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Wide-range high-linearity current-controlled pulse-width/delay circuits

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Abstract: A wide-range high-linearity current-controlled pulse-width/ delay circuit suitable for current-mode controlled techniques is presented in this paper. The proposed circuit has been fabricated with 0.35 μm CMOS 2P4M processes. The chip area is only 0.33 mm $\times$ 0.12 mm. The experimental results show the variation of the output frequency within $\pm$0.2%, the tolerance of duty cycle is less than 0.2%. The current-controlled pulse-width/delay circuit is supply independent and can be operated at 2.5 V. The linear range of input current is from 4 μA to 277 μA, and corresponding duty cycle of pulse-width output is from 1.59% to 97.2%. The experimental results agreed with the theoretical analysis are presented in this paper.

Keywords: PWM circuit, delay circuit

Classification: Integrated circuits

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1 Introduction

During the last few years, there has been increasing interest in smart power circuits. Applications include displays, automotive electronics, biomedical systems, telecommunications and many others. In these applications, the current-mode control loop is usually used to speed up dynamic response. Therefore, the current-mode control loops and current sensing techniques of the output current are necessary in both voltage-mode and current-mode switch-mode power converters (SMPC) and motor driving circuits [1, 2, 3, 4, 5, 6, 7, 8]. Furthermore, current-mode control loops can detect open-load, short-circuit and over-current situations for both energy saving and protection purposes. The switch-mode power converters and motor driving circuits usually consist of integrated pulse-width-modulation (PWM) controllers, but there are few really current-mode PWM controllers proposed until now. Most of the current-mode-controlled techniques mentioned above are still using voltage-mode PWM controller together with current-to-voltage converter to implement current-mode PWM controller. The major disadvantages of those PWM controllers are: (1) the sensing circuits will cause a larger loading effect to affect the power path performance, especially using sensing resistors and transformers. (2) The chip area of the PWM controller will be larger, because of the additional current-to-voltage conversion circuits. (3) If the sensing resistor is used, the resistance will cause the trade off problems between the signal amplitude and noise immunity. In this paper, the current-mode controlled pulse-width/delay circuit is proposed. This circuit is kernel circuit of current-mode PWM controller and can be also used as delay control circuit. Experimental results are included to justify the proposed current controlled scheme.

2 Circuit Descriptions

The proposed current-mode pulse-width/delay circuit is shown in figure 1, which is a PLL-based pulse-width/delay circuit. This circuit includes a phase-frequency detector (PFD), a charge pump circuit, a loop filter and a voltage-controlled oscillator (VCO). The phase-frequency detector is designed as a NOR-based PFD and the VCO is implemented with ring oscillator. Since this circuit has been connected with the negative feedback, for the circuit to

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be stable, the output frequency f_{out} of voltage-controlled oscillator will equal to the reference frequency f_{in}. The pulse width of pulse-width output V_{PWM} can be obtained as the phase difference of the reference frequency and the output frequency of the voltage-controlled oscillator. The duty cycle D of the pulse-width output V_{PWM} can be derived as the following equation:

$$D = \frac{I_{in}K_{VCO}\left(sC_PR_P + 1\right)}{2\pi\left(s^3C_2C_PR_P + s^2\left(C_P + C_2\right)\right) + I_PK_{VCO}\left(sC_PR_P + 1\right)} \tag{1}$$

where K_{VCO} is the gain of the voltage-controlled oscillator. If $s = 0$, the duty cycle can be rewritten as

$$D = \frac{I_{in}}{I_P} \tag{2}$$

The duty cycle of pulse-width output V_{PWM} will be proportional to input currentI_{in}. The linearity of the circuit will be good. Since the duty cycle, controlled by input current, is the difference of input frequency and output frequency, one can use this circuit as a delay controlled circuit by taking the output frequency of voltage-controlled oscillator as an output.

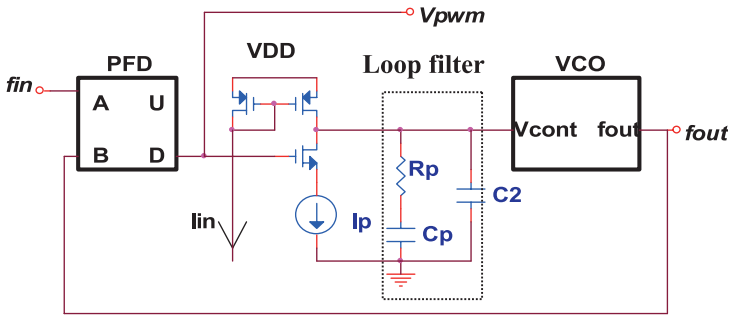

Fig. 1. the proposed current-mode pulse-width/delay circuit

3 Experimental Results

To verify the performance of the proposed current-controlled pulse-width/delay circuit, this circuit has been implemented using 0.35 μm CMOS 2P4M processes. The photograph of the proposed circuit is shown in figure 2. The chip area of this circuit is only 0.33 mm $\times$ 0.12 mm. The experimental results are shown in figures 3 and 4, which results are independent on supply voltages. Figure 3 shows the experimental results of input reference frequency, output frequency and pulse-width output, from top to bottom, when the proposed circuit operated at 2.5-V supply voltage. The tolerance of the duty cycle is shown in figure 4 (a). The variation of output frequency is shown in figure 4 (b). The experimental results show the variation of the output frequency within $\pm$0.2%, the linearity tolerance of duty cycle is less than 0.2%. The linear range of input current is from 4 μA to 277 μA, and corresponding duty cycle of pulse-width output is from 1.59% to 97.2%.

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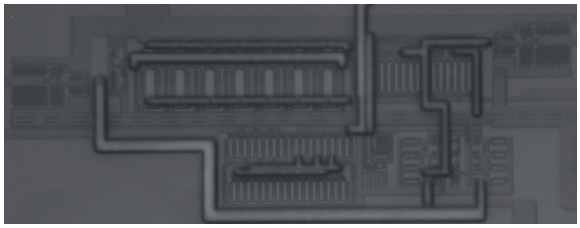
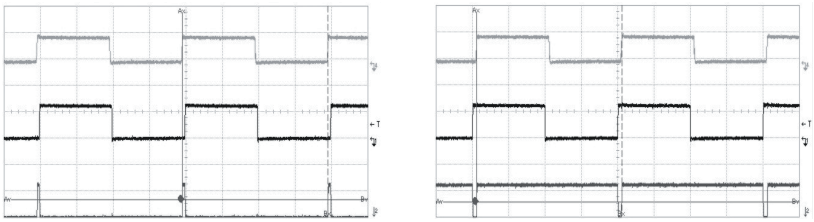
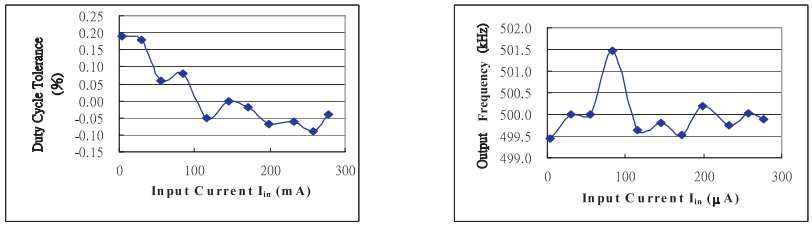


Fig. 2. the photograph of the proposed pulse-width/delay circuit



(a) (b)

Fig. 3. the experimental results of the proposed circuit operated at supply voltage 2.5 V, from top to bottom, the traces are 500-kHz reference frequency f_{in}, output frequency f_{out} and PWM output, respectively. (a) low duty, (b) high duty (horizontal scale: 500 ns/div; vertical scale: 2 V/div)



(a) (b)

Fig. 4. (a) the experimental results of duty cycle tolerance of the PWM output; (b) the experimental results of output frequency variation

4 Conclusions

The wide-range high-linearity current-controlled pulse-width/delay circuit suitable for current-mode controlled techniques is presented in this paper. The experimental results confirmed with the theoretical analysis are described in this paper. This circuit is useful for switching power supply applications and motor driving circuits.

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