A Low-voltage High-speed PWM signal generation Based on Relaxation oscillator

Montree Siripruchyanun

Department of Teacher Training in Electrical Engineering, Faculty of Technical Education,
King Mongkut's Institute of Technology North Bangkok, Bangsue, Bangkok, Thailand, 10800.
Email: mts@kmitnb.ac.th

Abstract: This paper a new simple PWM (Pulse Width Modulation) signal generation based on modified relaxation oscillator is introduced. Its advantages of the proposed principle are that the precise PWM signal can be easily achieved with a high frequency range up to several megahertz and a low-voltage power supply. The proposed circuit can accept either voltage or current modulating signal. It is very suitable for developing into Integrated Circuits (ICs) form in communication applications. The simulation and experimental results are also depicted, they shown good agreement with theoretical anticipation.

1. Introduction

A PWM signal is widely utilized in the areas of communication, especially in optical communication and instrumentation. By the reason, the PWM signal generator has been realized in Integrated Circuits (ICs) form that makes it convenient to implement. However, the circuit configuration is typically composed of current sources, flip-flop, comparators and analog switches as well [1]. It causes it comprises a bulk of transistors. Although, the recently previous literatures have proposed the simple PWM signal generator [2-5], the scheme details do have limitation of maximum frequency of PWM output signal due to a slew rate of the active elements. In addition, some above proposed methods, their duty cycle of PWM output signal does not linearly vary with modulating signal which causes it has some distortion after demodulation.

The purpose of this article is to present an innovation of PWM signal generation. The proposed principle can be achieved by modifying the relaxation oscillator. Its benefits of the proposed circuit are that it can yield the precise PWM output signal whose duty cycle is linearly dependent on a magnitude of the modulating (information) signal over a high-speed and low-voltage. The modulating signal in current form can be directly accepted and the circuit realization is simple. The circuit performances are also proved here in which is accordant in our expectations.

2. Principle

2.1 The conventional relaxation oscillator

The relaxation oscillators using emitter-coupled connection of Bipolar Junction Transistors (BJTs) are wide utilized in many areas, especially in communications [6-7] due to their abilities in high frequency performance. This causes they are developed into Voltage Controlled Oscillators (VCOs) and Current Controlled Oscillators (CCOs) forms [8-9]. Figure 1 is a simplified diagram of a relaxation oscillator circuit demonstrating the presented principle. The circuit is derived from the emitter-coupled multivibrator configuration and can provide a square-wave output. Its operation can be briefly explained as follows.

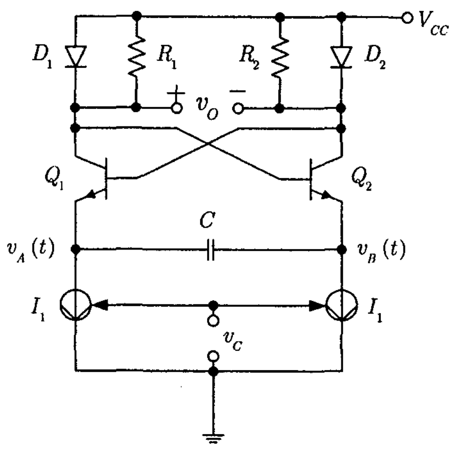


Figure 1. The classical relaxation oscillator circuit

At any given time Q_1 and D_1 or Q_2 and D_2 are conducting, such that the capacitor C is alternately charged and discharged by constant current source I_1. The output across D_1 and D_2 corresponds to a symmetrical square wave, with a peak-to-peak amplitude of $2V_{BE}$, where V_{BE} is the transistor base-emitter voltage drop. The output V_A is constant when Q_1 is on, and becomes a linear ramp with a slope equal to $(-I_1/C)$ when Q_1 is off. The output $v_B(t)$ is the same as $v_A(t)$, except for a haft-cycle delay. Both of these linear ramp waveforms have peak-to-peak amplitudes of $2V_{BE}$. The signals at the various points are shown in Figure 2 and the frequency of oscillation can be expressed as

$$f_O = \frac{I_1}{4V_{BE}C} \tag{1}$$

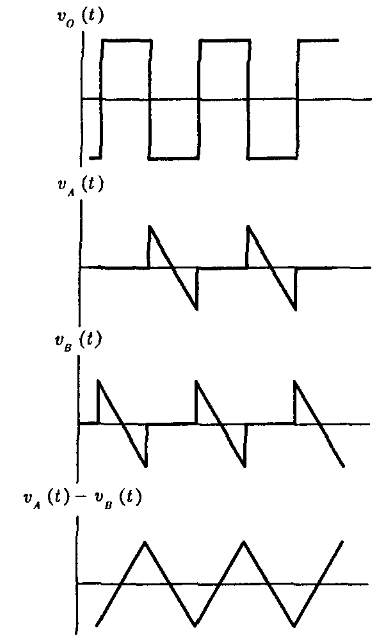


Figure 2. The signals of the circuit in Figure 1

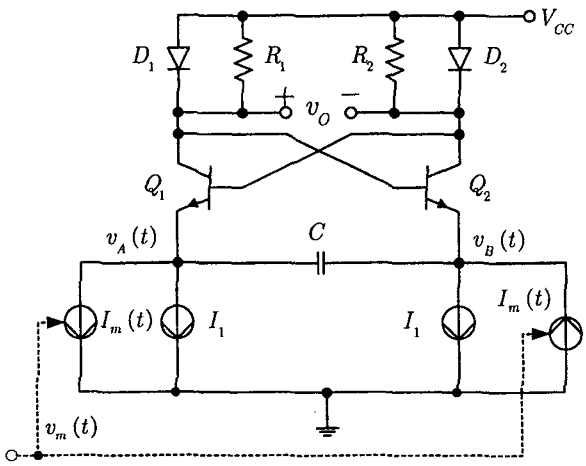


Figure 3. The proposed principle

2.2 The proposed principle and circuit

The PWM signal output can be obtained by adjusting the charged and discharged constant current values to make them depend on a modulating signal. It can be achieved by adding 2 current sources followed by Figure 3.

From the circuit, we found that during positive voltage interval of the PWM signal output, Q_2 is on and Q_1 is off. The current charging the capacitor is $I_m(t) + I_1$: where $I_m(t)$ is an instantaneously modulating signal.

Thereby the positive voltage interval: T_1 can be expressed as

$$T_1 = \frac{2V_{BE}C}{I_1 + I_m(t)} \tag{2}$$

For another period, it means the negative voltage interval we clearly see that the current charging the capacitor is $I_1 - I_m(t)$. As a result, the negative voltage period: T_2, with the same derivation, can be calculated from

$$T_2 = \frac{2V_{BE}C}{I_1 - I_m(t)} \tag{3}$$

The oscillation period: T, summation result of equation (2) and (3), can be consequently shown as

$$T = \frac{4I_1V_{BE}C}{I_1^2 - I_m^2(t)} \tag{4}$$

The oscillation frequency: f, inversion of T, can be easily obtained by

$$f = \frac{I_1^2 - I_m^2(t)}{4I_1V_{BE}C} \tag{5}$$

The duty cycle of the PWM signal output: D which is a ratio of T_1 to T would be

$$D = \frac{T_1}{T} = \frac{I_1 + I_m(t)}{2I_1} \tag{6}$$

In conventional, the duty cycle should be illustrated in percentage form, that is

$$D(\%) = \frac{I_1 + I_m(t)}{2I_1} \times 100\% \tag{7}$$

It means that, from equation (6), if $I_m(t) = 0$ the duty cycle of the PWM output signal would be 50% which is agree with the most typical applications. It is also discernibly shown that, besides, the duty cycle is linearly dependent on the modulating signal.

Figure 4 shows the proposed circuit generated from the PWM signal generation in Fig. 3. Where Q_8 and Q_9 work as diode. Q_3 - Q_4 function as current mirror of $I_m(t)$ while Q_4 - Q_7 function as current mirror of $-I_m(t)$. In this circuit, it is noted that the modulating signal must be more than zero. This causes the current mirrors continuously work.

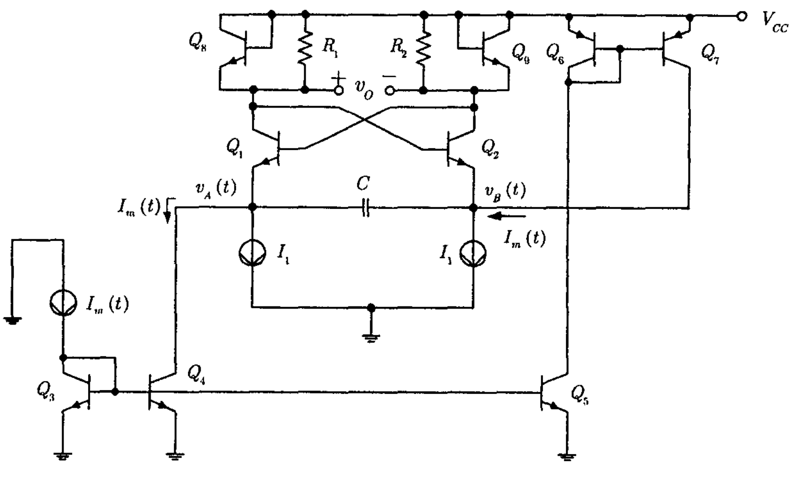


Figure 4. The completely proposed PWM signal generator

3. simulation and experimental results and discussions

To prove the performances of the proposed circuit, The simulations have been firstly set up. Pspice simulation program was used, the PNP and NPN transistors were simulated using the parameters of the PR200N and NR200N bipolar transistors, respectively [10]. The power supply voltage used was 1V [11-12]. The passive elements are 100pF capacitor and 150Ω resistors to obtain more than 10MHz frequencies. The first result, the duty cycle and frequency of PWM output signal against modulating signal variations, is shown in Figure 5. It should be noted that the duty cycle of the PWM output signal linearly depends on the magnitude of modulating signal followed by equation (7) whereas its frequencies are reduced relative to the magnitude of modulating signal followed by equation (5)

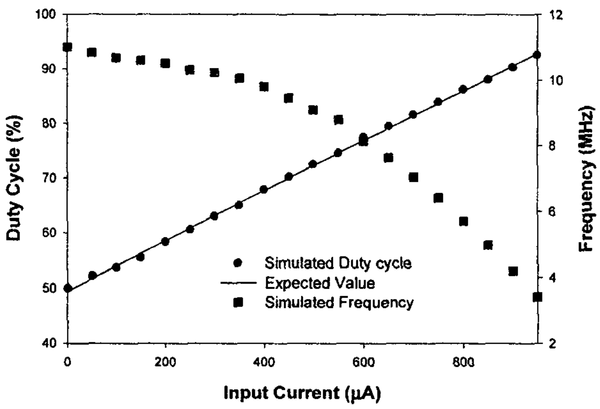
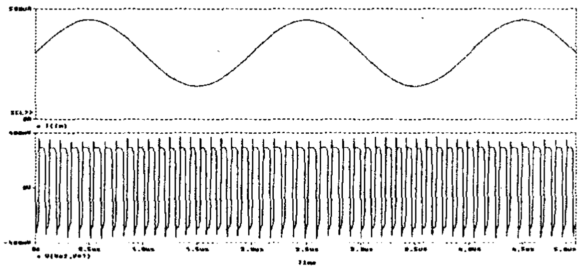


Figure 5. Static characteristics of the proposed PWM signal generator

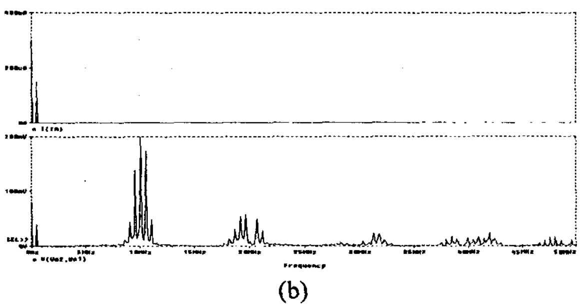
Figure 6(a) demonstrates the PWM signal against the modulating signal applying a sinusoidal signal of 50kHz frequency and $150\mu A$ amplitude with $300\mu A$ DC offset level. The frequency spectrum of the PWM output signal can be seen in Figure 6(b) relative to that of sinusoidal input signal. It comprises the sinusoidal input signal component, which can be recovered using an appropriated-cutoff frequency low pass filter [13].

The experiments were also set up to confirm that the proposed circuit can operate in practice. We used CA3096s transistor arrays as transistors. The experimental circuit was operated by 5V power supply voltage with the same values of the passive devices to the simulation circuit. The experimental results are illustrated in Figure 7(a)-(c) when the modulating input signals respectively are sinusoidal, triangular and square wave of 50kHz frequency.

The experimental frequency spectrum of the PWM putput signal in the case of sinusoidal input of 50kHz is also shown in Figure 8. It consists of the sinusoidal input signal component as well.

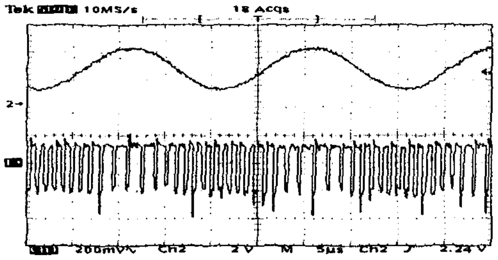


(a)

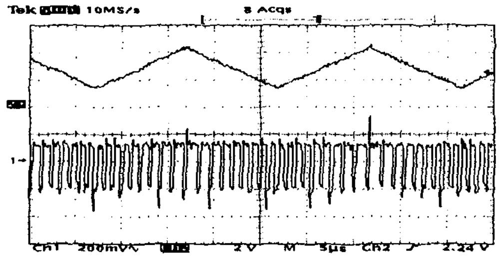


(b)

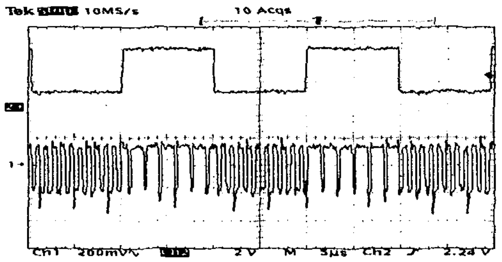
Figure 6. The PWM output signal relative to the sinusoidal modulating input in (a)Time domain (b) Frequency domain



(a)



(b)



(c)

Figure 7. The experimental results of the PWM output signals against the various modulating input signals.

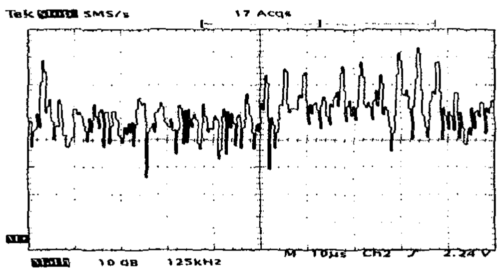


Figure 8. Experimental result of the frequency spectrum of the PWM output signal in case sinusoidal 50kHz modulating signal

4. Conclusions

The new PWM signal generation based on modified relaxation oscillator scheme has been introduced. The proposed circuit providing the precise PWM signal output whose duty cycle linearly depends on the magnitude of a modulating signal with a high-speed and low-voltage power supply. Due to the simplicity of the circuit details, it is very suitable to fabricate into integrated circuit form [14]. The main applications are in the high-speed communication systems.

Acknowledgement

The Author would like to thank Associate Professor Dr. Paramote Wardkein Department of Telecommunication Engineering, Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang for his valuable suggestions and discussions.

References

[1] APEX Microtechnology, "PWM Basics, Pulse Width Modulator Amplifier ", *Application Note 30.*

[2] M.Siripruchyanun and P. Wardkein, "A temperature-insensitive VCO and derivative PWM signal generator", *ASIC, 2001. Proceedings. 4th International Conference on*, pp.224 –227, Oct. 2001.

[3] M.Siripruchyanun and P. Wardkein, "Differentiated input and frequency-constant PWM signal generation based on novel Schmitt trigger", *Communication and Information Technology, Proceedings. International Symposium on*, pp.618 –621, Nov. 2001.

[4] M.Siripruchyanun,P. Wardkein and P.Sangpisit, "A simple pulse width modulation using CCII", *2000 TENCON proc.*, Vol. I, pp. 1452-1457, Sep. 2000.

[5] T. Techarat, S.Roungprakhon and P.Wardkein, "A simple PWM generator", 3^{rd} *Inter. Symp.on Wireless Personal Multimedia Commu,* pp. 896-899. Nov. 2000.

[6] D. Johns and K. Martin, *Analog Integrated Circuit Design*, New York; Wiley, 1997, Ch. 16.

[7] D. O. Pederson and K. Mayaram, *Analog Integrated Circuits for Communications*, Massachusetts; Kluwer Academic Publishers, 1991, Ch. 11.

[8] N. T. Tchamov, T. Neimi and N. Mikkola, "High-performance differential VCO based on Armstrong oscillator topology", *Solid-state Circuits, III Journal of,* Vol. 36, Issue 1, pp. 139-141, Jan. 2001.

[9] N. Tchamov, A. Popov, and P. Jarske, "New loe-power/high-speed double cross-coupled ICO/VCO", *Wireless Applications Digest, 1997, IEEE MTT-S Symposium on Technologies for*, pp. 157-158, 1997.

[10] D. R. Frey, "Log-domain filtering: An approach to current-mode filtering", *Proc. Inst. Eng., Vol. 140, pt. G*, pp. 406-416, Dec. 1993.

[11] A. Popov, N. Tchamov, and P. Jarske, "New high-speed double –cross ICO/VCO", *Electronics, Circuits, and Systems, 1996, ICECS '96, Porceeding of the Third IEEE International conference on*, Vol. 1, pp. 243-246, 1996.

[12] N. Tchamov, A. Popov, and P. Jarske, "New low-power ICO/VCO with double cross-coupled high-speed architecture", *Analog and Mixed IC Dessign, 1996, IEEE-CAS Region 8 Workshop on*, pp. 16-19, 1996.

[13] N. Maneejiraprakarn, P. Wardkein and I. Aroonsangsareechai, "A mathematical analysis of PWM and PPM spectrum for simple demodulation", *Ladkrabang Engineering Journal* (Thai language), Vol. 15, No. 2, pp. 142-147, Dec. 1998.

[14] A. B. Grebene, "Monolithic waveform generation", *IEEE Spectrum*, pp. 34-40, April 1972.