The Temperature Insensitive and Electronic Tuning of Current-mode First-order Allpass Filters

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Abstract. *This article presents the three circuits of current-mode first-order allpass filters which are electronically tunable and temperature insensitive. The proposed circuits provide separate elements which are CCII, CCTA, grounded resistor and grounded capacitor. The pole frequency and phase response can be tuned by input bias currents of CCTA. Furthermore, low impedances of input and high impedances of output that are advantageous for use in current-mode configuration. In addition, the proposed allpass filters are temperature insensitive and the sensitivities are low. The PSPICE program was used to corroborate the performances of the proposed allpass filters. They show a good results and according to theoretical.*

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1. Introduction

Nowadays, first-order allpass filters (APF) or phase shifts are receiving attention since they have several applications such as a high-Q band-pass filter for use in measurement, instrument systems and communication systems [1-5]. Furthermore, first-order APF can be used in sinusoidal oscillator circuits which are quadrature oscillators for use in communication systems, multiphase oscillators for use in power electronic systems [6-8]. In the last decade, current-mode circuits have been widely published since there are many benefits such as wide bandwidth, high slew rate, greater linearity, low power consumption and low voltage supply [1-2, 9]. A review of the literature found that the APF circuits are frequently used for differences in active building blocks such as CCCII, OTA, CDTA, CFTA, VDTA, CCCCTA, and CFTA. Most APF circuits are designed for using with grounded passive elements [1-2, 5-7, 9-15] that are able to compensate/eliminate stay capacitances at nodes/ports and reduce the fabrication area of IC [1]. In addition, they are easily adjusted to the pole frequency and phase response by tuning the parasitic resistances (R_x) [10-13, 15-17] or transconductance gains (g_m) [10, 14-16, 18-24]. However, various APFs [1-3, 7, 10-24] are very sensitive to temperature variations that cause the variations of the pole frequency and phase responses. When the communication systems, power electronic and/or other systems based-on APF are used, then they may be failed. Also, some circuits [3-4, 8, 16-23] use floating capacitors which increase the area of IC fabrication. The proposed first-order allpass filters are compared with previously published of [1-24] and the results are shown in Table 1.

This paper presents the synthesis of three current-mode APFs. They have the same following features:

- The structure of all APFs employ CCTA, CCII, grounded capacitor and grounded resistor.
- The pole frequency and phase response are easily adjusted by tuning the DC bias current of CCTA.
- High impedance of output and low impedance of input which is suitable for current-mode configurations.
- The operations of APF circuits are less sensitive to temperature.

The PSPICE simulation confirms the theoretical analysis has been included.

2. Principle and Operation

2.1 Second Generation Current Conveyor

Since the proposed circuits are based-on CCII or second generation current conveyor, it was researched and published in 1970 by Sedra and Smith [25]. They are popularly used in analog signal processing. Also, the electrical characteristics of CCII are expressed in equation (1) and the symbols are depicted in Fig. 1.

$$\begin{bmatrix} I_y \\ V_x \\ I_z \end{bmatrix} \begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} I_x \\ V_y \\ V_z \end{bmatrix}. \tag{1}$$

Ref.	Active element	Numbers of R+C	Grounded capacitor	Electronic tune	Matching condition	Temperature insensitive
[1]	ZC-CFTA	0+1	✓	✓	×	×
[2]	CFTA	1+1	✓	✓	×	×
[3]	VDTA	0+1	×	✓	×	×
[4]	CDBA	3+1	×	×	✓	×
[5]	FDCCII	2+1	✓	×	×	×
[6]	CCCDTA	0+1	✓	✓	×	×
[7]	DVCCTA	1+1	✓	✓	×	×
[8]	OTRA	3+1	×	×	✓	×
[9]	DDCC	3+1	✓	×	×	×
[10]	CCCCTA	0+1	✓	✓	×	×
[11]	CCCII	0+1	✓	✓	×	×
[12]	CCCII	0+1	✓	✓	×	×
[13]	CCCII+DIVB	0+1	✓	✓	×	×
[14]	OTA	0+1	✓	✓	×	×
[15]	CCCCTA	0+1	✓	✓	×	×
[16]	CCCCTA	0+1	×	✓	×	×
[17]	CCCII	1+1	×	✓	×	×
[18]	DBTA	1+1	×	✓	×	×
[19]	CDTA	0+1	×	✓	×	×
[20]	CC-VCII	0+1	×	✓	✓	×
[21]	CCCTA	0+1	×	✓	×	×
[22]	VDIBA	0+1	×	✓	×	×
[23]	CDTA	1+1	×	✓	×	×
[24]	OTA	0+1	✓	✓	×	×
Proposed circuit	CCII+CCTA	1+1	✓	✓	×	✓

Table 1 Comparison between various allpass filters

2.2 Current Conveyor Transconductance Amplifier

CCTA or current conveyor transconductance amplifier was published in 2005 by Prokop and Musil [26]. It is very useful in analog signal processing. Moreover, it is convenient to use for voltage-mode or current-mode circuits since it has many advantages such as a wide bandwidth, and a high slew rate. Also, the current output can be easily controlled by a DC bias current. In 2009, Lahiri [27] presented CCIITA by connection with CCII at the front-end and operational transconductance amplifier (OTA) at the rear-end. Also, Jantakun and Siriphruchayanun [28] have improved CCTA by cascading CCII with dual OTA. The electrical symbol and equivalent circuit of CCTA are depicted in Fig. 2 (a) and (b), respectively. The relation of voltage and current of CCTA can be depicted in the following matrix expression:

$$\begin{bmatrix} I_y \\ V_x \\ I_z \\ I_{O1} \\ I_{O2} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & \pm g_{m1} & 0 \\ 0 & 0 & \pm g_{m2} & 0 \end{bmatrix} \begin{bmatrix} I_x \\ V_y \\ V_z \\ V_O \end{bmatrix}, \qquad (2)$$

where g_{m1} and g_{m2} are the transconductance gains of CCTA. If CCTA is constructed with a bipolar transistor, the transconductance gains can be expressed by

$$g_{m1} = \frac{I_{B1}}{2V_T}, \tag{3}$$

and

$$g_{m2} = \frac{I_{B2}}{2V_T}, \tag{4}$$

where V_T is the thermal voltage that is equal to 0.026V at room temperature. I_{B1} and I_{B2} are external DC bias currents for control g_{m1} and g_{m2} at port o_1 and o_2, respectively.

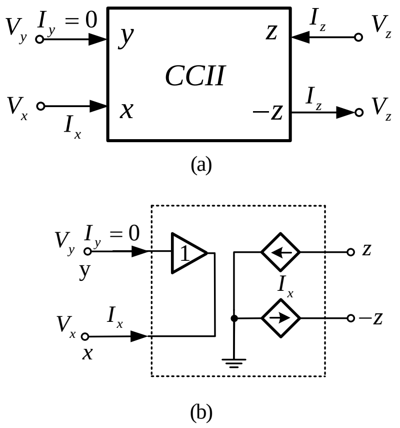


Fig. 1 CCII (a) symbols (b) equivalent circuit.

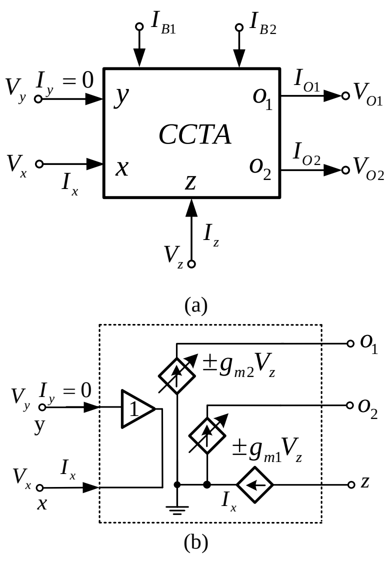


Fig. 2 CCTA (a) symbols (b) equivalent circuit.

2.3 Current-mode First-order Allpass Filters

The three circuits of the proposed APF circuits are shown in Fig. 3. Each structure employs single elements that are CCII, CCTA, grounded resistor and grounded capacitor. The CCIIs are used as input terminals with low impedance and spitted of input signal. The CCTAs and grounded elements are configured as temperature insensitive of integrator by improvement of [28-29]. Furthermore, the proposed APFs are low impedances of input and high impedances of output that can be used for cascading to high order filters or directly driving to load. The current transfer functions of the proposed APF circuits are the same and realized as

$$\frac{I_o}{I_{in}} = \frac{s - \dfrac{g_{m1}}{g_{m2}RC}}{s + \dfrac{g_{m1}}{g_{m2}RC}}. \tag{5}$$

The pole frequency (ω_0) can be expressed as

$$\omega_0 = \frac{g_{m1}}{g_{m2}RC}, \tag{6}$$

and the phase response (ϕ) of the proposed APF are obtained as

$$\phi = 180 - 2\tan^{-1}\frac{g_{m2}\omega RC}{g_{m1}}. \tag{7}$$

Substituting the transconductance gains as shown in (3) – (4) into (5) – (7), the current transfer function, pole frequency and phase response can be rewritten, respectively, as:

$$\frac{I_o}{I_{in}} = \frac{s - \dfrac{I_{B1}}{I_{B2}RC}}{s + \dfrac{I_{B1}}{I_{B2}RC}}, \tag{8}$$

$$\omega_0 = \frac{I_{B1}}{I_{B2}RC}, \tag{9}$$

and

$$\phi = 180 - 2\tan^{-1}\frac{I_{B2}\omega RC}{I_{B1}}. \tag{10}$$

It is evident that the parameters of the proposed APF which are the pole frequency and phase response can be adjusted by tuning the DC bias currents of CCTA that are I_{B1} or I_{B2}. Also, if the resistors and capacitors are free from temperature, the APF circuits are not responsive to temperature variation. Furthermore, the pole frequency and phase response are temperature insensitive and suitable for applications in communication and measurement systems. In addition, the grounded capacitor is connected at a high-impedance port that easily accommodates the latent capacity at the nodes and makes the fabrication area of IC smaller [30-32]. Also, the grounded resistor is suitably connected, it can absorb the internal resistance at the low-impedance port.

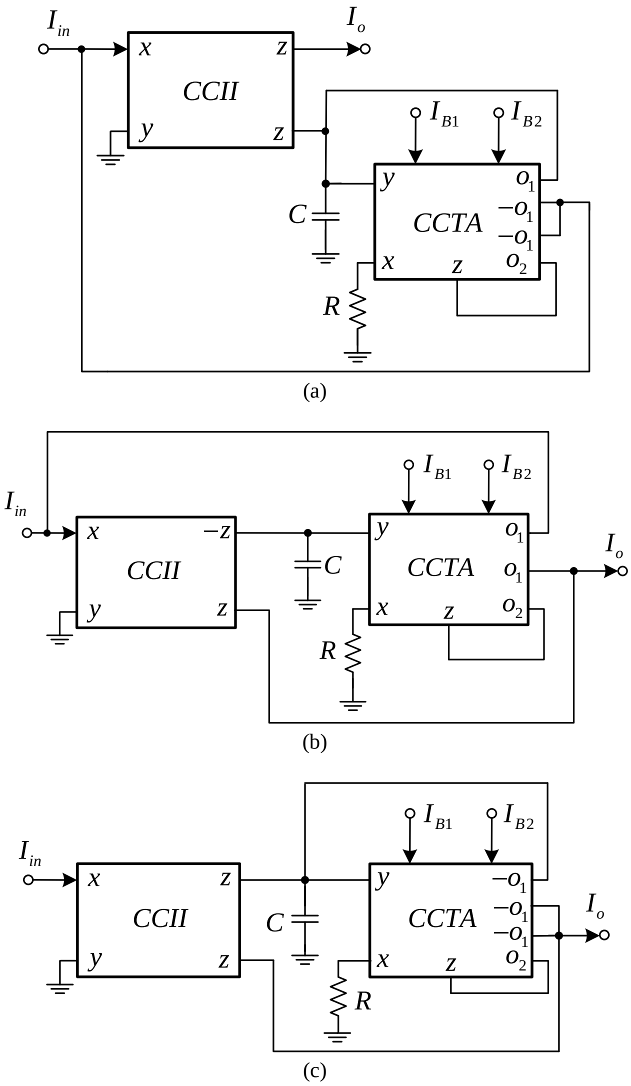


Fig. 3 Proposed APF circuits

2.4 Sensitivities Analysis

The sensitivities of the elements in the APF circuits are expressed in (11)

$$S_{I_{B2}}^{\omega_0} = S_R^{\omega_0} = S_C^{\omega_0} = -1, S_{I_{B1}}^{\omega_0} = 1, S_{V_T}^{\omega_0} = 0. \quad (11)$$

The sensitivities of elements are equal to unity in magnitude. Moreover, the sensitivity of temperature is equal to zero which means that the proposed APF circuits are insensitive to temperature.

2.5 Non-ideal Effects Analysis

The effects of CCII and CCTA are non-ideal as a result of tracking errors of voltage/current of CCII and CCTA. These errors changed the electrical characteristics of CCII and CCTA to (12) and (13), respectively.

$$\begin{bmatrix} I_y \\ V_x \\ I_z \end{bmatrix} \begin{bmatrix} 0 & 0 & 0 \\ 0 & \alpha & 0 \\ \gamma & 0 & 0 \end{bmatrix} \begin{bmatrix} I_x \\ V_y \\ V_z \end{bmatrix}, \quad (12)$$

and

$$\begin{bmatrix} I_y \\ V_x \\ I_z \\ I_{O1} \\ I_{O2} \end{bmatrix} \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & \alpha & 0 & 0 \\ \gamma & 0 & 0 & 0 \\ 0 & 0 & \pm\beta_1 g_{m1} & 0 \\ 0 & 0 & \pm\beta_2 g_{m2} & 0 \end{bmatrix} \begin{bmatrix} I_x \\ V_y \\ V_z \\ V_O \end{bmatrix}, \quad (13)$$

α and γ are the tracking errors of the voltage and current of CCII and CCTA, respectively, as well as β which is the tracking error of transconductance gain of CCTA. The pole frequency and the phase response of APF circuits are modified to (14) and (15), respectively.

$$\omega_0 = \frac{\gamma_1\gamma_2\alpha_2\beta_1 g_{m1}}{g_{m2}\beta_2 RC}, \quad (14)$$

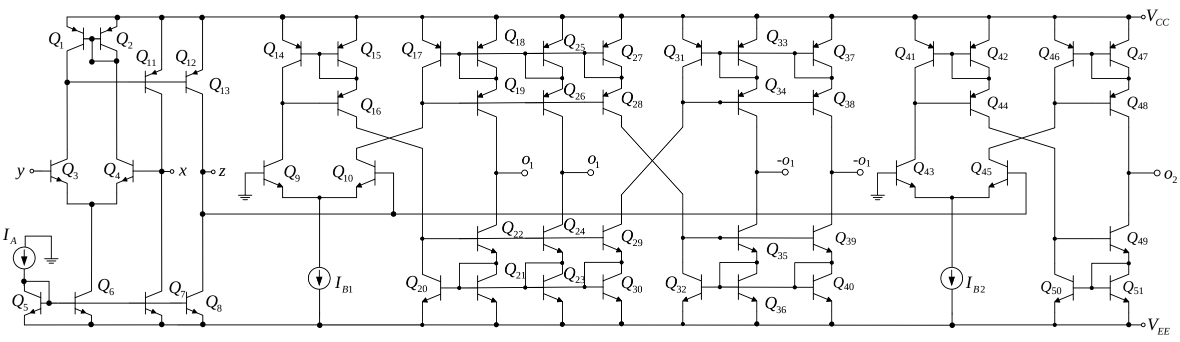
and

$$\phi = 180 - 2\tan^{-1}\frac{\beta_2 g_{m2}\omega RC}{\gamma_1\gamma_2\alpha_2\beta_1 g_{m1}}. \quad (15)$$

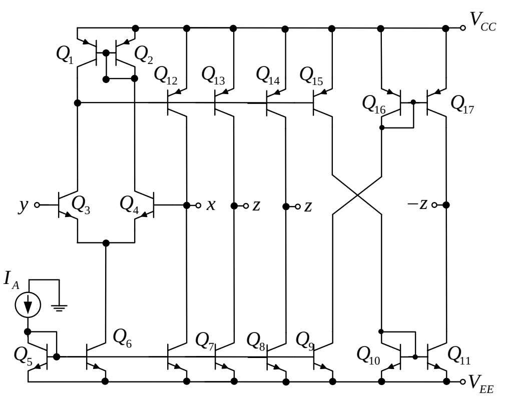
3. Computer Simulations

The APF circuit in Fig. 3 (c) was selected as an example to verify the performance of proposed APF versus using PSPICE simulations. The construction of CCTA and CCII are shown in Fig. 4. They use the transistor model parameters PR200N and NP000N which are the transistor arrays ALA400 from AT&T. The proposed APF design with $R = 1\text{k}\Omega$, $C = 1\text{nF}$, $I_{B1} = I_{B2} = 100\mu\text{A}$, $I_A = 100\mu\text{A}$, and $\pm 1.5\text{V}$ supply.

Fig. 5 shows the plotting of the simulation results of the current gain and phase responses of the proposed APF. The pole frequency is about 156.15kHz, where the calculation of the pole frequency yields 159.15kHz (error -1.88%). Fig.6 shows the electronic controllability of the proposed APF by keeping it to be constant $I_{B2} = 100\mu\text{A}$, when the phase responses for I_{B1} are $50\mu\text{A}$ $70\mu\text{A}$, $100\mu\text{A}$ and $150\mu\text{A}$, respectively. The pole frequencies with 90 degree phase shift are varied from 83.48kHz, 114.42kHz, 156.15kHz to 210.89kHz, respectively. The performance capability of the proposed APF varies according to temperature as shown for $25^\circ C$, $50^\circ C$ and $100^\circ C$ in Fig. 7. They show that the gain and phase response of the proposed APF are slightly affected by temperature which is in accord with the theory in (8) – (10).



(a)



(b)

Fig. 4 Internal construction (a) CCTA (b) CCII

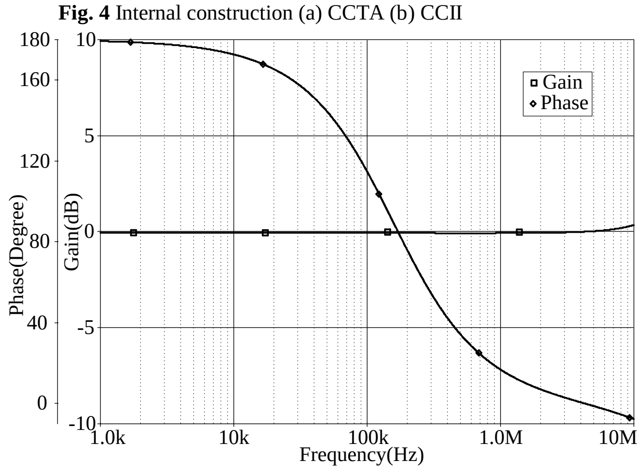


Fig. 5 Gain and phase response of proposed APF

The simulation results in the time-domain of the proposed APFs are shown in Fig. 8. A sinusoidal signal is applied as input APF with $80\mu A_{p-p}$ amplitude and 156.15kHz frequency. The phase response of the time-domain is about 87.16 degrees which is close to 90 degrees (a deviation of -3.15%). The simulation of phase responses in the time-domain are demonstrated in Fig. 9, when the bias current I_{B1} is changed from $50\mu A$, $70\mu A$, $100\mu A$ and $150\mu A$, respectively, when kept at $I_{B2} = 100\mu A$. The phase responses of the sinusoidal signals vary to 53.91, 67.80, 87.16 and 103.78 degrees, respectively.

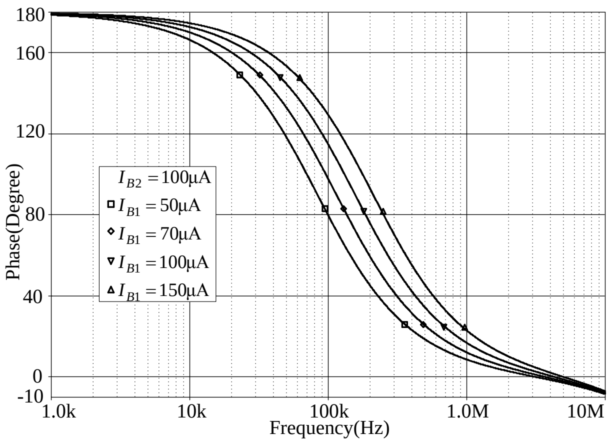


Fig. 6 Phase response variation for I_{B1}

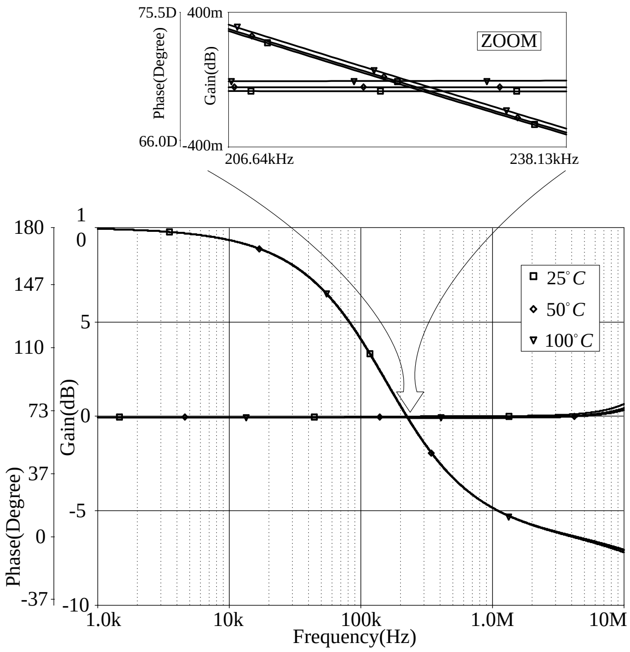


Fig. 7 Gain and phase responses of APF due to various temperatures

This confirms that the proposed APF is temperature insensitive when a sinusoidal signal is applied as input APF and adjusted to temperatures of 25, 50 and 100 degrees Celsius, respectively. The sinusoidal output deviates slightly according to the temperatures as displayed in Fig. 10. In addition, the effects of temperature changes on the efficiency of the proposed APF results in the gain and phase response errors shown in Fig. 11. They are the results of the relative errors in the gain and phase responses versus various temperatures. The current gain errors due to temperatures being at about 0.70 at 0°C and -0.47 at 100°C. The phase responses are unaltered for all temperatures.

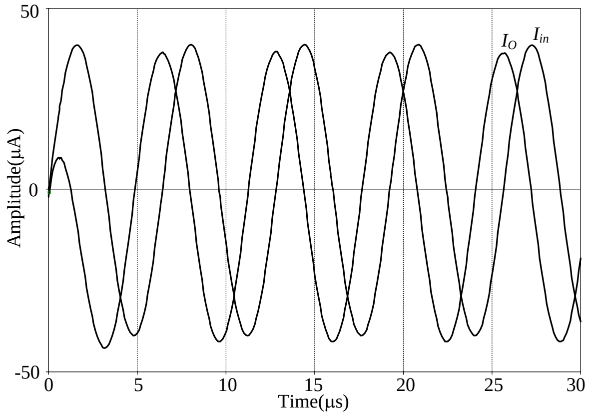


Fig. 8 The time-domain response of APF to a sinusoidal input signal

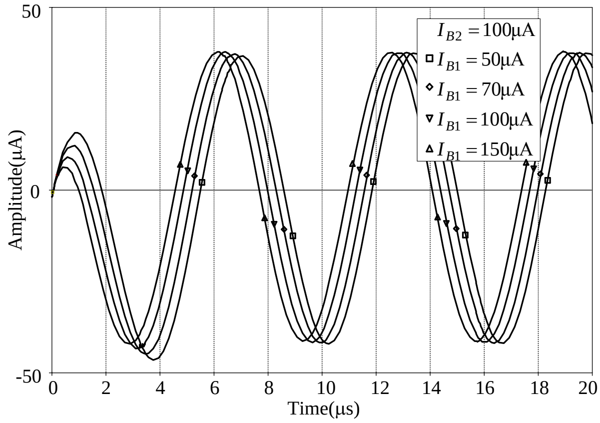


Fig. 9 Time-domain response for difference values of I_{B1}

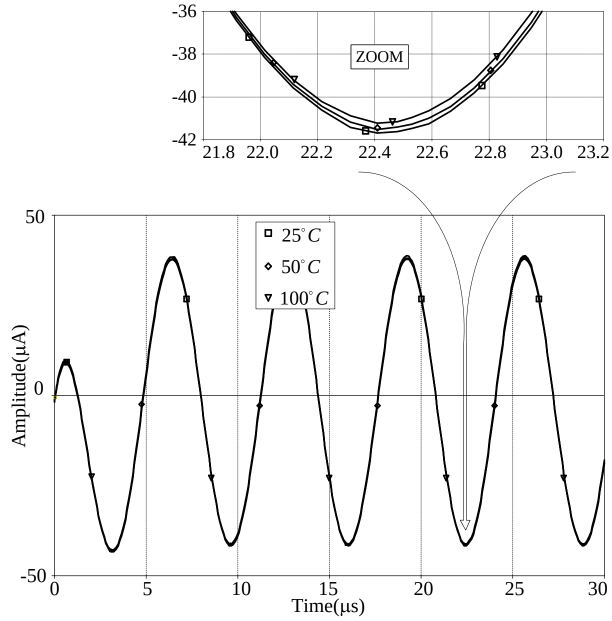


Fig. 10 Time-domain response due to various temperatures

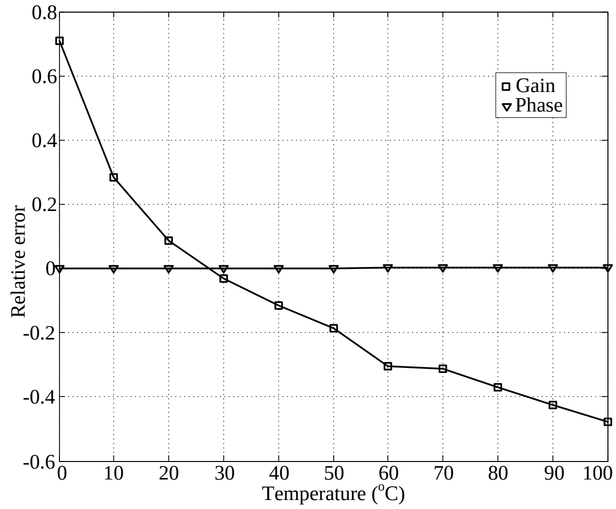


Fig. 11 Relative errors of the gain and phase responses due to various temperatures

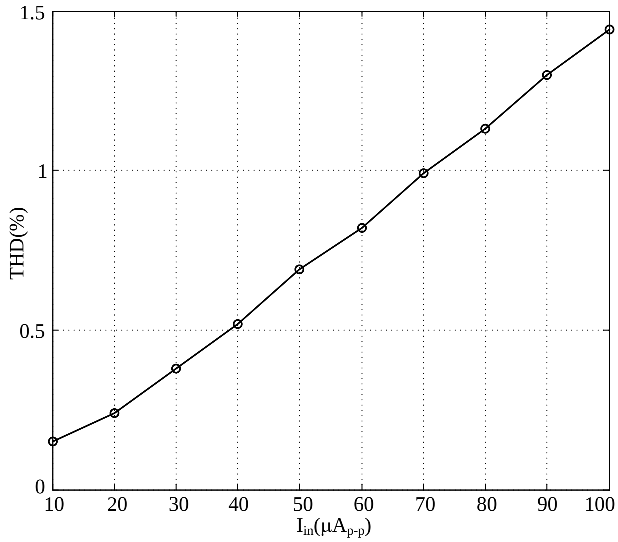


Fig. 12 The relation of %THD and amplitude of input signals

The last of the simulation results are shown in Fig. 12. They are %THD (total harmonics distortion) according to the sinusoidal output signals versus the amplitude of the sinusoidal input signals. In this case, the bias currents are set $I_{B1} = I_{B2} = 100\mu A$ and feed the sinusoidal signal with 156.15kHz frequency as input to the proposed APF. Then, the amplitude of the sinusoidal signals varies from $10\mu A_{p-p}$ to $100\mu A_{p-p}$. It is evident that the minimum and maximum %THD are 0.15% and 1.44% with the amplitudes of the sinusoidal signals at $10\mu A_{p-p}$ and $100\mu A_{p-p}$, respectively.

4. Conclusion

The three current-mode allpass filters are presented. They consist of single CCII, single CCTA, single grounded capacitor and single grounded resistor. The current-mode allpass filters have the following advantageous features: a) electronic tuning of the pole frequency and phase response via DC bias current of CCTA, b) low impedances of input and high impedances of output which is good for current-mode configuration, c) the sensitivities of the pole frequency are low, d) the operation of all APFs are the temperature high insensitive. The results obtained using the PSPICE program establishes that the performances of the proposed APFs are in very good agreement with the theoretical analysis.

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