Low-Voltage High-Speed PWM Signal Generations Based on Relaxation Oscillator

Montree. Siripruchyanun*

Abstract

This paper new two simple PWM (Pulse Width Modulation) signal generations based on modified relaxation oscillator are introduced. Their 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 circuits are able to accept either voltage or current modulating signal. They are 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 two innovations of PWM signal generation. The proposed principle can be achieved by modifying the relaxation oscillator. Their benefits of the proposed circuits are that they 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 from the first circuit or in voltage form applied to the second circuit. The both circuit realizations are 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 widely 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]. Fig. 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.

* Department of Teacher Training in Electrical Engineering, King Mongkut's Institute of Technology North Bangkok

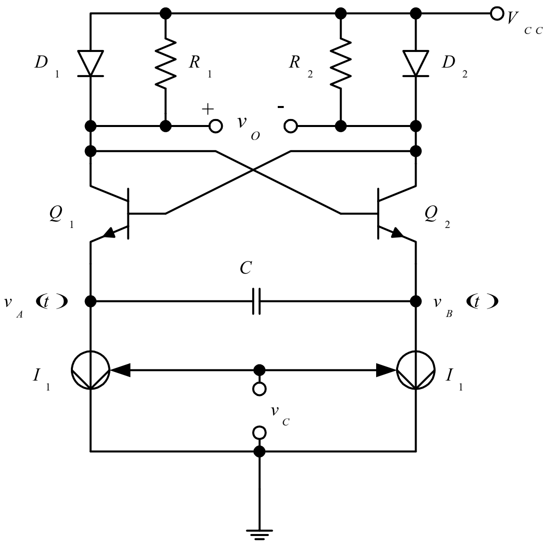


Fig. 1 The classical relaxation oscillator circuit

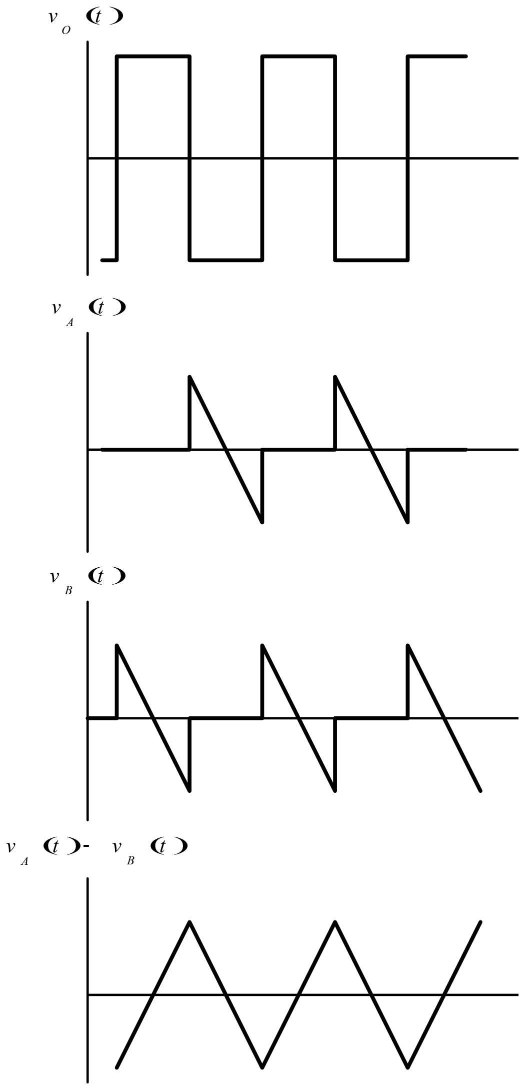


Fig. 2 The signals of the circuit in Fig. 1

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 a 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 Fig. 2 and the frequency of oscillation can be expressed as

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

2.2 The Proposed Principle

The PWM signal output can be obtained by adjusting the charged and discharged constant current values to make them dependent on a modulating signal. It can be achieved by adding 2 current sources followed by Fig. 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 an $I_m(t)+I_1$: where $I_m(t)$ is an instantaneously modulating signal.

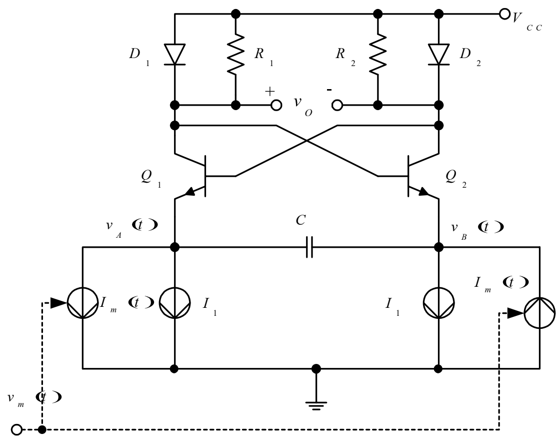


Fig. 3 The proposed principl

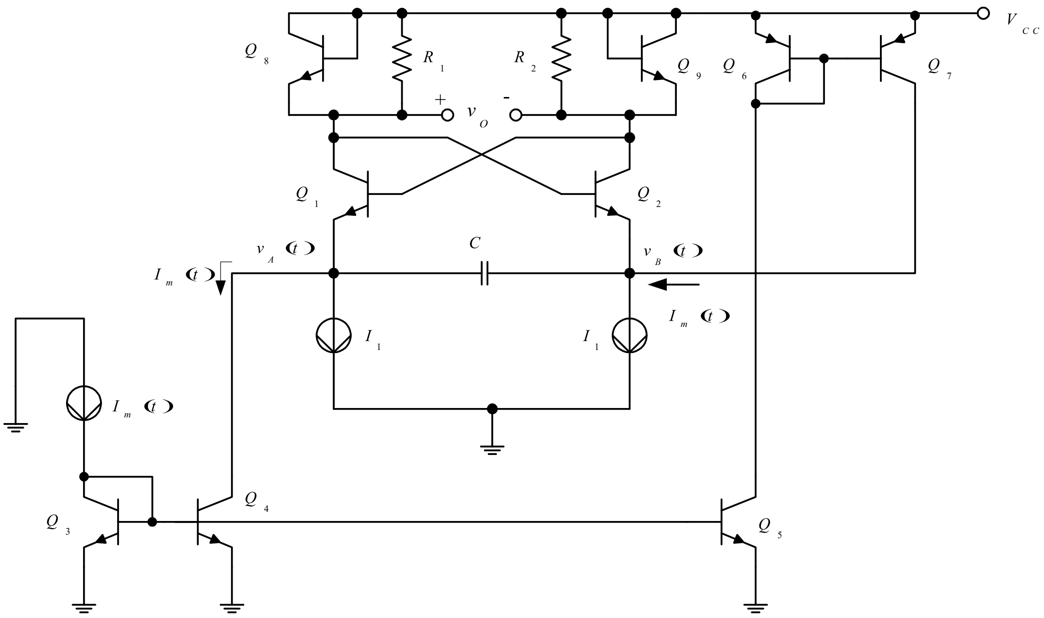


Fig. 4 The first proposed PWM signal generator

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 time interval that negative voltage interval we clearly see that the current charging the capacitor is an $I_1 - I_m(t)$. 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 a 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.

2.3 The First Proposed Circuit

Fig. 4 shows the first 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 a current mirror of $I_m(t)$ while Q_4 - Q_7 function as a 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.

2.4 The Second Proposed Circuit

From the first circuit, however, the modulating signal is limited as a positive current and the only more than 50% duty cycle can be received at the PWM output terminal. The modulating signal in voltage form can be applied to the PWM signal generator using the second circuit shown in Fig. 5. A multiple output second generation current conveyor ($CCII\pm$) [10] is utilized to function as a voltage to current converter. The modulating signal can be positive or negative range if the proposed circuit is biased with dual supply voltages. Thereby the variable duty cycle of 0-100% can be achieved.

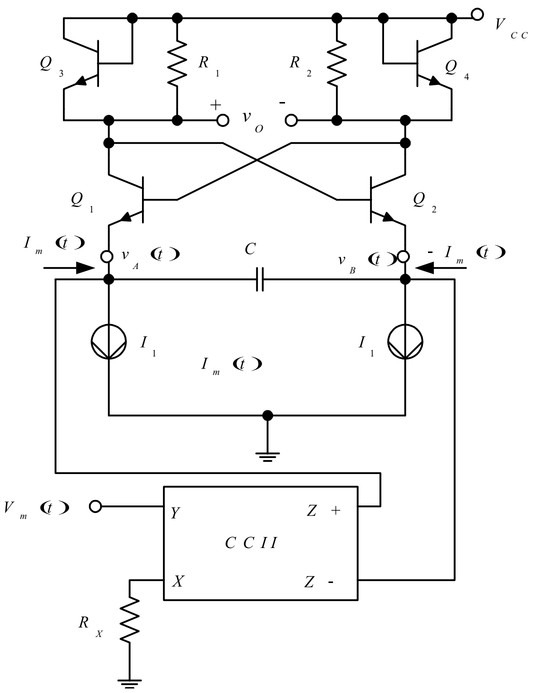


Fig. 5 The second proposed PWM signal generator

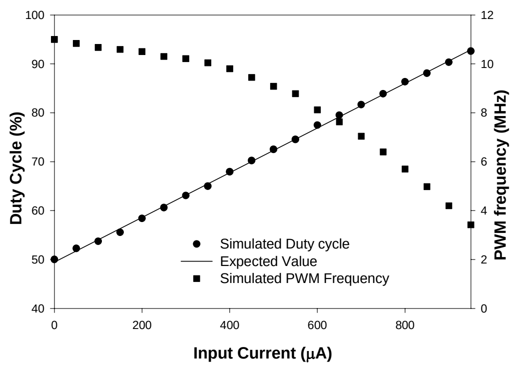
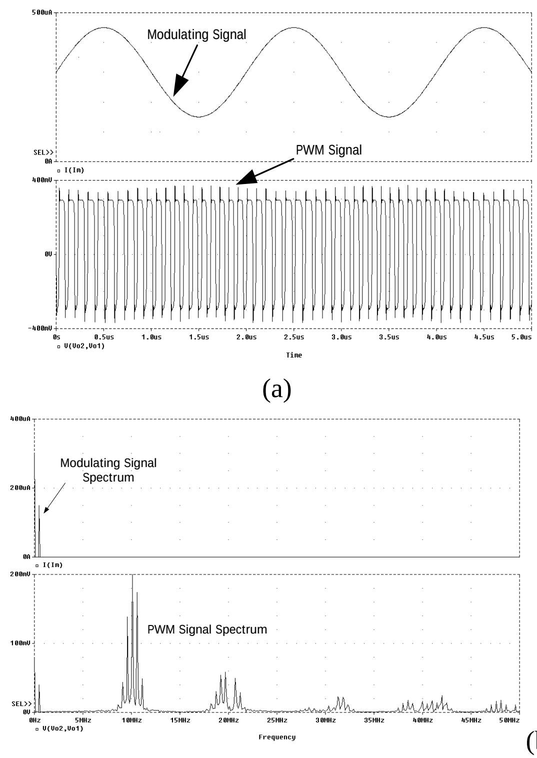


Fig. 6 Static characteristics of the first proposed PWM signal generator



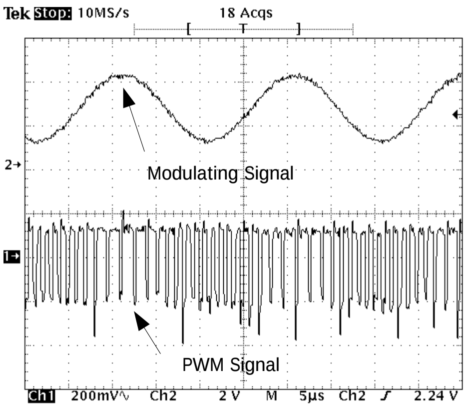
(a)

(b)

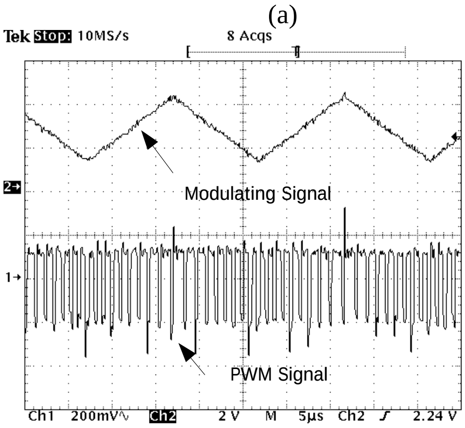
Fig. 7 The simulated results of the sinusoidal modulating input of the first circuit relative to the PWM output signal in (a) Time domain (b) Frequency domain

3. Simulation and Experimental Results and Discussions

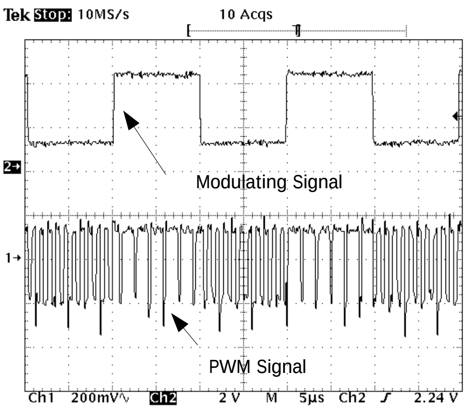
To prove the performances of the proposed circuits, The simulations have been firstly set up. Pspice simulation program was used, the PNP and NPN transistors were simulated using the parameters of the PR200N and NR200N bipolar transistors, respectively [11]. The power supply voltage used was 1V [12-13] applied to the first circuit. The passive elements are 100pF capacitor and 150Ω resistors to obtain more than 10MHz frequencies. The first result of the first circuit, the duty cycle and frequency of PWM output signal against DC modulating current variations, is shown in Fig. 6. 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)



(a)



(b)



(c)

Fig. 8 The experimental results of the various modulating input signals against the PWM output signals

Fig. 7(a) demonstrates the PWM signal of the first circuit against the modulating signal applying a amplitude with $300\mu A$ DC offset level. The frequency sinusoidal signal of 500kHz frequency and $150\mu A$ spectrum of the PWM output signal can be seen in Fig. 7(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 [14].

The experiments were also set up to confirm that the first 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 Fig. 8(a)-(c) when the modulating input signals respectively are sinusoidal, triangular and square wave of 50kHz frequency.

The experimental frequency spectrum of the PWM output signal in the case of sinusoidal input of 50kHz is also shown in Fig. 9. It consists of the sinusoidal input signal component as well.

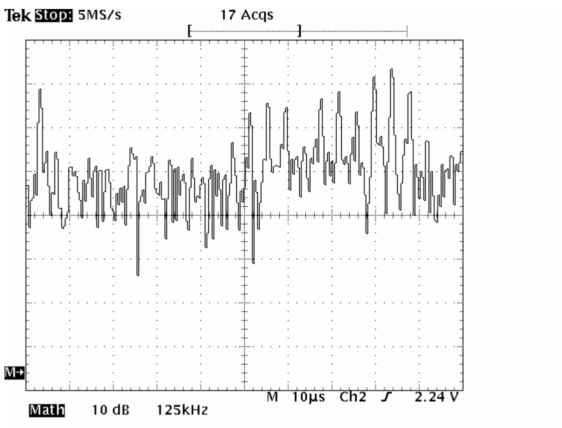


Fig. 9 Experimental result of the frequency spectrum of the PWM output signal in case sinusoidal 50kHz modulating signal

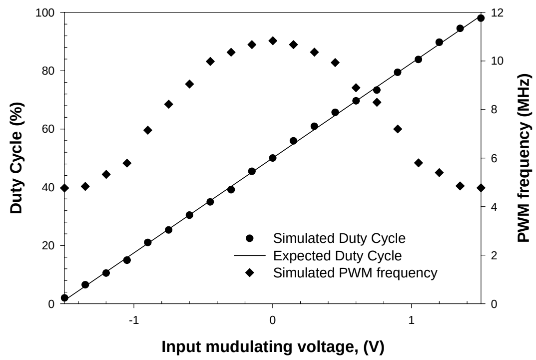


Fig. 10 Static characteristics of the second proposed PWM signal generator

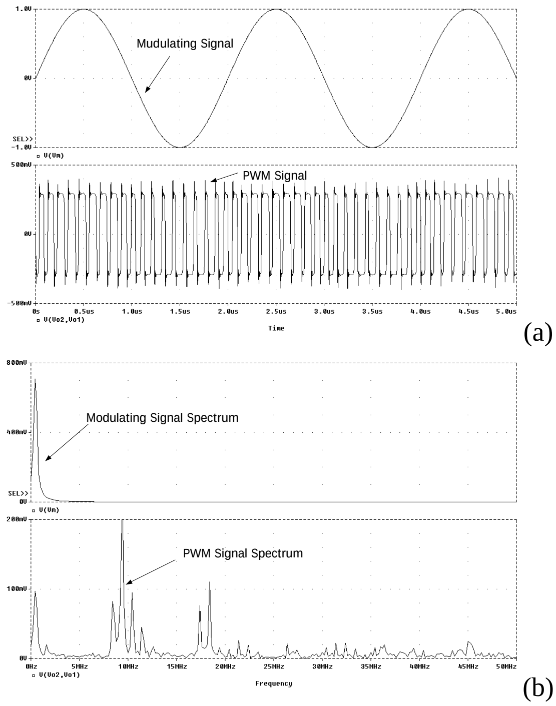


Fig. 11 The simulated results of the PWM output signal of the second circuit relative to the sinusoidal modulating input in (a) Time domain (b) Frequency domain

The simulation results of the second proposed circuit are also illustrated. Fig. 10 shows the duty cycle and frequency of PWM output signal against the DC modulating voltage variations whereas the power supply voltage was $\pm 1.5V$ with the same element values and parameters to the first circuit and R_X of $1.5k\Omega$. It insists that the duty cycle of approximate 0-100% can be obtained. Fig. 11(a) demonstrates the PWM signal output of the second circuit against the modulating signal applying a sinusoidal signal of 500kHz frequency and 1V amplitude. The frequency spectrum of the PWM output signal can be seen in Fig. 11(b) relative to that of sinusoidal input signal. It comprises the sinusoidal input signal component as well.

4. Conclusions

The new PWM signal generations based on modified relaxation oscillator scheme have been introduced. The proposed circuits 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. The modulating (information) signal in current form can be applied to the first circuit while the modulating signal in voltage form can be fed to the second circuit. In addition the modulating current signal can be available with the second circuit by feeding it to the X terminal whereas the Y terminal is connected to ground. Due to the simplicity of the circuit details, they are very suitable to fabricate into integrated circuit forms [15]. The main applications are in the high-speed communication systems.

5. 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. Siripruchyanun, M. and Wardkein, P. "A temperature-insensitive VCO and derivative PWM signal generator." *ASIC, 2001. Proceedings. 4th International Conference on*, pp.224 –227, Oct. 2001.
3. Siripruchyanun, M. and Wardkein, P. "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. Siripruchyanun, M., Wardkein, P. and Sangpisit, P. "A simple pulse width modulation using CCII." *2000 TENCON proceedings*. I (Sep. 2000)

: I452-I457.

5. Techarat, T., Roungprakhon ,S. and Wardkein, P. “A simple PWM generator.” *3rd Inter. Symp.on Wireless Personal Multimedia Commu,* pp. 896-899. Nov. 2000.
6. Johns, D. and Martin, K. *Analog Integrated Circuit Design*. New York; Wiley, 1997, Ch. 16.
7. Pederson, D. O. and Mayaram, K. *Analog Integrated Circuits for Communications*. Massachusetts; Kluwer Academic Publishers, 1991, Ch. 11.
8. Tchamov, N. T., Neimi, T. and Mikkola, N. “High-performance differential VCO based on Armstrong oscillator topology.” *Solid-state Circuits, III Journal of.* 36, Issue 1 (Jan. 2001) : 139-141.
9. Tchamov, N., Popov, A. and Jarske, P. “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. Abuelma’atti, M.T. and Al-Qahtani, M.A. “A new current-controlled multiphase sinusoidal oscillator using translinear current conveyors.” *Circuits and systems, IEEE trans. on,* Vol. 45, No. 7, pp. 881-885, July 1998.
11. Frey, D. R. “Log-domain filtering: An approach to current-mode filtering.” *Proc. Inst. Eng.*, 140, pt. G (Dec. 1993) : 406-416.
12. Popov, A,. Tchamov, N. and Jarske, P. “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.
13. Tchamov, N., Popov, A. and Jarske, P. “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.
14. Maneejiraprakarn, N., Wardkein, P. and Aroonsangsareechai, I. “A mathematical analysis of PWM and PPM spectrum for simple demodulation.” *Ladkrabang Engineering Journal* (Thai language).15, 2 (Dec. 1998) : 142-147.
15. Grebene, A. B. “Monolithic waveform generation.” *IEEE Spectrum*. (April 1972) : 34-40.