Immittance Function Simulators Using a Finite Gain-bandwidth Product of Operational Amplifier and Their Applications

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A method for utilizing the immittance function simulators using a finite gain-bandwidth product of an operational amplifier is presented. High Q 2nd-order band-pass filter can be realized by using the proposed active-C and active-R simulators. Experimental results agree well with theoretical ones.

Key words : Circuit theory and design, Active filter, Immittance function, Immittance function simulator,OP amp., Gain-bandwidth product

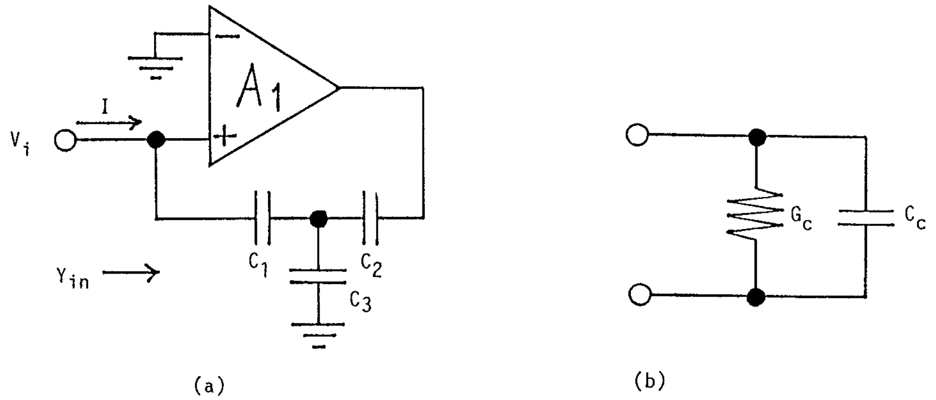
1. Introduction

Many papers on the immittance simulator using active elements have been reported(1-12). These simulators can be applied for realizing the immittance function of various electronic networks, such as the filter circuit and oscillator. Several applications of the immittance function simulator using a finite gain-bandwidth product of an operational amplifier has been given by the authors(11, 12). Combining two immittance function simulators in parallel, one of which contains a negative circuit element, has not been considered as yet.

In this paper, we deal with the two simulators, one is an active-C simulator for generating a negative conductance (negative G) in parallel with a capacitance (C) and the other with an active-R simulator for generating positive conductance (G) in parallel with an inductance (L). By combining the both simulators in parallel, we can obtain the simulator of C-G-L parallel connection. As an application of such simulator, a high-Q 2nd-order bandpass filter is presented. Finally, we consider a realization of 2-port network, that is Pi network composed of various circuit elements such as a capacitance, an inductance and a frequency dependent negative resistance (FDNR).

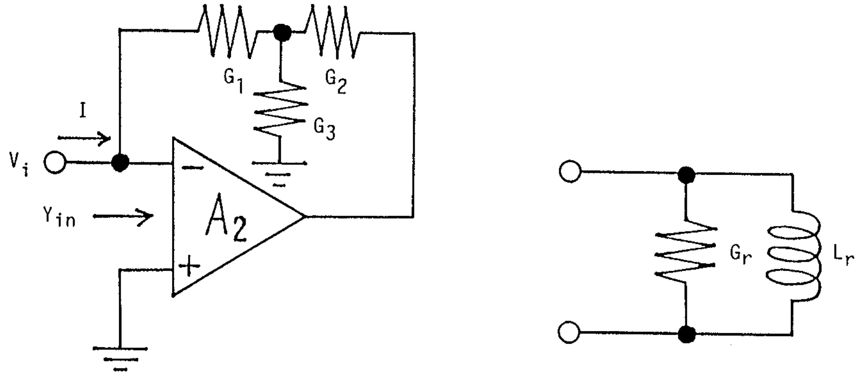
2. Circuit configuration

The authors have presented the active-C simulator for realizing a negative conductance in parallel with a capacitance(12). By combining the negative G-C parallel simulator with the parallel G-L simulator, we can realize the 2nd-order bandpass filter with a high-Q factor.



(a)　　(b)

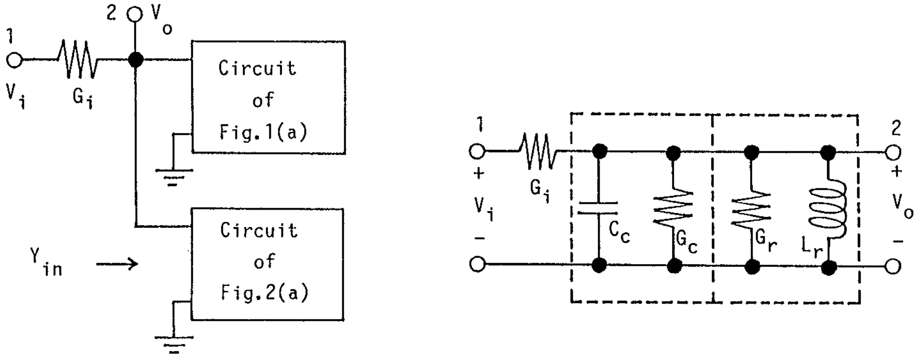
Fig. 1 Negative conductance - capacitance parallel simulator and its equivalent circuit.



(a) (b)

Fig. 2 Conductance - inductance parallel simulator and its equivalent circuit.

Figs. 1 and 2 show the simulation circuits and their equivalent circuits for generating the negative G-C parallel connection and G-L parallel connection, respectively. Notice that the both schemes are active-C and active-R form, respectively.



(a) (b)

Fig. 3 High-Q 2nd-order bandpass filter and its equivalent circuit.

Figs. 3(a) and (b) are the high-Q 2nd-order bandpass filter using the above simulators and its equivalent circuit. The driving-point admittance function Y_{in} viewed from terminal 2 is calculated by using the single pole model for the open-loop gain A_1 of operational amplifier, that is , $A_1=B_1/s$, where B_1 denotes the gain-bandwidth product of the amplifier. Then we can obtain Y_{in} as shown below.

$$Y_{in} = sC_C + G + 1/sL_r \qquad (1)$$

$$C_C = C_1(C_2+C_3)/(C_1+C_2+C_3) \qquad (2)$$

$$L_r = (G_1+G_2+G_3)/(G_1G_2B) \qquad (3)$$

$$G = G_C + G_r \qquad (4)$$

$$G_C = -C_1C_2B/(C_1+C_2+C_3) \qquad (5)$$

$$G_r = G_1(G_2+G_3)/(G_1+G_2+G_3) \qquad (6)$$

Where $B_1=B_2=B$.

Then, the transfer function T $(=V_O/V_i)$, gain constant H, ω_O and Q for the scheme shown in Fig. 3(a) are given as follows.

$$\begin{aligned} T &= G_i/(G_i + Y_{in}) \\ &= Hs/[\ s^2 + (\ W_0/Q\ )s + W_0^2\ ] \end{aligned} \qquad (7)$$

$$H = G_i\ /\ C_C \qquad (8)$$

$$W_0 = 1\ /\quad L_r\ C_r \qquad (9)$$

$$Q = [1/(G_i + G)]\quad C_C\ /\ L_r \qquad (10)$$

From Eq. (7), we can see that the proposed circuit has the characteristic of 2nd-order bandpass filter. Since G_C is negative as shown in Eq. (5), the condition $G=G_C+G_r > 0$ must be satisfied for stable operation. Then it is clear that the bandpass filter circuit with high Q can be realized by minimizing the value of G.

3. Experimental results

The operational amplifiers used in the experiment were LF356 satisfying the condition of the gain-bandwidth product $B_1/(2\pi)=B_2/(2\pi)=4.5$[MHz] at ± 15[V] regulated supply. And also, the input signal $|V_i|$ was 100[mV].

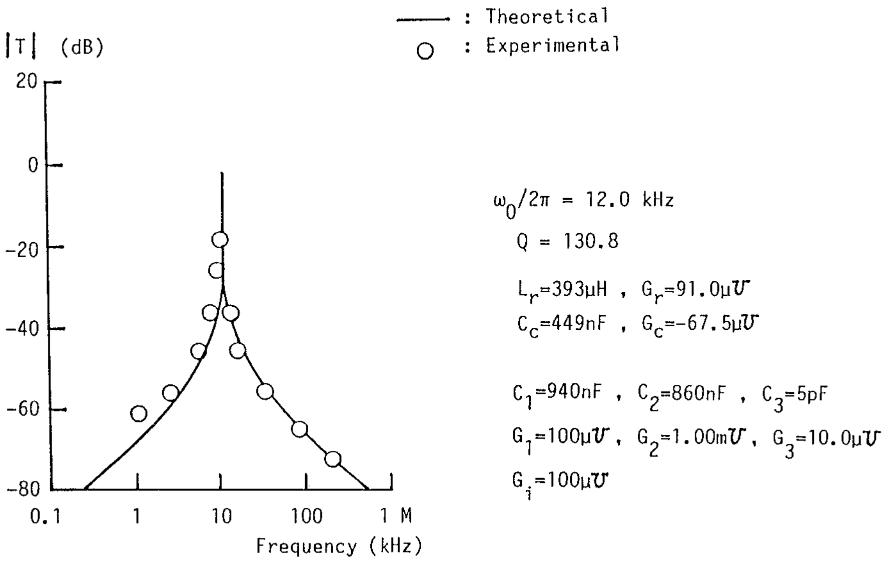


Fig. 4 Experimental result.

Fig. 4 shows the frequency response of the high Q 2nd-order bandpass filter. The cutoff frequency $\omega_0/(2\pi)$, Q and simulated theoretical values of C, G and L for the scheme are given in the figure. We can see that experimental results agree well with the theoretical ones, and the 2nd-order bandpass filter circuit using the C-G-L parallel simulator works successfully over the wide frequency range.

4. Realization of 2-port network

We have explained the simulation circuit of 1-port type, that is, the grounded immittance function simulator. In this chapter, we deal with the simulator of 2-port type, such as Pi network and T network etc.

Fig. 5 (a) and (b) show the 4th-order bandpass filter using the proposed simulator of 2-port type, and its equivalent circuit, respectively. If we express the relation between port 1 and 2 of the scheme in terms of the y parameters, we obtain

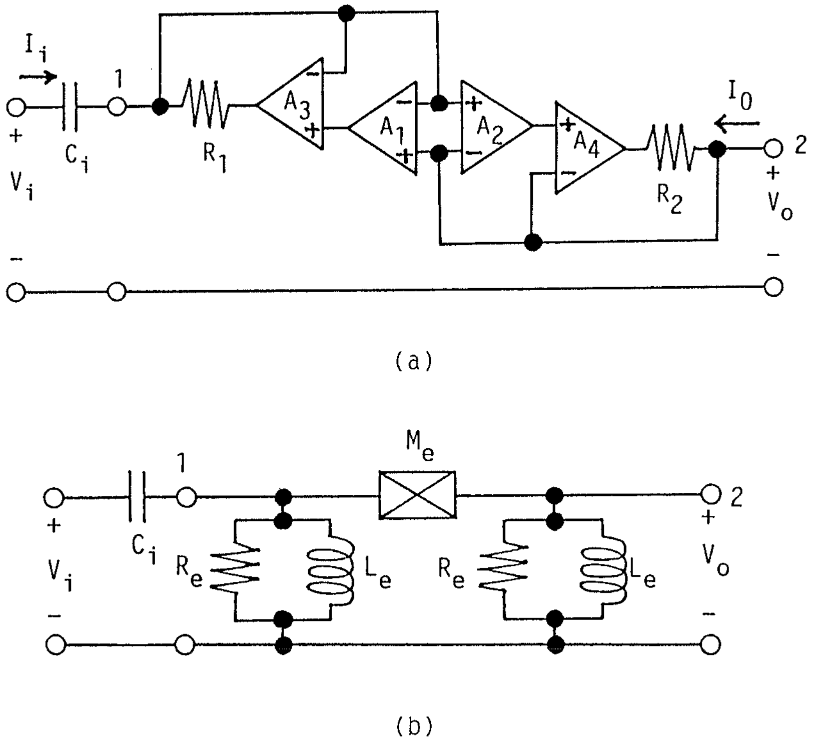


Fig. 5 4th-order bandpass filter and its equivalent circuit.

$$[\,y\,] = \begin{bmatrix} (1+A_{34}+A_{12}A_{34})/R & -A_{12}A_{34}/R \\ -A_{12}A_{34}/R & (1+A_{34}+A_{12}A_{34})/R \end{bmatrix} \quad (11)$$

where

$$\left.\begin{aligned} R_1 &= R_2 = R \\ A_1 &= A_2 = A_{12} \\ A_3 &= A_4 = A_{34} \end{aligned}\right\} \quad (12)$$

The each simulated element values are given as follows.

$$R_e = R \tag{13}$$

$$L_e = R / B_{34} \tag{14}$$

$$M_e = R / B_{12} B_{34} \tag{15}$$

The transfer function $T(=V_C/V_i)$ of the circuit of Fig. 5(a) is

$$T = eS^2 / (S^4+aS^3+bS^2+cS+d) \tag{16}$$

where

$$a = (1+C_iR_eX)/(C_iR_e) \tag{17}$$

$$b = (2XM_e+C_iR_e{}^2)/(C_iR_eM_e) \tag{18}$$

$$c = (X^2M_e+2R_e)/(C_iR_eM_e) \tag{19}$$

$$d = 2X / C_iM_e \tag{20}$$

$$e = R_e / M_e \tag{21}$$

$$X = R_e / L_e \tag{22}$$

From Eq. (16), it is shown that the proposed circuit has the response of 4th-order bandpass filter.

5. Conclusion

In this paper, we have proposed 1-port and 2-port immittance function simulators using a finite gain-bandwidth product of an operational amplifier. It has shown that the 2nd-order bandpass filter using the proposed 1-port simulators has a magnitude characteristic with a high Q. Theoretical analysis showed that the proposed 2-port simulator can be applied to 4th-order bandpass filter.

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