Oscillation Controlled Electronic Systems Design Using Posicast-Based Pulse Pre-Shaping

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Abstract*— In this paper, a novel method is proposed to make electronic systems instability safe using pulse pre-shaping techniques. The under test target systems in this work are the electronic systems that experience pulse like inputs. This method reduces the overshoot of the system's response and improves the settling time significantly using Posicast-based input command shaping. The method is applied on three types of systems which have oscillation and overshoot in their step response. Simulation results are shown to verify the effectiveness of the proposed method on oscillation and overshoot canceling. Experimental results of HSPICE simulations show that the overshoot of discussed systems is decreased more than 95% and in some cases is canceled completely that leads to increase of phase margin and complete stability of system. Also, the settling time is improved more than 78% for each three systems. Besides, the effects of pre-shaped Posicast pulse non-idealities like variations and jitters on systems response are completely simulated. The effective non-ideal factors on Posicast response are: variation in time of applying Posicast command (jitter noise) and voltage level of Posicast command.

Keywords- Second-order systems; Overshoot; Posicast; Pre-shaping, Stability; CMOS op-amp; Step response.

I. INTRODUCTION

The control systems specifications could be measured by some determined input signals called "standard test input signals". This concept helps the designers to realize the system under test's specifications and allows the designer to compare several control systems easily. Generally, the standard performances of a system are measured by applying step signal to system's input. The measured parameters from system's output are rise time, peak time, settling time, and overshoot [1].

The overshoot and its relevant factors are the main parameters that affect directly the stability of a system. The desired system for designers is that the output reaches to final value without any oscillation.

Posicast was originally proposed by O. J. M. Smith to cancel the oscillatory behavior of lightly damped systems [2]. One of the earliest textbook descriptions of Posicast is found in [3]. Posicast reshapes the step input command into two parts. The first part is a scaled step that causes the first peak of the oscillatory response to precisely meet the desired final value. The second part of the reshaped input is scaled and time-delayed to precisely cancel the remaining oscillatory response, thus causing the system output to stay at the desired value [4].

Posicast-based input pre-shaping is used widely on control systems. Some of these applications are as follows: A Posicast-based control method is presented for both buck and boost converters in [5]. An integral compensator with a single gain K is used with the Posicast element to ensure the proper steady-state response. In contrast to the PID controller, the proposed method only needs to tune the gain K, and the compensated system has improved gain margin and phase margin. In [6] a three step modulation signal shaping compensator is designed and proposed to improve the LC resonant damping in a PWM CSR system. Using Posicast-based controller in DC-DC converters to eliminate the overshoot on their step response is presented in [7]. Compared to classical PID control, the new control results in lower noise in the control signal because the controller has a lower gain in high frequency. Some other applications of Posicast are presented in [8]-[11].

Two main concepts of control systems are speed and stability that can be determined in time-domain by settling time and the overshoot percent, respectively. In frequency-domain, phase margin is used to determine system stability which has reversed relation with the overshoot percent in time-domain as in Figure1.

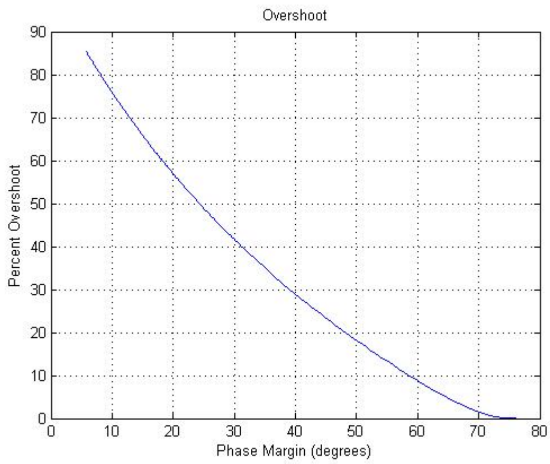


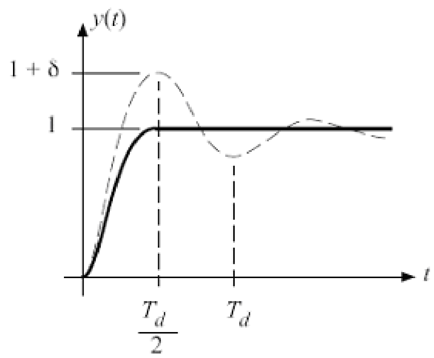
Figure 1. Overshoot vs. Phase margin

Our target systems for applying Posicast are all second-order systems and a wide range of analog integrated systems which are operating with pulses as their input like Op-Amp comparators and Digital-Analog Converters. So, the systems stability is measured and compared before and after applying Posicast in terms of overshoot and settling time of systems response. The proposed method is applied on a typical second-order system, a two-stage op-amp, and a three-stage op-amp. The experimental results show that using this method reduces the overshoot significantly and this leads to an increased stability. Besides, because of decreasing the system's settling time, the system will be faster. To shape the input pulse to Posicast pulse, a CMOS pre-shaper is designed and implemented in our other work [12]. This pre-shaper can generate Posicast pulses as sharp as the simulation's pulses.

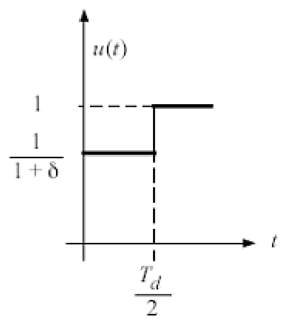
This paper is organized in the following manner: Section 2 is about specifications of control systems and u(t)-based system characterization. In this section the effective factors on system stability are introduced, too. Classical Posicast is described in section 3. In section 4 the application of proposed Posicast-based method on electronic systems is described. The effects of non-idealities of pre-shaped pulse on system response are presented in section 5. Section 6 includes the conclusion of the paper.

II. POSICAST, THEORY AND CONCEPTS

Consider a system having a lightly damped step response as shown in Figure 2(a)-dashed.



(a) System output (dashed is uncompensated)



(b) Posicast command

Figure 2. (a) Step response (dashed), Posicast response (solid)
(b) Posicast command [4]

The overshoot in the response can be described by two parameters. First, the time to the first peak is one half the under-damped response period T_d. Second, the peak value is described by $1+\delta$ where δ is the normalized overshoot, which ranges from zero to one.

Posicast splits the original step input command into two parts, as illustrated in Figure 2(b). The first part is a scaled step that causes the first peak of the oscillatory response to precisely meet the desired final value. The second part of the reshaped input is full scale and time-delayed to precisely cancel the remaining oscillatory response, thus causing the system output to stay at the desired value. Such is the idea behind "half-cycle Posicast," which can be modeled using just the two parameters δ and T_d. The resulting system output is shown in Figure 2(a)-solid [4].

III. USING POSICAST IN ELECTRONIC SYSTEMS

In this section, at first, the proposed method is applied on a typical second-order system and simulated by MATLAB to present the authors claim clearly.

Then two operational amplifiers (two and three stages) with oscillation and overshoot on their step response are discussed. The results which obtained from HSPICE simulations show the effectiveness of Posicast input on oscillation canceling.

A. A typical second-order system

Assume a second-order system with transfer function as:

$$Y(s)=\frac{\omega_n^2}{s^2+2\zeta\omega_n s+\omega_n^2}=\frac{4}{s^2+0.8s+4} \qquad (8)$$

The step response of the system is shown in Figure 3(Dotted). The system has an oscillation with 50% overshoot and the settling time is 9.7s. Regarding the Posicast theory, the δ and $T_d/2$ parameters are 0.50 and 1.6s respectively. So, the first level of Posicast input signal should be

$$\frac{1}{1+\delta}=\frac{1}{1+0.5}\approx 0.66 \qquad (9)$$

and the time of applying the second level of Posicast input signal should be $T_d/2=1.6s$ after the first level.

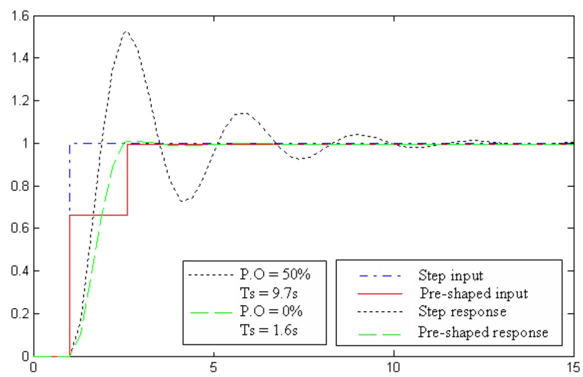


Figure 3. Step response and Posicast response of second-order system

Applying of such a signal and the result is presented in Figure 3. As shown, the overshoot completely is canceled and the settling time is decreased from 9.7s to 1.6s by applying Posicast input.

B. A two-stage operational amplifier

The schematic of a two-stage operational amplifier [13] is shown in Figure 5. The simulation result of step response of this op-amp (Figure 6-Dotted) shows an oscillation with 23% overshoot and 286ns settling time. The calculated parameters of Posicast command for oscillation canceling are as follows:

The first voltage level: 0.82v

The second voltage level: 1.00v

The second level applying time: 63ns after first level

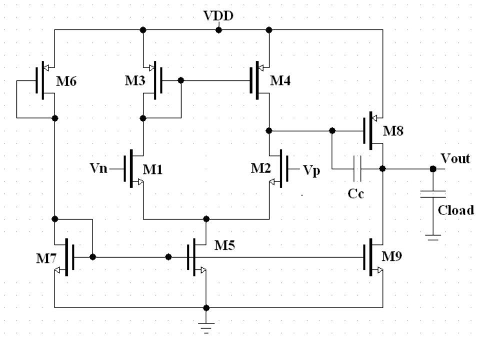


Figure 5. The schematic of two-stage op-amp [13]

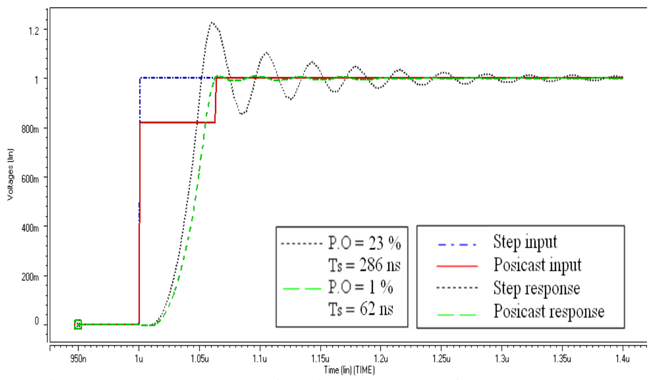


Figure 6. Step response and Posicast response of two-stage op-amp

The result of applying a command with nominated specifications to the two-stage op-amp (Figure 5) is shown in Figure 6.

Using Posicast command (Figure 6-Solid) is caused a significant improvement in system response (Figure 6-Dashed). The overshoot is decreased from 23% to 1% (completely canceled) and settling time is reached from 286ns to 60ns (more than 4 times improvement).

C. A three stage operational amplifier

As another example, the Posicast input is applied on a three stage op-amp [14] that is shown in Figure 7. The step response of op-amp (Figure 8-Dotted) have 39% overshoot and the settling time is 52ns. The δ and $T_d/2$ parameters for this system are 0.39 and 8ns, respectively. So, the first level of Posicast input should be has 71% of final amplitude and the time of applying second level is calculated about 8ns to have maximum oscillation canceling.

As shown in Figure 8, by applying an input with mentioned specifications, Posicast response of op-amp has 1% overshoot and the settling time is reached to 8ns.

One can see that in this situation, besides the almost complete overshoot cancellation, there is a more than six times improvement in the system's settling time in comparison with the step response results.

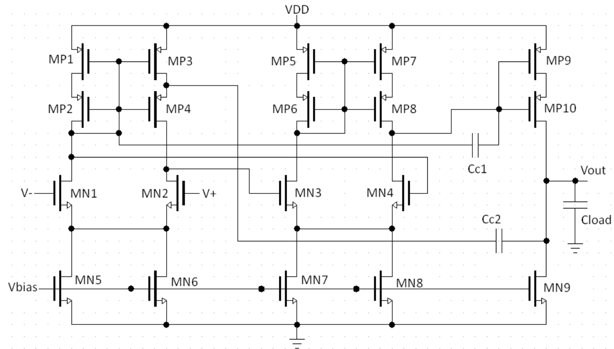


Figure 7. The schematic of a tree stage op-amp [14]

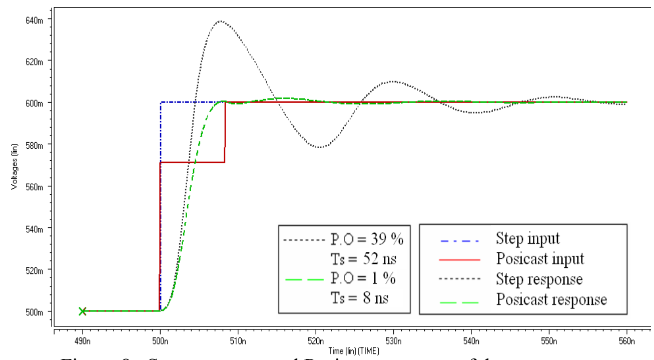


Figure 8. Step response and Posicast response of three stage op-amp

D. Quantitative evaluation of results

The results of applying Posicast on each three systems are shown in Table 1. The results show that the overshoot and settling time of systems are improved significantly. In all tables, P.O. is Percent Overshoot and Ts is Settling time.

Table 1. Percent of improvements

Systems	P.O. improvement	Ts improvement
Second-order Sys.	100 %	83 %
2-stage Op-amp	95 %	78 %
3-stage Op-amp	97 %	84 %

IV. EFFECT OF NON-IDEALITIES

In using of Posicast, the desired response will be achievable if the Posicast command be an ideal command with sharp edges and without any delay and variation. But, existence of non-ideal factors in design and implementation will non-ideality in Posicast command.

In this section, two important non-ideal factors on Posicast response are simulated for three mentioned systems. These non-idealities are variation in the amplitude of the first level of Posicast command and variation in the applying time of the second level of Posicast command. Also, the system's sensitivity curves to mentioned variations are plotted.

A. Variation in the amplitude of the first level of Posicast command

In this part, the effect of variation of the first level of Posicast command on system response is studied. For each system, the system response for step input, Posicast input, and non-ideal Posicast input with deviation from the calculated value of the first level of Posicast command are simulated. The deviations are assigned in values of 4 and 10 percents of the final value of step response.

The results (Table 2) show that the amplitude of the first level of Posicast command is an effective factor on Posicast response. Any deviation from set point for the first level of Posicast command will increase the system's oscillation. But, as presented in Table 2, even a large deviation like 10% gives us a better response in comparison with step response.

Table 2. Systems response to inputs with non-idealities on the first level of Posicast command

		Input	P.O.	Imp*	Ts	Imp
Second-order Sys.		Step	50	-	9.7s	-
	Posicast**	-10 %	7	86%	5.4s	44%
		-4 %	2	96%	3.1s	68%
		0 %	0	100%	1.6s	83%
		+4 %	7	86%	3.9s	59%
		+10 %	16	68%	6.9s	28%
		Average	6.4	87.2%	4.2s	56.4%
2-stage Opamp		Step	23	-	286ns	-
	Posicast	-10 %	17	26%	266ns	6%
		-4 %	5	78%	184ns	35%
		0 %	1	95%	62ns	78%
		+4 %	7	69%	207ns	27%
		+10 %	15	34%	248ns	13%
		Average	9	60.4%	193ns	31.8%
3-Stage Opamp		Step	39	-	52ns	-
	Posicast	-10 %	8	79%	31ns	40%
		-4 %	4	89%	29ns	44%
		0 %	1	97%	8ns	84%
		+4 %	6	84%	12ns	76%
		+10 %	14	64%	30ns	42%
		Average	6.6	82.6%	22ns	57.2%

* Imp: Percent of improvement

** Posicast: Ideal and non-ideal Posicast inputs

B. Variation in the applying time of the second level of Posicast command (Jitter)

The effects of variation in the applying time of the second level of Posicast command are studied in this section.

For each system, the system response for step input, Posicast input, and non-ideal Posicast input with deviation in the applying time of the second level of Posicast command (jitter noise) is simulated and results are shown in Table 3. The set-point for time of applying of the second level of Posicast command id defined as the ideal time and the variations time are 4 and 10 percent of ideal time before and after it (set-point time).

Table 3. Systems response to inputs with non-idealities in the applying time of the second level of Posicast command

		Input	P.O.	Imp	Ts	Imp
Second-order Sys.		Step	50	-	9.7s	-
	Posicast	-10 %	8	84%	5.5s	43%
		-4 %	4	92%	4.2s	56%
		0 %	0	100%	1.6s	83%
		+4 %	2	96%	3.1s	68%
		+10 %	3	94%	5.9s	60%
		Avg	3.4	93.2%	4.0s	62%
2-stage Opamp		Step	23	-	286ns	-
	Posicast	-10 %	13	43%	252ns	11%
		-4 %	6	73%	197ns	31%
		0 %	1	95%	62ns	78%
		+4 %	5	78%	185ns	35%
		+10 %	8	65%	239ns	16%
		Average	6.6	70.8%	187ns	34.2%
3-Stage Opamp		Step	39	-	52ns	-
	Posicast	-10 %	7	82%	26ns	50%
		-4 %	3	92%	17ns	67%
		0 %	1	97%	8ns	84%
		+4 %	2	94%	14ns	73%
		+10 %	3	92%	25ns	51%
		Average	3.2	91.4%	18ns	65%

Regarding simulation results, the time of applying of the second level of Posicast command is the other important factor of Posicast response and any deviation of it can leads to increment of system oscillation. But, similar to section 5.2, even a large deviation in applying time of the second level of Posicast command gives us a better response in comparison with step response.

C. Sensitivity curves

Effect of studied non-ideal factors on system response to Posicast input, show that if the parameters of Posicast pulse have deviation from ideal set-point, the overshoot and settling time of system response will increase in comparison with the using of ideal Posicast pulse. Assume the overshoot less than 5% as a measure of system stability. So, sensitivity curves show the acceptable variation in Posicast pulse parameters to have less than 5% overshoot in system response.

The sensitivity curves for Variation in the amplitude of the first level of Posicast command and Variation in the applying time of the second level of Posicast command for studied two-stage Op-Amp are presented in Figure 9 and Figure 10, respectively.

As presented in Figure 9, the possible range for variation in the amplitude of the first level of Posicast command to achieve less than 5% overshoot in system response is 0.78v to 0.85v and the ideal voltage level is 0.82v that leads to 1% overshoot. The acceptable range for Variation in the applying time of the second level of Posicast command is 60ns to 67ns that is presented in Figure 10. Also the ideal applying time is 63ns which leads to 1% overshoot.

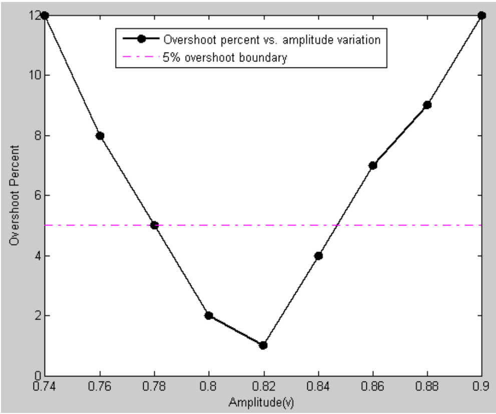


Figure 9. Sensitivity of system response to Variation in the amplitude of the first level of Posicast command

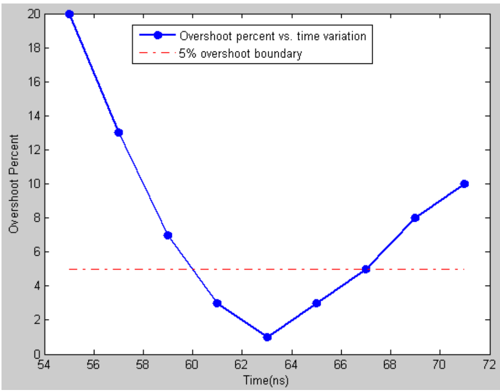


Figure 10. Sensitivity of system response to Variation in the applying time of the second level of Posicast command

V. CONCLUSION

In this paper, the authors have recommended the Posicast-based pulse pre-shaping method to use in electronic systems stability improvement. The new method which is used in this paper is based on the Posicast control for canceling the system overshoot and stabilization of it.

The proposed method has been applied on various Op-Amps with different specifications. In this work the effect of Posicast based method is presented on three systems: a typical second-order system, a two-stage op-amp, and a tree-stage op-amp in this work. All of these systems have a large overshoot percent and oscillation in their step responses. For verifying the effect of Posicast, these three systems are simulated with MATLAB/Simulink and HSPICE. The simulation results show the effectiveness of proposed method on overshoot canceling and system stabilization.

The experimental results show that using Posicast caused more than 95% improvement in overshoot and more than 78% improvement in settling time of systems which studied in this paper. Also, simulating the variation of non-ideal factors on Posicast response shows the effect of variations on system response and the acceptable range of variations in Posicast pulse to have the desired overshoot in system response.

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