Proceedings of the International MultiConference of Engineers and Computer Scientists 2017 Vol I,
IMECS 2017, March 15 - 17, 2017, Hong Kong

PIDA Controller Realized on Commercial IC Current Feedback Operational Amplifiers

S. Buakaew, W. Narksarp, C. Wongtaychatham, and W. Sangpisit

***Abstract*— In this paper, the circuit-realization of the proportional – integral – derivative – acceleration (PIDA) controller is presented. The circuit is realized with commercially available active components i.e. only four current feedback operational amplifiers (CFOAs) along with passive R and C components. The parameters of the PIDA controller including the proportional gain, the integral time, the derivative time and acceleration gain can be easily adjusted via these resistors and/or capacitors. The proposed PIDA controller offers simple structure with a small number of active elements to be used. The computer simulations results utilizing commercial IC AD844 are demonstrated to confirm the validity of the proposed PIDA controllers.**

***Index Terms*— PID Controller, PIDA controller, current feedback operational amplifier (CFOA), commercial IC**

I. Introduction

A proportional –integral – derivative controller (PID) is a classic scheme and widely used in the process control industry for its general applicability and performance satisfaction to most control systems. As a brief recall of controller tuning, the P termed for proportional, I for integral and D for derivative are adjusted in order to meet given performance specifications of the speed of response, system stability and steady state error, respectively. Various design techniques to obtain the controller have been developed. Electronic types of PID controllers employ active building blocks i.e., operational amplifier, current conveyor CDBAs and CCCDBAs were successively proposed [2]-[4]. Nevertheless, it is known that a PID controller is essentially implemented for the typical first and second-order plants [5]. In the third and higher -order systems such as the ac motor system for motion control, it is quite difficult to achieve acceptable transient and steady state performance utilizing only a PID controller. This is the result of the number of zeros of the PID controller being less than the order of the plant [5].

Manuscript received December 22, 2016; revised January 10, 2017. This work was supported in part by King Mongkut's Institute of Technology Ladkrabang and Siam University.

S. Buakaew is with the Department of Electronics Engineering, Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand, 10520 (e-mail:seangrawee46@gmail.com).

W. Narksarp was with the Department of Electrical Engineering, Siam University, 38 Petkasem Rd., Phasicharoen Bangkok, Thailand, 10160 (corresponding author to provide e-mail:wipavan.nar@siam.edu).

C. Wongtaychatham is with Department of Electronics, Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand, 10520.

W. Sangpisit was with Department of Telecommunications Engineering, Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand, 10520.

However, this limitation can be overcome by adding one more zero to the conventional PID resulting in the so-called PIDA controller (Proportional Integral Derivative Acceleration). The PIDA controller leads to faster and smoother responses as compared with those from the PID controller [5]. Some methodologies to design PIDA controllers are reported [9]-[10]. Few circuit designs of PIDA controllers are currently presented. One report of PIDA controller as such has been published [7]. The algorithm is similar to that of PID presented in [4]. The circuit realization relies on quite a number of both operational transconductances as the main active elements together with passive components. So far as thoroughly literature reviewing, it is believed that still there is plenty of room for research development of practical circuitry to implement PIDA controllers.

The Current feedback operational amplifiers (CFOAs) have received a great deal of attention in analog circuit design for both current as well as voltage mode. A few manufactures make CFAOs commercially available via bipolar and CMOS technology. The CFOAs are well known for their superior performance in high speed and high slew rate as well as low distortion [11]. As a result, they are suitable for RF and IF circuit implementation for communication systems. Various practical circuit applications, including the PID controller [8], are made possible with CFOAs in place of the traditional operational amplifier. The same limitation mentioned in [5] exists when used for controlling high order plant.

The main purpose of this paper is to present a new PIDA controller. The proposed PIDA controller is realized from only four commercial current feedback operational amplifiers (CFOAs) and some passive components. The circuit exhibits several attractive features. The circuit configuration yields simplicity. The numbers of active elements are significantly reduced when compared with the existing PIDA controller [7]. All passive components are connected to either actual or virtual ground. In addition, the introduced PIDA do not request passive component matching requirement. Last but not least, the parameters of the proposed PIDA controller can be arbitrarily chosen. Finally, computer simulations in order to examine the performance of the developed PIDA controller exhibit satisfactory.

II. CFOA-Based PIDA Controller

Generally, the transfer function of a PIDA controller can be written as follows

$$T(s)=\frac{V_{out}(s)}{V_{in}(s)}=K_P+\frac{K_1}{s}+\frac{K_D s}{s+d}+\frac{K_A s^2}{(s+d)(s+e)}$$
$$=K\frac{(s+a)(s+b)(s+z)}{s(s+d)(s+e)} \quad \ldots..(1)$$

Where the terms $-a,-b,-z$ and $-d,-e$ are, respectively, the zeros and poles of transfer function. Provided that $a,b,z<<d,e$, then $(s+d)$ and $(s+e)$ become non-dominant terms resulting in the following expression for the PIDA controller

$$T(s)=\frac{V_{out}(s)}{V_{in}(s)}=K_P+\frac{K_1}{s}+K_D s+K_A s^2$$
$$=K_P+\frac{1}{T_I s}+T_D s+K_A s^2 \quad (2)$$

Where K_P, T_I, T_D and K_A are, respectively, the proportional gain, the integral time constant, the derivative time constant and the acceleration gain.

The category of the integrated circuit device widely-known as the current feedback operational amplifiers (CFOAs) is to be used for implementing the above PIDA controller. The symbol of the CFOA is shown in Fig. 1.

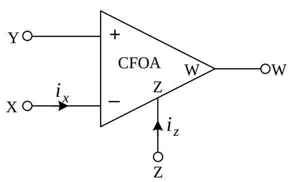

Fig.1. Circuit symbol of the CFOA

the CFOA possesses the input/output relationship described by the following matrix equation:

$$\begin{bmatrix}V_x\\ I_y\\ I_Z\\ V_O\end{bmatrix}=\begin{bmatrix}0&1&0&0\\0&0&0&0\\1&0&0&0\\0&0&1&0\end{bmatrix}\begin{bmatrix}I_x\\ V_y\\ V_Z\\ I_O\end{bmatrix} \quad (3)$$

With the CFOAs used as the basis for active components, a novel PIDA controller is proposed and depicted in Fig. 2.

Coopering with the input/output relationship as given in (3), then routine analysis at node v_a yields the following transfer function

$$\frac{V_a(s)}{V_{in}(s)}=-\frac{C_1C_2R_1R_2s^2+(C_2R_2+C_1R_1)s+1}{C_2R_1s} \quad (4)$$

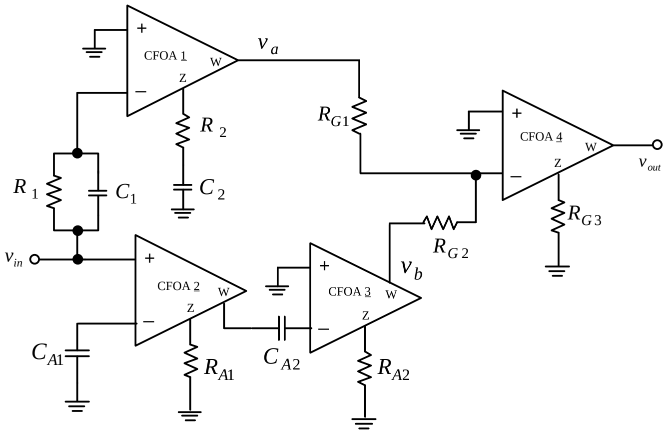

Fig.2. The proposed PIDA controller circuit

Meanwhile, the transfer function at node v_b can be analyzed and expressed as

$$\frac{V_b(s)}{V_{in}(s)}=-C_{A1}C_{A2}R_{A1}R_{A2}s^2 \quad (5)$$

Further analysis gives the input/output relationship of the proposed PIDA controller as written in the following equation

$$\frac{V_{out}(s)}{V_{in}(s)}=\frac{R_{G3}}{R_{G1}}\left(C_1R_2s+\frac{(C_2R_2+C_1R_1)}{C_2R_1}+\frac{1}{C_2R_1s}\right)+\left(C_{A1}C_{A2}R_{A1}R_{A2}s^2\right) \quad (6)$$

Equating the controller transfer function (2) with that given in (6) leads to the following system parameters

$$K_P=\frac{R_{G3}}{R_{G1}}\left(\frac{C_2R_2+C_1R_1}{C_2R_1}\right) \quad (7a)$$

$$T_I=\frac{R_{G1}C_2R_1}{R_{G3}} \quad (7b)$$

$$T_D=\frac{R_{G3}}{R_{G1}}\left(C_1R_2\right) \quad (7c)$$

$$K_A=\frac{R_{G3}}{R_{G2}}\left(C_{A1}C_{A2}R_{A1}R_{A2}\right) \quad (7d)$$

Remarkably, the proposed PIDA controller circuit in Fig.2 features tunability for all the related parameters via the system passive components. Tuning the derivative time constant (T_D) and the integral time constant (T_I) is possible through, respectively, R_1 and R_2 with capacitor being some fixed values. In the meantime, the proportional gain K_P can be adjusted via R_{G3} and/or R_{G1}. In addition, the acceleration gain (K_A) can be tuned independently by varying the value of R_{A1} or R_{A2}.

The sensitivities of the parameters of the proposed PIDA controller with respect to passive elements are no greater than unity in magnitude, which are acceptably small.

III. Simulation Results

In order to confirm the theoretical validity of the proposed PIDA controller, the PIDA controller circuit in Fig. 2 is simulated using the PSPICE simulation program. The commercially available AD844 [12], an integrated circuit device belonging to the widely-known category of the CFOAs, is used as the active elements in this simulation. The voltage supplies of the AD844 is equal to $V_{DD} = -V_{SS} = 10$ V. The passive component values are chosen as $R_1 = R_2 = 10$ kΩ and $C_1 = C_2 = 1$nF. The frequency response of the absolute voltage at node v_a obtained by PSPICE simulation of the proposed circuit and the ideal case are shown in Fig. 3. It can be seen that, in the range of 100 Hz- 1 MHz, the frequency response of the proposed circuit agrees perfectly well with the ideal frequency response. Notably, it exhibits the frequency response of the PID controller.

The frequency response at node output of the proposed PIDA controller can be illustrated in Fig.4. The passive components are chosen as $R_{G1} = R_{G2} = R_{G3} = 1$ kΩ, $R_{A1} = R_{A2} = 10$ kΩ, $C_{A1} = C_{A2} = 1$ nF, $R_1 = R_2 = 10$kΩ and $C_1 = C_2 = 1$nF. Obviously, the simulation result matches up to the theoretical one over the wide frequency range from 100Hz to 1MHz.

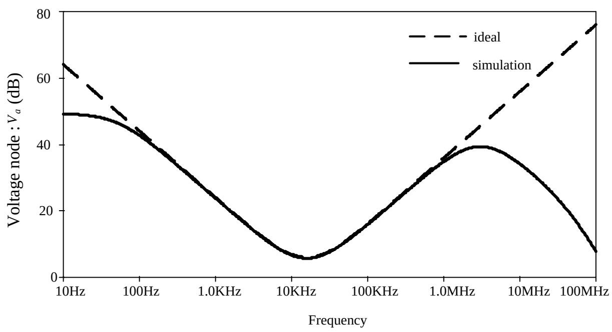

Fig.3. Frequency response of the proposed PIDA controller taken at the absolute voltage node v_a

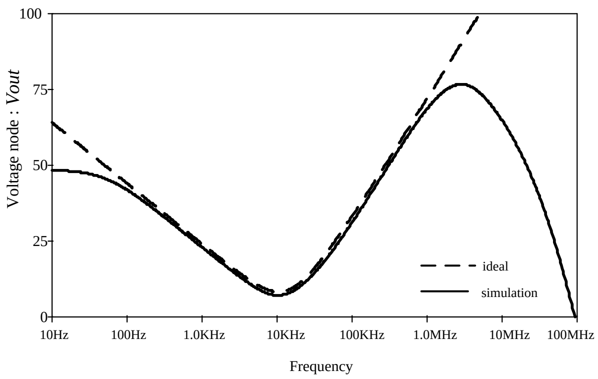

Fig.4. Frequency response of the proposed PIDA controller at the output node v_{out}

The next simulation is to demonstrate the time domain performance of the proposed PIDA controller. The controller parameters are designed to have the following values: $K_p = 3.5$, $T_I = 1\times10^{-4}$ s, $T_D = 5\times10^{-4}$ s, $K_A = 2.5\times10^{-9}$. The passive components are then selected as follows: $R_{G1} = R_{G2} = R_{G3} = 1$ kΩ, $R_{A1} = R_{A2} = 10$ kΩ, $C_{A1} = C_{A2} = 5$ nF, $R_1 = 2$ kΩ $R_2 = 5$ kΩ and $C_1 = C_2 = 100$ nF. The time domain response, excited by a ramp input signal of amplitude 0 -100 mV, is shown in Fig.5. The time domain response of the output of the proposed PIDA controller is represented by the solid line. Whereas the negative output voltage at node v_a is represented by the dashed line. It can be seen that the output signal of the proposed PIDA controller have a faster time response than the PID controller response.

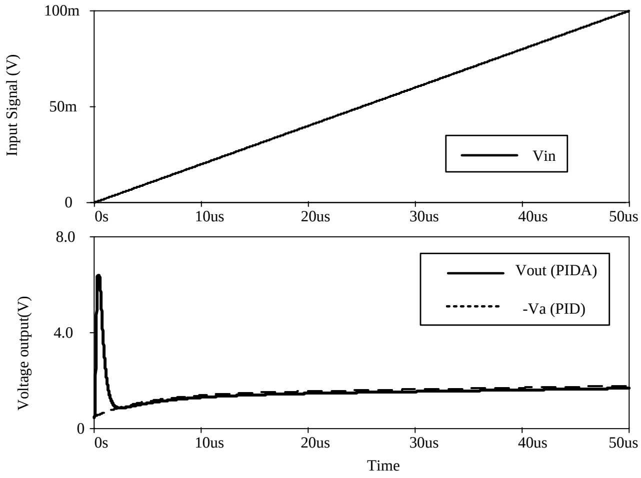

Fig.5. The output response in time domain of the proposed PIDA controller when input is ramp signal

Fig.6 shows the time domain responses of the proposed PIDA controller when the acceleration gain parameter K_A is varied. Three cases for $K_A = 1\times10^{-10}$, 4×10^{-10} and 2.5×10^{-9}, are studied. All three cases utilize $R_{G1} = R_{G2} = R_{G3} = 1$ kΩ, $R_{A1} = R_{A2} = 10$ kΩ, $R_1 = R_2 = 10$kΩ and $C_1 = C_2 = 1$nF. For the case $K_A = 1\times10^{-10}$, selecting $C_{A1} = C_{A2} = 1$ nF. For $K_A = 4\times10^{-10}$, selecting $C_{A1} = C_{A2} = 2$ nF and for $K_A = 2.5\times10^{-9}$ selecting $C_{A1} = C_{A2} = 5$ nF.

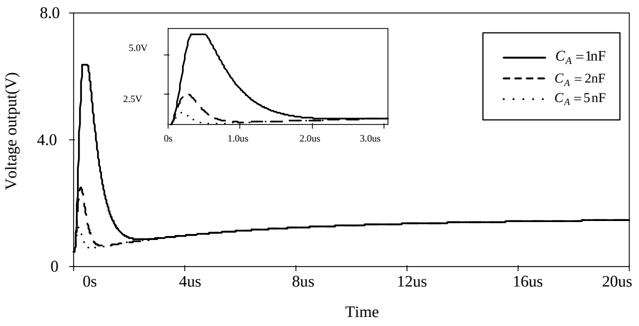

Fig.6. The time domain responses of the proposed PIDA controller with different acceleration gains

The simulation results affirm that the speed of time domain responses can be obtained in hand. Also the percentage of overshoot can be reduced by selecting the large acceleration gain.

Fig.7 shows the effect of different proportional gain K_P. In this simulation, the parameters K_P of the PIDA controller are varied via the resistance R_2. Three cases are studied. The cases K_P = 1.4, 2, and 2.4 are made possible through R_2 = 2kΩ, 5kΩ, and 7kΩ, respectively, while the other parameters are kept the same as those of the previous simulation. Again the ramp signal with amplitude increasing from 0 mV to 100 mV is inserted as the input to the system. It can be seen that the steady state response can be controlled through the proportional gain K_P.

In addition, the simulation results in Fig.8 shows time domain responses of the proposed PIDA when the integral time constant T_I are varied via R_1. With the parameters selected as $R_{G1} = R_{G2} = R_{G3} = 1$ kΩ, $R_{A1} = R_{A2}$ =10 kΩ, $C_{A1} = C_{A2}$ =5 nF, R_2 = 10kΩ, and $C_1 = C_2$ =100nF, three cases are studied for different integral time constant. The cases $T_I = 5\times10^{-5}$, $T_I = 1\times10^{-6}$,and $T_I = 2\times10^{-6}$ are made possible by picking R_1 = 0.5kΩ, 1kΩ and 2kΩ, respectively.

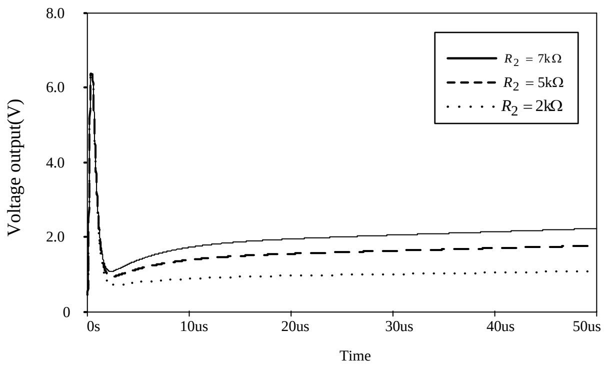

Fig.7. The time domain responses of the proposed PIDA controller with different proportional gain.

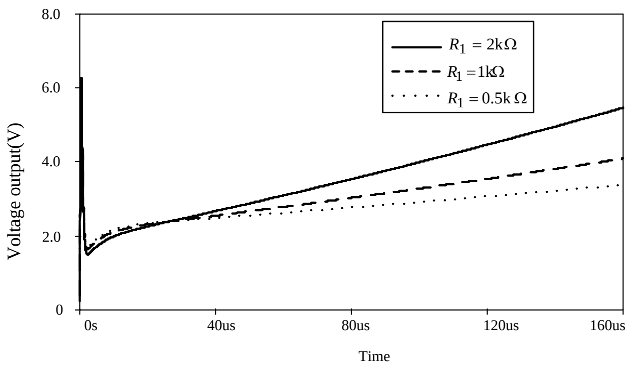

Fig.8. The time domain responses of the proposed PIDA controller with different integral time constant.

IV. CONCLUSION

In this paper, a circuit configuration for realizing the PIDA controller has been presented. The attractive feature of the circuitry is that the proposed PIDA controller can be realized by a small number of only four commercial CFOAs. Furthermore, the proposed PIDA controller also offers simple structure with adjustability for the system performance. The results of computer simulation show that the proposed PIDA controller agrees well with the theoretical predication.

REFERENCES

[1] K. J. Astrom and T. Haggulund, "The future of PID control ," Control Eng. Practice, vol.9, 2001.

[2] A.U. Keskin, " Design of a PID controller circuit employing CDBAs," International Journal of Electrical Engineering Education, vol. 43, pp.48-56, 2006.

[3] S. Srisakutiew and M. Siripruchyanun, "A synthesis of electronically controllable current – mode PI, PD and PID controllers employing CCCDBAs," Circuits and Systems, vol.4, pp.287-292, 2013.

[4] V. Silaruam, A. Lorsawatsiri and C. Wongtaychatham, "Novel Resistorless mixed-mode PID controller with Improved low-frequency performance," Radioengineering Journal, vol.22, pp.932-940, 2013.

[5] S. Jung and R. C. Dorf, "Analytic PIDA controller design technique for a third order system," Proceedings of 35th IEEE conference on decision and control, Kobe, Japan, pp. 2513-2518, 1996.

[6] D.Y. Ha, I.Y. Lee, and et.al, "The design of PIDA controller with pre-compensator," Proceedings of the IEEE international symposium ISIE, Pusan, Korea, pp.798-804, 2001.

[7] I. Chaisayun and S. Pianprantong "A mixed-mode PIDA controller employing OTAs" The 3rd International Conference on Technical Education, Bangkok, Thailand, pp.59-64, 2015

[8] M. Sagbas; M. Koksal; U. E. Ayten, "Design of dominantly proportional PID controller using a single commercially available active component,'' The 36th international conference on telecommunication and signal processing, Rome, Italy, pp.427-430, 2013.

[9] S. Sornmuang and S. Sujitjorn, "GA-Based PIDA Control Design. 10th WSEAS International Conference on System Theory and Scientific Computation (ISTASC'10)," 2010. pp.192-197.

[10] P. Ukakimaparn, P. Pannil, and P. Boonchuay, "PIDA Controller Designed by Kitti's Method," ICROS-SICE International Joint Conference, Fukuoka International Congress Center, Japan, 2009, pp 18-21.

[11] J A. Svoboda, L. McGory and S. Webb, "Applications of a commercially available current conveyor," Int. J. Eletron, vol.70, pp.159-164, 1991.

[12] Analog Devices, "Linear products data book," Norwood, Ma, 1990.

ISBN: 978-988-14047-3-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)