Electronically Adjustable Voltage-mode First-order Allpass Filter Using Single Commercially Available IC

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Electronically Adjustable Voltage-mode First-order Allpass Filter Using Single Commercially Available IC

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Abstract. In this design, the use of single commercially available integrated circuit (IC), LT1228 from Linear Technology Corporation, to implement the first order allpass filter is presented. The passband voltage gain of the presented first allpass filter (APF) is unit and constant throughout the operation frequency, while the phase response is electronically tuned by changing the external DC bias current. With this property, the proposed first order filter can be used as phase shifter with microcontroller controllability. Tuning phase property is not required any matching condition. The proposed phase shifter consists of one LT1228, one capacitor and two resistors which is attractive for off the shelf implementation. Moreover, the impedance at output voltage node is exhibit low which can connect to other circuit without the requirement of external voltage buffer. The expected performances of the proposed circuit are proved by Pspice simulation using macro model parameters. Also, the quadrature sinusoidal oscillator which is designed from the connecting of the proposed filter and integrator is chosen as application example.

1. Introduction

It is well-known that analog filter is one of the important functions in analog signal processing circuits. This circuit is found in many applications for examples in communication system, power electronic systems, instrument and measurement system etc. [1]. The allpass filter is one of analog filter which has been developed and proposed continuously [2-5]. The property of allpass filter is different from the high-pass, low-pass, band-pass and band-stop filter because there is no stop-band for allpass filter. So, the allpass filter is used to pass the input signal to output signal with constant amplitude for all frequency. However, the phase of the output signal will be shifted from the phase of input signal [6].

The LT1228 is integrated circuit manufactured by Linear Technology Corporation [7]. This integrated circuit is considered as active building block (ABB) which is interesting active device for design the analog signal circuit. The LT1228 consists of two basic active blocks, operational transconductance amplifier (OTA) and current feedback amplifier (CFA). The transonductance (g_m) of LT1228 is electronically controlled via DC bias current. So, the LT1228 based circuits [8-11] are easily controlled by microcontroller which is the important requirement for modern circuit.

Several voltage-mode first order allpass filters or phase shifter circuits employing the voltage or current ABBs have been reported in the open literature [12-31]. However, these reposed first order allpass filters have at least one of the following inconveniencies:

- Contain more than one active building block [13, 18, 21].

- Lack of electronic controllability [12, 17, 23, 24, 26, 27, 28, 29, 30, 31].
- Tuning phase property requires the constraint matching condition of two active or passive elements [15, 16, 17, 25, 28, 29].
- Impedance at output voltage node doesn't exhibit low which requires the voltage buffer for cascading [15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 27, 28, 29, 30, 31].
- Need the active building block which contains multiple current output terminal [15, 16, 24, 27].
- The used active building block is not implemented from single commercially available IC [14, 15, 16, 17, 18, 19, 20, 23, 24, 26, 27, 28, 29, 30].

This paper introduces the design of voltage mode phase shifter circuit employing single LT1228 as active building block connecting with single capacitor and two resistors. The tuning of phase response is electronically adjusted with no need of the constraint matching condition of two active or passive elements. The functionalities of the presented phase shifter circuit were simulated by Pspice program.

2. Principle of Operation
In this section, the details of active building block and proposed first order allpass filter are given as follows.

2.1. LT1228
In this section, brief detail of the main active device will be described. The internal configuration of LT1228 is shown in Fig. 1. It has eight pins which is the connection of OTA and CFA. The high impedance inverting and non-inverting voltage inputs are pin 2 and 3, respectively. The high impedance current output of OTA which is connected to the non-inverting voltage input of CFA is at pin 1. The external bias current used to control the transconductance of OTA is at pin 5. The high impedance non-inverting voltage input of CFA is at pin 8. The low impedance voltage output is at pin 6. The negative and positive voltage power supplies are respectively at pin 4 and pin 7. The electrical symbol of LT1228 is illustrated in Fig. 2. The electrical property of LT1228 is characterized with the following matrix equation

$$I_Z = g_m\left(V_+ - V_-\right); V_x = V_z; V_W = I_X R_T \tag{1}$$

where R_T represents the transresistance of LT1228 and it is infinity in ideal case. The transconductance gain of LT1228 is adjusted electronically via I_B [3]

$$g_m = 10 I_B \tag{2}$$

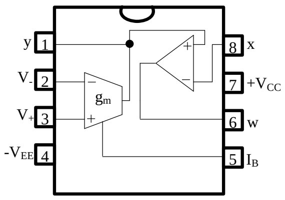

Figure 1. Pin configuration of LT1228. [7]

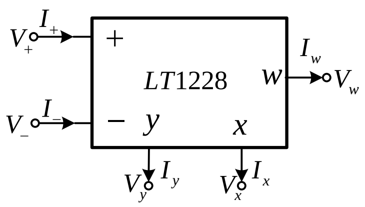

Figure 2. Symbolic of LT1228. [11].

2.2. Proposed voltage-mode first order allpass filter
Figure 3 shows the proposed circuit composed of one LT1228, one capacitor and two resistors. It is found that the voltage output is at low impedance terminal w. The voltage transfer function of the circuit in Fig. 3 is as follow:

$$T(s) = \frac{v_o}{v_i} = -\left(\frac{g_m - sC}{g_m + sC}\right) \tag{3}$$

Considering the voltage transfer function as appeared in (3), passband voltage gain, the phase response (θ) and the natural frequency (ω_0) are obtained respectively as

$$|T(s)| = 1; \theta = 180 - 2\tan^{-1}\left(\frac{\omega C}{g_m}\right) \text{ and } \omega_0 = \frac{g_m}{C} \quad (4)$$

Thus, the θ and ω_0 are electronically varied by adjusting the external DC bias current I_B. It should be noted from (4) that the phase response is shifted from 180° to 0° which is implied that the phase of the output voltage is leaded to the phase of the input voltage. Moreover, the ω_0 can be linearly controlled via I_B.

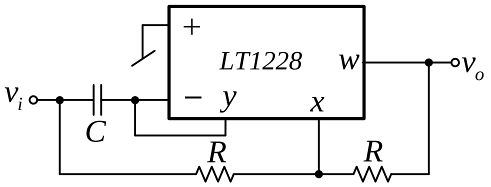

Figure 3. The proposed first order allpass filter

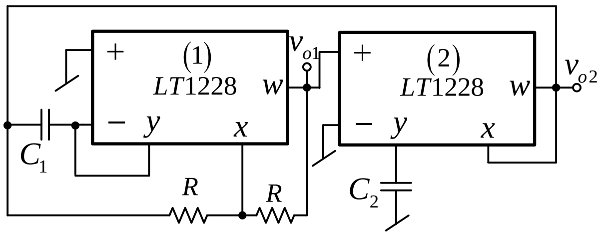

Figure 4. The quadrature oscillator based on proposed first order allpass filter.

2.3. Application example as the quadrature sinusoidal oscillator

To show the utilization of the proposed fist order filter, it is employed to design the quadrature oscillator by connecting the first order and inverting lossy integrator. The complete voltage mode quadrature sinusoidal oscillator is shown in Fig. 4. It is noted that the output voltage nodes, v_{o1} and v_{o2} are at w terminals which have low impedance. Consequently, it can be connected to other circuit or driven external load without the requirement of any external voltage buffer. Routine analysis of the circuit in Figure 4, the characteristic equation is obtained as

$$s^2C_1C_2 + sC_2g_{m1} - sC_1g_{m2} + g_{m1}g_{m2} = 0 \quad (5)$$

From (5), the frequency of oscillation (FO) and condition of oscillation (CO) can be expressed as

$$\omega_0 = \sqrt{\frac{g_{m1}g_{m2}}{C_1C_2}} \text{ and } C_2g_{m1} \le C_1g_{m2} \quad (6)$$

It is found from (6) that the FO and CO can be electronically controlled via g_{m1} or g_{m2} which is easily controlled by microcontroller. The phase relationship of v_{o1} and v_{o2} is given by

$$\frac{v_{o2}}{v_{o1}} = \frac{g_{m2}}{sC_2} \quad (7)$$

The phase difference between the output voltage v_{o1} and v_{o2} is 90° where the phase of the v_{o1} signal is leaded to the phase of the v_{o2} signal as analyzed in (7).

3. Simulation Results

First, the workability of the filter topology given in Fig. 3 was verified through PSPICE program. The DC power supply voltages, V_{CC} = -V_{EE} were equal to ±5V and external DC bias current of LT1228 employed to adjust the transconductance value was chosen as I_B = 65 μA. In this design, the values of resistors and capacitor were chosen as 1kΩ and 1nF, respectively. The simulated passband voltage gain and phase characteristic of the output voltage are shown in Fig. 5. It is evident that the passband voltage gain is unity (0dB) and constant over operational frequency while phase response is shifted from 180° to 0° which is accordance to the theoretical prediction (Eq. 4). At frequency of 100kHz, the simulated values of passband voltage gain and phase response are 0.992 and 91.52° respectively. The theoretical these values calculated from (4) at frequency of 100kHz are 1 and 91.97°, respectively. A little error deviation of 0.8% and 0.49% between the theoretical and simulation value stems from the non-ideality of LT1228 such as the voltage/current tracking errors and the parasitic elements etc.

Figure 6 shows the phase response of the output voltage where the external DC bias current I_B was changed to 35μA, 65μA and 115μA. It is evident that at frequency of 100kHz, the phase response are respectively located to 57.49°, 91.52° and 121.99°, respectively. This result confirms the theoretical expectation as analyzed in (4).

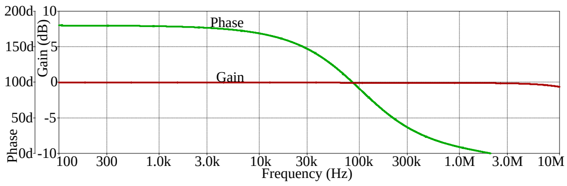

Figure 5. Simulated gain and phase response

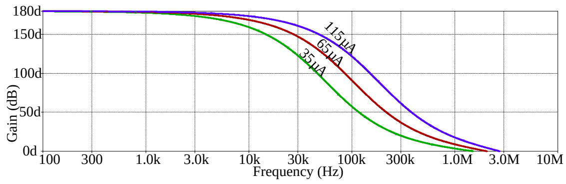

Figure 6. Phase relationship of for different I_B.

Second, the performances of the quadrature sinusoidal oscillator in Figure 4 were verified via PSpice program. The DC power supply voltages, V_{CC} = -V_{EE} were equal to ±5V and external DC bias currents of LT1228 employed to adjust the transconductance values were chosen as I_{B1} = 65 μA and I_{B2}=70μA. In this design, the values of resistors and capacitor were chosen as R=1k and C_1=C_2=1nF. The simulated sinusoidal output waveform during steady state is shown in Fig. 7. It is found that the circuit in Fig. 4 can generated the quadrature sinusoidal output waveform as analyzed in (7). The simulated output spectrum of v_{o1} and v_{o2} signals is illustrated in Fig. 8, where the FO is 100kHz. The total harmonic distortions (THD) of v_{o1} and v_{o2} signal are 1.54% and 1.31%, respectively.

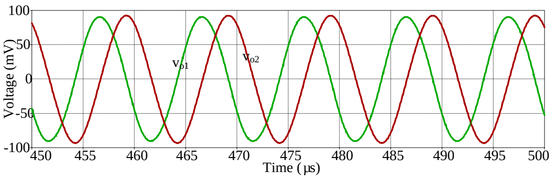

Figure 7. Simulated quadrature output waveform

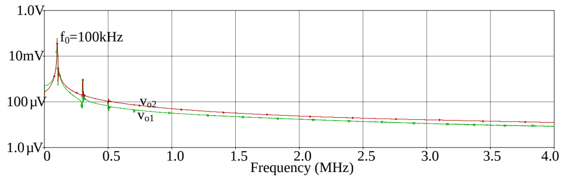

Figure 8. Output spectrum.

4. Conclusion

The single commercially available IC, LT1228 based voltage-mode first order allpass filter is designed in this paper. The advance features of the proposed circuit are electronic tunable phase response, low output impedance and minimum number of active element. Moreover, the matching condition of active or passive element is not required for tuning the phase response which is easy to design the bias current circuit by controlling with microcontroller. To show the usability of the proposed circuit, the quadrature oscillator is designed by connecting the proposed first order filter and lossless integrator. The presented circuits were verified via Pspice simulations and the results agree well with theoretical expectation.

5. References

[1] C. Psychalinos, C. Kasimis, and F. Khateb, “Multiple-input single-output universal biquad filter using single output operational transconductance amplifiers,” AEU - International Journal of Electronics and Communications, vol. 93, pp. 360-367, 2018.

[2] W. Jaikla, A. Noppakarn and S. Lawanwisut, “New gain controllable resistor-less current-mode first order allpass filter and its application,” Radioengineering, vol. 21, no. 1, pp. 312–316, 2012.

[3] A. Chaichana, M. Kumngern, M. Siripruchyanun, and W. Jaikla, "Amplitude controllable current-mode first order allpass filter including minimum component count circuits," Proceedings of 38th International Conference on Telecommunications and Signal Processing, 2015.

[4] W. Tangsrirat, “On the realization of first-order current-mode AP/HP filter,” Radioengineering, vol. 22, pp. 1007-1015, 2013.

[5] W. Tangsrirat, T. Pukkalanun, and W. Surakampontorn, “Resistorless realization of current-mode first-order allpass filter using current differencing transconductance amplifiers,” Microelectronics Journal, vol. 41, pp. 178-183, 2010.
[6] D. Biolek and V. Biolkova, “Allpass filter employing one grounded capacitor and one active element,” Electronics Letters, vol. 45, pp. 807-809, 2009.
[7] http://www.linear.com/product/LT1228
[8] S. Klungtong, D. Thanapatay, and W. Jaikla, “Three-input single-output voltage-mode multifunction filter with electronic controllability based on single commercially Available IC,” Active and Passive Electronic Components, 2017.
[9] S. Siripongdee and W. Jaikla, “Universal filter using single commercially available IC: LT1228,” Proceedings of the 3rd International Conference on Mechatronics and Mechanical Engineering, 2016.
[10] S. Siripongdee and W. Jaikla, “Electronically controllable grounded inductance simulators using single commercially available IC: LT1228,” AEU – International Journal of Electronics and Communications, vol. 76, pp. 1-10, 2017.
[11] P. Suwanjan, S. Siripongdee, and W. Jaikla, “Three-inputs single-output voltage-mode universal filter with orthogonal control using single commercially available IC,” Proceedings of the 2017 European Conference on Electrical Engineering and Computer Science (EECS), 2017, pp. 454-457.
[12] R. Nandi, K. Mathur, and S. Pattanayak, “Single-CFA first-order allpass filter,” IEICE Electronics Express, vol. 13, 2016.
[13] R. Nandi, K. Mathur, and S. Pattanayak, “Electronically tunable allpass filter: linear VCO design,” IEICE Electronics Express, vol. 13, 2016.
[14] J. Satansup, and W. Tangsrirat, “Single VDGA-base first-order allpass filter with electronically controllable passband gain,” Proceedings of the 7th International Conference on Information Technology and Electrical Engineering, ICITEE 2015, 2015, pp. 106–109.
[15] D. Prasad, K. Panwar, D.R. Bhaskar, and M. Srivastava, “CDDITA-based voltage-mode first order all pass filter configuration,” Circuits and systems, vol. 6, pp. 252–256, 2015.
[16] S. Maneewan, N. Udorn, D. Duangmalai, P. Silapan, and W. Jaikla, “A voltage-mode first order allpass filter based on VDTA,” Advances in Electrical and Electronic Engineering, vol. 12, pp. 40–46, 2014.
[17] J. W. Horng, C. M. Wu, and N. Herencsar, “Fully differential first-order allpass filters using a DDCC,” Indian Journal of Engineering and Materials Sciences, vol. 21, pp. 345-350, 2014.
[18] V. K. Dixit, R. Gupta, and K. Pal, “Novel DVCCs based voltage-mode first-order allpass section,” Proceedings of the 2014 International Conference on Signal Processing and Integrated Networks, SPIN 2014, pp. 497–501, 2014.
[19] M. Kumngern, V. Mongkol and S. Junnapiya, “Voltage-mode allpass section employing only one DDCCTA and one capacitor,” Proceedings of the Eleventh International Conference on ICT and Knowledge Engineering, pp. 1–4, 2013.
[20] S.Z. Iqbal, C. Psychalinos and N. Parveen, “First-order allpass filter using multi-input OTA,” International Journal of Electronics, vol. 100, no. 10, pp. 1373-1382, 2013.
[21] M. Kumngern, “Realization of electronically tunable first-order allpass filter using single-ended OTAs,” Proceedings of the IEEE Symposium on Industrial Electronics and Applications, ISIEA 2012, vol. 12, pp. 100–103, 2012.
[22] M. Kumngern, and J. Chanwutitum, “Voltage-mode first-order allpass filter using single-ended OTAs and grounded capacitor,” Proceedings of the Second International Conference on Digital Information and Communication Technology and its Applications, DICTAP 2012, pp. 305–308, 2012.
[23] H. Chen, S. Wang and K. Huang , “Grounded-capacitor first-order filter employing single DVCC,” Proceedings of the IEEE 3th International Conference on Communication Software and Networks, vol. 11, pp. 401–404, 2011.

[24] J. W. Horng, “High input impedance first-order allpass, highpass and lowpass filters with grounded capacitor using single DVCC,” Indian Journal of Engineering and Materials Sciences, vol. 17, pp. 175-178, 2010.

[25] C. Tanaphatsiri, W. Jaikla, and M. Siripruchyanun, “An electronically controllable voltage-mode first-order all-pass filter using only single CCCDTA,” Proceedings of the International Symposium on Communications and Information Technologies, vol. 8, pp. 305–309, 2008.

[26] J.W. Horng, C.L. Hou, C.M. Chang, Y.T. Lin, I.C. Shiu and W.Y. Chiu, “First-order allpass filter and sinusoidal oscillators using DDCCs,” International Journal of Electronics, vol. 93, no. 7, pp. 457–466, 2006.

[27] M. A. Ibrahim, S. Minaei, and H. Kuntman, “DVCC based differential-mode all-pass and notch filters with high CMRR,” International Journal of Electronics, vol. 93, pp. 231-240, 2006.

[28] B. Metin and O. Cicekoglu, “Novel cascadable allpass filter with a grounded capacitor,” Proceedings of the 49th IEEE International Midwest Symposium on Circuits and Systems, pp. 242–244, 2006.

[29] K. Pal and S. Rana, “Some new first-order all-pass realizations using CCII,” Active and Passive Electronic Components, vol. 27, pp. 91-94, 2004.

[30] M. A. Ibrahim, H. Kuntman, and O. Cicekoglu, “First-order all-pass filter canonical in the number of resistors and capacitors employing a single DDCC,” Circuits Systems and Signal Processing, vol. 22, pp. 525-536, 2003.

[31] O. Çi çekoğlu, H. Kuntman, and S. Berk, “All-pass filters using a single current conveyor,” International Journal of Electronics, vol. 86, pp. 947-955, 1999.S. Siripongdee and W. Jaikla, “Universal filter using single commercially available IC: LT1228,” Proceedings of the 3rd International Conference on Mechatronics and Mechanical Engineering, 2016.

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