can be seen that the circuits shown in Figs. 1 and 2 are equivalent to each other if the following equation is satisfied.

$$g_{a1}/g_{b1} = g_{a2}/g_{b2} = \cdots = g_{an}/g_{bn} = g_c/g_d \tag{3}$$

Replacing the circuit of Fig. 1 with that of Fig. 2 reduces (n-1) operational amplifiers and 2(n-1) resistors.

3. Design Example

A complex filter which satisfies the following specifications is designed.

Third-order complex elliptic filter	
Passband	4.5–5.5 kHz
Passband ripple	1.25 dB
Minimum attenuation	40.5 dB

In the same fashion as the existing researches [4], [5], a circuit shown in Fig. 3 which meets the above specifications can be designed. In this figure, circuits A surrounded by dotted lines are removed [5]. When R_L = 1, circuits B surrounded by dotted lines are also removed. Bringing OA's represented by A, B, C, D, E, and F together gives the circuit shown in Fig. 4. The operational amplifiers used in this experiment are LF356's. The feedback resistors of the NIC's are decided such that the influence of GB product of operational amplifiers decrease.

The experimental results obtained by the measurement technique described in [8] and simulated results are shown in Figs. 5 and 6. In these figures, dash dotted lines show the gain characteristics of the proposed circuit realized by using

Table 1 Element values of the experimental circuit shown in Fig. 4.

Element	Value	Element	Value	Element	Value
R_s	20	R_{gy}	20	R_1	0.8930
R'_1	0.9173	R''_1	1.010	R_2	2.323
R_{2C}	12.55	R_3	0.8930	R'_3	0.9614
r_1	0.8930	r_2	1.010	r_3	2.323
r_4	2.323	r_5	0.8930	r_6	0.9614
C_1	33.11	C_{2L}	13.70	C_{2C}	2.537
C_3	33.11				

R′s in kΩ, C′s in nF

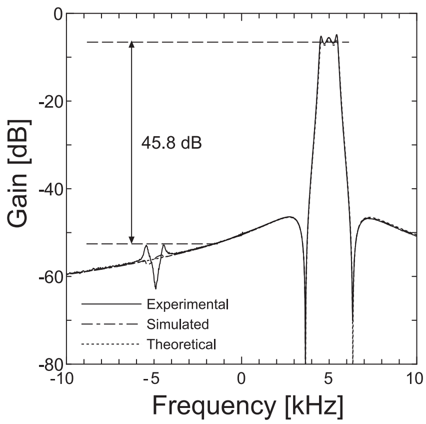

Fig. 5 Experiment result (overall).

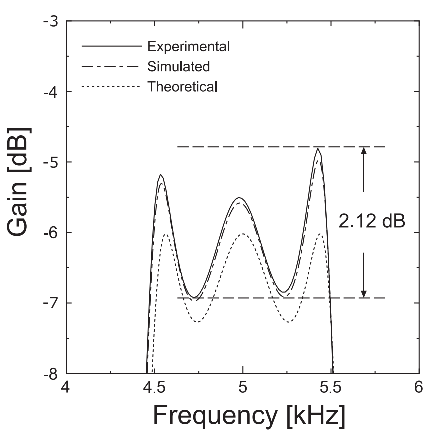

Fig. 6 Experiment result (near passband).

ideal operational amplifiers with GB products of 5 MHz. The experimental results show that the proposed filter exhibits a complex elliptic response and an image rejection of 45.8 dB.

The number of the required components are summarized in Table 2 and Table 3. From Table 2, it is found that the components required in the proposed circuit are fewer than those in the conventional complex filter with finite transmission zeros. From Table 3, it is found that the required components are not reduced when the proposed method is applied to the complex filter without finite transmission zeros [4]. Although it is difficult that the conventional method [4] is applied to the complex filter with finite transmission zeros, the proposed one can applied to the filters with or without finite transmission zeros.

Table 2 The number of the required components for complex filter with finite transmission zeros.

Order	Proposed			Conventional [5], [6]		
	OA	C	R	OA	C	R
3rd	6	8	29	14	8	49
5th	10	14	49	26	14	87
$(2k+1)$th	$4k+2$	$6k+2$	$20k+9$	$12k+2$	$6k+2$	$38k+11$

OA: Operational Amplifier

Table 3 The number of the required components for complex filter without finite transmission zeros.

Order	Proposed			Conventional [4]		
	OA	C	R	OA	C	R
3rd	6	6	27	6	6	27
5th	10	10	44	10	10	44
$(2k+1)$th	$4k+2$	$4k+2$	$17k+10$	$4k+2$	$4k+2$	$17k+10$

OA: Operational Amplifier

4. Conclusion

In this paper, a reduction of the number of components included in direct simulation type active complex filter is proposed. The validity of the proposed method is confirmed through experiment. Compared with the conventional method, the proposed method has wide generality.

The further investigation is required to compensate GB product of the operational amplifiers.

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