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Simple first-order multifunction filter

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A new first-order configuration simultaneously implementing LP, HP, and AP filtering functions is presented. The circuit is based on and employs two CCIIs, two floating, two grounded resistors, and one grounded capacitor. The topology of the circuit is amenable for construction using translinear conveyors (CCCII) also. This version of the circuit facilitates electronic control of cutoff frequency besides offering saving in components as it employs only one capacitor and two resistors instead of five passives. The realizability condition for allpass response is simple and temperature independent. The circuit enjoys low sensitivity figures. The, PS (PSPICE) PICE simulation is obtained confirming the theoretical analysis.

[**Keywords:** Voltage mode, Current conveyor, Current controlled conveyor, First order filter]
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1 Introduction

The construction of current-mode and voltage-mode circuits using CCII, a robust and versatile active circuit building block, has received substantial attention as the simulated circuits offer several distinct advantages including large bandwidth and improved current drive capability over OTA and OA based continuous-time circuits[1-6]. A critical study reveals that the reported circuits implement only one filtering signal viz. AP besides having complex component matching conditions[7-10]. Most of the reported first order CCII AP filters have a serious drawback of having a capacitor at terminal–x which contributes to deterioration in their performance at higher operating frequencies. Besides, such type of circuits cannot be converted into their translinear version the employment of which provide the advantage of electronic tuning capability without using additional hardware and/or inducing the change in the topology. The expressions for transconductance gains of OTA $\left(g_m = \frac{I_o}{2V_T}\right)$ and CCCII $\left(G = \frac{1}{R_x} = \frac{2I_o}{V_T}\right)$ shows that the power consumption of OTA based circuits is four times that of CCCII circuits for the same values of transconductance gains, necessitating the increasing use of the latter building block[12].

In this paper, we are proposing a novel first-order filter structure capable of implementing LP, HP, and AP filtering characteristics simultaneously. The topology of the circuit is such that, it can also be realized using translinear conveyors. The latter circuit offers saving in the components as it uses only one grounded capacitor (suitable for IC design) and two resistors apart from lending electronic tunability to the cutoff frequency of the filtering responses, which is highly desirable in contemporary IC design. The realizability condition for allpass response for both the circuits is temperature independent and as such can work well under varying environmental conditions; a problem encountered in the circuits reported earlier[10]. It is worth to note here that recently, current conveyor based first-order all-pass sections have found application in dual-element frequency controlled oscillators with certain benefits in harmonic rejection and quadrature property[11].

2 Theory

2.1 Circuit description

A routine analysis of the proposed structure shown in Fig. 1 yields the following voltage transfer functions:

$$T_{HP} = \frac{V_2}{V_1} = \frac{s}{\left[s + \frac{R_1}{R_3 R_4 C}\right]} \quad \ldots (1)$$

$$T_{LP} = \frac{V_3}{V_1} = \frac{\frac{1}{R_3 C}}{s + \frac{R_1}{R_3 R_4 C}} \quad \ldots (2)$$

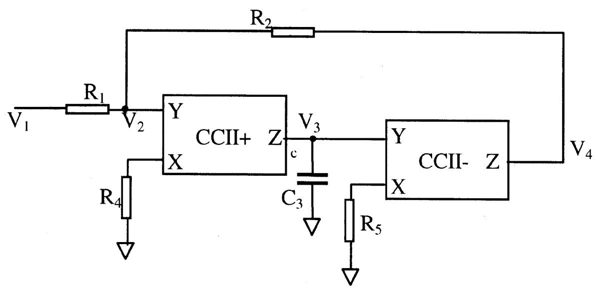

Fig. 1—Proposed first-order filter circuit using CCIIs

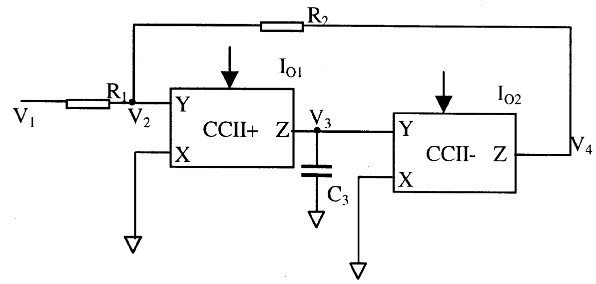

Fig. 2—Translinear conveyor version of Fig. 1

$$T_{AP} = \frac{V_4}{V_1} = \frac{s - \dfrac{R_2}{R_3 R_4 C}}{s + \dfrac{R_1}{R_3 R_4 C}} \quad \ldots (3)$$

The realizability condition for allpass circuit and its translinear version is same and is $R_1/R_2 = 1$, which is simple and stable against temperature variations as it is a function of resistor ratio. The cutoff frequency of LP, HP, and AP responses is tunable through the resistors R_3 and/or R_4 besides C independent of the realizibility condition and is given by

$$\omega_o = \frac{R_1}{R_3 R_4 C} \quad \ldots (4)$$

The phase relation for AP response is given by

$$\phi(\omega) = 2\,\text{arc}\ \tan\left(\frac{\omega_0 R_3 R_4 C}{R_1}\right) \quad \ldots (5)$$

The phase can be adjusted independent of ω_0 and of realizability condition through frequency of the signal. The phase can also be adjusted through R_3 and/or R_4 without disturbing the realization condition, thus adding flexibility to the tuning procedure. The translinear conveyor based version of the proposed circuit shown in Fig. 2 has the following voltage transfer functions:

$$T_{HP} = \frac{s}{s + \dfrac{R_1}{R_{X_1} R_{X_2} C}} \quad \ldots (6)$$

$$T_{LP} = \frac{\dfrac{1}{R_{X_1} C}}{s + \dfrac{R_1}{R_{X_1} R_{X_2} C}} \quad \ldots (7)$$

$$T_{AP} = \frac{s - \dfrac{R_1}{R_{X_1} R_{X_2} C_2}}{s + \dfrac{R_1}{R_{X_1} R_{X_2} C_1}} \quad \ldots (8)$$

The latter circuit has the same condition of realizability viz. $R_1 = R_2$.

The cutoff frequency for LP, HP and AP filters is given by

$$\omega_o = \frac{R_1}{R_{X_1} R_{X_2} C} \quad \ldots (9)$$

where R_{xi} is the input resistance at the terminal X of the *i*th translinear conveyor and equals to

$$R_{Xi} = \frac{V_{Ti}}{2 I_{oi}} \quad \ldots (10)$$

where, V_{Ti} and I_{oi} are the thermal voltage and bias current of *i*th translinear conveyor.

The phase angle for AP response is as follows

$$\phi(\omega) = 2\,\text{arc}\ \tan\left(\frac{\omega R_{X_1} R_{X_2} C}{R_1}\right) \quad \ldots (11)$$

From Eq. (9) one can see that the frequency can be linearly adjusted over a wide range of frequency as it depends upon the product of the two parasitic resistances which are electronically controlled through their respective bias currents.

2.2 Sensitivity

The sensitivities for the circuit and its translinear conveyor based version are given as

$$S_{R_3}^{\omega_o} = -S_{R_4, R_5, C}^{\omega_o} = 1$$

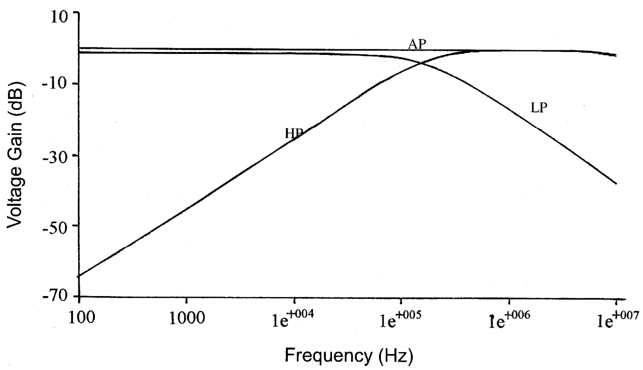

Fig. 3—Magnitude-frequency responses of LP, HP and AP

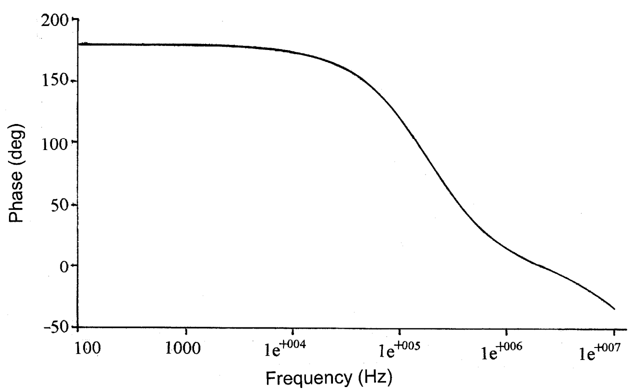

Fig. 4—Phase-frequency responses of AP

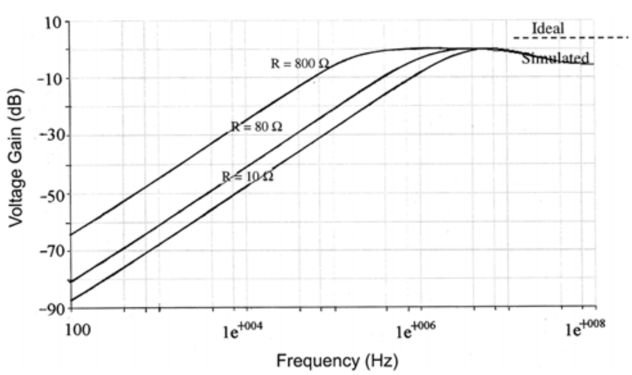

Fig. 5—Variation of voltage gain with frequency for different values of resistance R_4

$$S^{\omega_o}_{R_3} = -S^{\omega_o}_{R_{X_1},R_{X_2},C} = 1$$

which are equal to unity.

3 Results

The PSPICE simulation was carried out to prove the workability of the proposed circuit shown in Fig. 1. AD844 was used to implement CCII+, while as CCII− was implemented by cascading two CCII+. AD844 macro model supported by analog devices is a current feedback op-amp, which may be operated as CCII+ with the additional advantage of having a low impedance output, which buffers the voltage at the *z* output[9]. The simulated results are shown in Figs 3-5. Figure 3 depicts the magnitude response of LP, HP and AP, while Fig. 4 shows the phase variation with frequency. The filter was designed for a natural frequency of 200 kHz and for a phase shift of 90°. The design values are: $C = 1\ nF$, $R_1 = R_2 = R_4 = 1\ \text{k}\Omega$ and $R_3 = 800\Omega$. The variation of voltage gain with frequency for different values of resistor R_4 is depicted in Fig. 5. One can see from this Fig. 5 that gain of the filter can be varied over a wide range of frequency. The deviation in the magnitude-frequency response and phase-frequency response of the actual circuit from the ideal responses at high frequencies are caused by the limited frequency band of AD844.

4 Conclusion

A novel first-order multifunction filter implementing simultaneously three filtering responses LP, HP, and AP has been introduced. The circuit and its translinear version enjoy low sensitivity performance. The translinear conveyor version of the circuit employs a minimum number of passive components vis-à-vis its CCII counterpart and has simple topology as it employs fewer components, contributing to saving in the components and electronic tunability of ω_0 as well. The realizibility condition for allpass function is temperature insensitive being ratio of two resistors for both the circuits.

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