FM Demodulation Based on FM to PWM Conversion With Voltage Gain Control

Rapeepong Boongsri[1], Paramote Wardkein[1] and Peeramed Chodkaveekityada[2]
[1]Department of Telecommunication Engineering, Faculty of Engineering,
King Mongkut's Institute of Technology Ladkrabang, Chalong Krung Road, Ladkrabang, Bangkok 10520, Thailand
[2]Thaicom Public Company Limited, Nonthaburi 11000, Thailand
rapeepbo@gmail.com[1], pramote@telecom.kmitl.ac.th[1], peeramedc@hotmail.com[2]

Abstract - This paper attempts to present the FM demodulation based on FM to PWM conversion with voltage gain control (VGC). The proposed scheme is based on the basic principle of zero crossing (ZC) for conversing FM to PWM. The PWM-signal is filtered by low pass filter (LPF). The result is the message signal (speech, music, etc.). The outstanding feature of this method is that the pulse width of PWM signal influences the amplitude of demodulated signal. It can be adjusted by VGC affecting the gain of a message signal. The proposed circuit has relatively simple and efficient. It consists of monostable multivibrator and low pass filter (LPF). The experimental and synthesis results from MATLAB confirm the mathematics analysis.

Keywords - Pulse-width modulation (PWM), Zero crossing (ZC), Voltage gain control (VGC)

1. Introduction

FM demodulation is widely used in communication systems as it has more immunity to noise and interference. In FM demodulation, a variety of different techniques have been proposed in several articles, as in [1]-[5]. For example, a direct demodulation the derivative FM signal is detected the envelope in order to demodulate message signal. Quadrature detector, as in [2] has the disadvantage; the inductor which is used as a component in a 90◦ phase shift cannot build in IC completely. Another technique of FM demodulation is Phase Locked Loop (PLL). Although PLL can be realized on an IC and the circuit will be smaller, it is an analog device, and requires the fine tuning for proper working.

In this paper, the FM demodulation based on FM to PWM conversion with voltage gain control is proposed. The model is based on the basic principle of zero crossing (ZC), which is suitable for an IC. The proposed circuit consists of monostable multivibrators and low pass filter. In literature, the demodulation by using Zero crossing have been developed, as in [6]-[10]. Since 1970, R.B Stone proposed FM Demodulator Zero-crossing Detector, as in [6], Michel Jean-Mary Dupuy proposed Impulse Duration Modulator in 1973, as in [7], in 1984 SK. Ray proposed the Zero-crossing-based approximate demodulation of wide-deviation FM, as in [8], FM Detector using Monostable Multivibrators has been presented by Makoto Furihata in 1985, as in [9] and E.K.B. Lee proposed ZC - IF demodulator in 1995, as in [10]. Although the FM demodulation by using zero crossing and PWM have been proposed in the past, the theoretical aspects of PWM are still missing. In addition, the width adjustment of the mono-pulse gaining the message signal has not been mentioned.

In this paper, the monostable multivibrator which controlled positive pulse width with voltage and low pass filter for demodulating FM signal is proposed. PWM signal deriving from FM signal is analysed by using Fourier series. The obtained mathematical expression shows how the positive pulse width affects the gain of massage signals. The circuit is compact, simple, and efficient for demodulating FM signal.

The organization of the article is given as follows: the brief review of Zero crossing the mathematical analysis of PWM signal and the synthesis of PWM signal are discussed in section II; the circuit description and experimental results are given in section III; finally, the conclusion is presented in section IV.

2. The proposed Principle

A. *The basic principle of zero crossing (ZC)*

The zero crossing (ZC) works on the principle that the message in an FM signal. Zero crossings are occurred at every period of a periodic signal. Thus, the number of zero crossing per unit time is the average frequency of the signal. In the high frequency, the numbers of zero crossing are much more in one unit of time. For example, as shown in Fig. 1, the FM demodulated signal, as in [9] by using the principle of zero crossing generates a stream of pulses, one pulse for each period of a signal. According to the signal frequency, the number of pulses per unit time is varied. Thus the average number of pulses varies according to the level of the signal frequency as well.

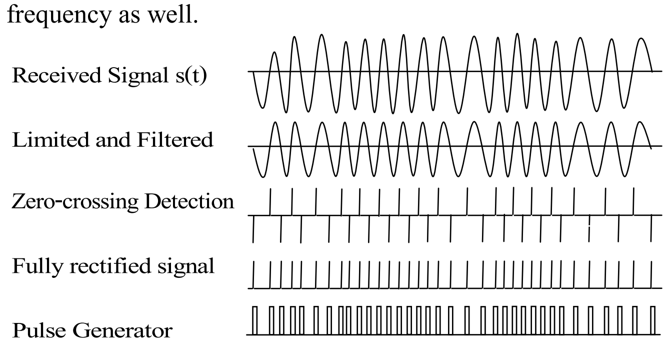

Fig. 1 FM demodulation by using the basic principle of Zero-Crossing (ZC)

B. *The mathematical analysis of PWM signal*

Based on the mathematical analysis of PWM signal proposed, as in [5]. As can be seen in (1), the $\Phi_{pwm}(t)$ is

PWM signal and A is the amplitude of positive pulse.

$$\Phi_{pwm}(t)=\left(Akm(t)/T\right)+\left(A/\pi\right)\sum_{n=1}^{\infty}\begin{pmatrix}+\sin\left(n\omega_0 t\right)/n \\ -\sin\left(n\omega_0\left(t-km(t)\right)\right)/n\end{pmatrix} \quad (1)$$

The $\Phi_{pwm}(t)$ is a constant periodic signal. By considering PWM signal shown in Fig. 2, the width of positive pulse is varied corresponding with message signal, $\Delta t_i = km(t)$ by $m(t)$ is message signal and Δt_i is the width of the positive pulse; i by i are positive integer number (i = 0, 1, 2,…)

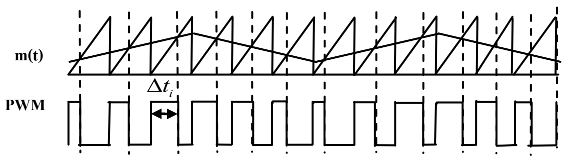

Fig. 2 PWM modulation; the frequency of message signal is constant.

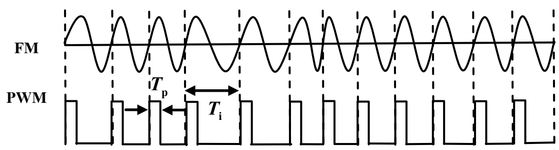

Fig. 3 PWM modulation; the frequency of message signal is not constant.

For FM signals, its frequency depends on the level of message signal. The period of each cycle of FM signals is inversely proportional to the strength of the message signal. In Fig. 3, we generate a PWM signal by using zero crossing with a fixed positive pulse width. We also moderate the rules of periodic, according to documents, as in [6] and assume that this signal is periodic. We will see that the PWM signal which is inconstant carrier frequency. Under situation, the modulation index of FM signal is small and relaxing the conventional periodic signal criteria. Therefore, Fourier series with exponential term are used in the analysis of this PWM signal. The $\Phi_{pwm}(t)$ is PWM signal as shown in (2),.

$$\Phi_{pwm}(t+T)=\Phi_{pwm}(t)$$

$$=F_0+\sum_{n=-\infty}^{\infty}F_n\exp\left(jn\omega_0 t\right) \quad (2)$$

whereas F_n is exponential Fourier series coefficients and n is an integer number by

$$F_n=\left(1/T\right)\int_{-T/2}^{T/2}\Phi_{pwm}(t)\exp\left(-jn\omega_0 t\right)dt \quad (3)$$

$\omega_0 = \omega_i$ is equal $2\pi/T_i$, T_i is the period of signal.

Considering periodic signal; i^{th} that is

$$F_n=\left(1/T_i\right)\int_0^{Tp}A\exp\left(-jn\omega_0 t\right)dt$$

$$=\left(A\exp\left(-jn\omega_0 t\right)/\left(-jnT_i\omega_i t\right)\right)\Big|_0^{Tp}$$

$$F_n=A\left(\exp\left(-jn\omega_i T_p\right)-1\right)\Big/-jn\omega_i T_i$$

$$=A\left(\exp\left(jn\omega_i T_p\right)-1\right)\Big/-jn2\pi \quad (4)$$

And the Fourier series coefficient F_0 is defined as

$$F_0=\left(1/T\right)\int_{-T/2}^{T/2}\Phi_{pwm}(t)dt$$

$$=\left(1/T_i\right)\int_0^{Tp}Adt$$

$$F_0=AT_p/T_i \quad (5)$$

Substituting F_n and F_0 into (2), so the (2), can be rewritten as

$$\Phi_{pwFM}(t)=\left(AT_p/T_i\right)+\sum_{n=-\infty}^{\infty}-A\left(\exp\left(-jn\omega_i T_p\right)-1\right)\exp\left(jn\omega_i t\right)\Big/jn2\pi$$

$$=\left(AT_p/T_i\right)+\sum_{n=-\infty}^{\infty}\begin{Bmatrix}-A\exp\left(jn\omega_i\left(t-T_p\right)\right)\Big/jn2\pi \\ +A\exp\left(jn\omega_i t\right)/jn2\pi\end{Bmatrix}$$

$$=\left(AT_p/T_i\right)+\sum_{n=1}^{\infty}\begin{Bmatrix}-A\exp\left(jn\omega_i\left(t-T_p\right)\right)\Big/jn2\pi \\ +A\exp\left(jn\omega_i t\right)/jn2\pi\end{Bmatrix}$$

$$+\sum_{n=1}^{\infty}\begin{Bmatrix}+A\exp\left(-jn\omega_i\left(t-T_p\right)\right)\Big/jn2\pi \\ -A\exp\left(-jn\omega_i t\right)/jn2\pi\end{Bmatrix}$$

$$=\left(AT_p/T_i\right)+\sum_{n=1}^{\infty}\begin{Bmatrix}-A\left(\exp\left(jn\omega_i\left(t-T_p\right)\right)-\exp\left(-jn\omega_i\left(t-T_p\right)\right)\right)\Big/jn2\pi \\ +A\left(\exp\left(jn\omega_i t\right)-\exp\left(-jn\omega_i t\right)\right)\Big/jn2\pi\end{Bmatrix}$$

$$=\left(AT_p/T_i\right)+\sum_{n=1}^{\infty}\begin{Bmatrix}-A\sin\left(n\omega_i\left(t-T_p\right)\right)\Big/n\pi \\ +A\sin\left(n\omega_i t\right)/n\pi\end{Bmatrix} \quad (6)$$

Equation (6) is mathematical expression showing the component of PWM signal that is converted from FM signals by monostable multivibrator circuit. Thus $T_i = 1/km(t)$, k is constant. $m(t)$ is a message signal. The first term of (6), can be expressed by

$$AT_p/T_i = AT_p km(t) \quad (7)$$

By substituting (7), (the first term) into (6), that is

$$\Phi_{pwFM}(t)=?AT_p km\left(t\right)+\sum_{n=1}^{\infty}\begin{Bmatrix}-A\sin\left(n\omega_i\left(t-T_p\right)\right)\Big/n\pi \\ +A\sin\left(n\omega_i t\right)/n\pi\end{Bmatrix} \quad (8)$$

As shown in (8), the first term $AT_p km(t)$ is the terms of the message signal. It is scaled by $AT_p k$ at low frequencies. Thus, we can detect the message signal by low pass filter (LPF).

C. The synthesis of PWM signal

To confirm analytical expression as shown in (8), it is then employed to synthesis $\Phi_{pwm}(t)$ using MATLAB program. The synthesis result is shown in Fig. 4 where the upper trace is the synthesized PWM signal, the middle trace is the sine wave input message signal $m(t)$ and the lower trace is the spectrum component of the synthesized signal. The synthesis result shows that the mathematical analysis in section II can be accurately generated PWM signal. The results agree well with the proposed principle.

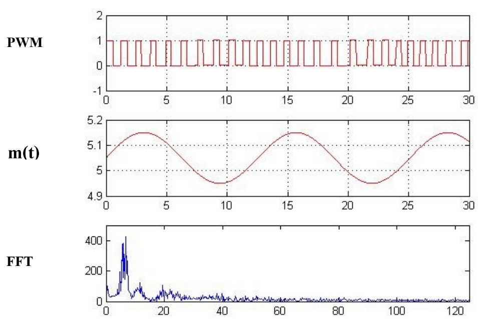

Fig. 4 synthesis result of PWM signal, which is generated by zero crossing of FM signal by using MATLAB program where the upper trace is the synthesized PWM signal, the middle trace is the message signal and the lower trace is the spectrum component of PWM signal after performing an FFT analysis.

3. The circuit description and experimental results

Based on the proposed principle in section II, the block diagram of FM demodulation based on FM to PWM conversion is shown in Fig. 5.

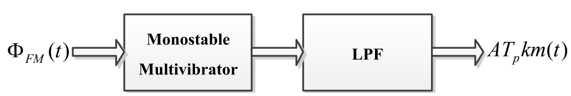

Fig. 5 block diagram of the FM demodulation

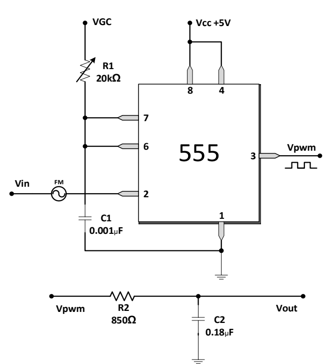

Fig. 6 FM Demodulation Circuit of the proposed scheme

The proposed circuit is shown in Fig. 6. It is designed by using the monostable multivibrators IC555 and low-pass filter, which can be adjusted frequency range. By considering analysis of the monostable multivibrators using IC555, the positive pulse T_p is given by

$$T_p = C_T R_T ln\left(V_{GC} / \left(V_{GC} - \left(2V_{CC}/3\right)\right)\right) \tag{9}$$

whereas $R_T = R_1 = 1.84k\Omega,\ fc = 1kHz,$

$C_T = C_1 = 0.001\mu F\ , V_{CC} = 5V$

Equation (8), the term $AT_pkm(t)$ is related to the pulse width T_p. As shown in (10), the terms of the message signal is considered by substituting T_p in (9), into the first term $AT_pkm(t)$ in (8), that is

$$AT_pkm(t) = AC_T R_T ln\left(V_{GC} / \left(V_{GC} - \left(2V_{CC}/3\right)\right)\right) km(t) \tag{10}$$

Using V_{GC} and A relationship, the voltage V_{GC} is adjusted. The amplitude gain of message signal $m(t)$ can be changed.

In order to describe the proposed circuit, let us consider Fig. 6; the carrier frequency is 20 kHz. The message signal is sine wave with has frequency 1 kHz and varies V_{GC} at 3.8V, 4.2V and 4.4V respectively. The experimental results are shown in Fig. 7 (a)–(c) where the upper trace is an input message signal. The middle trace is the demodulation signal. The lower trace is the spectrum components of the output message signal. It is noted that the output signal has a shape similar to the input message signal. It shows that the proposed circuit must be able to detect the FM signal.

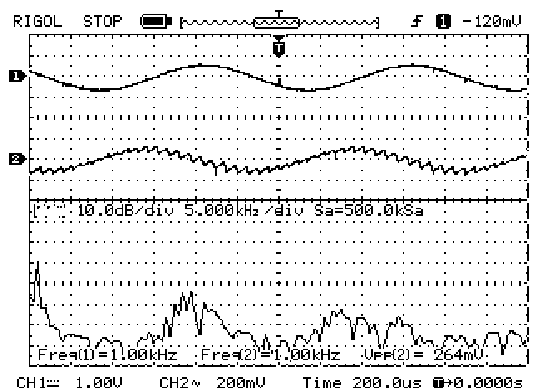

Fig. 7(a) Demodulated FM signal by adjust V_{GC} =3.8V

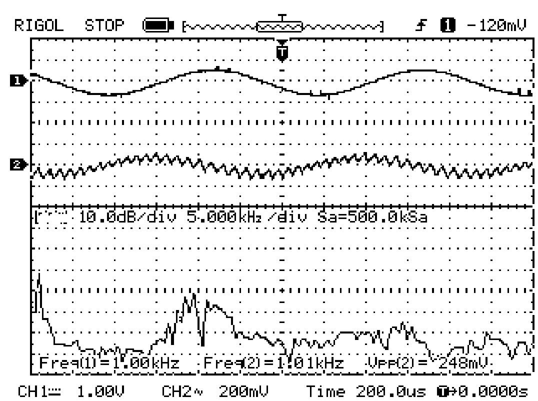

Fig. 7(b) Demodulated FM signal by adjust V_{GC} =4.2V

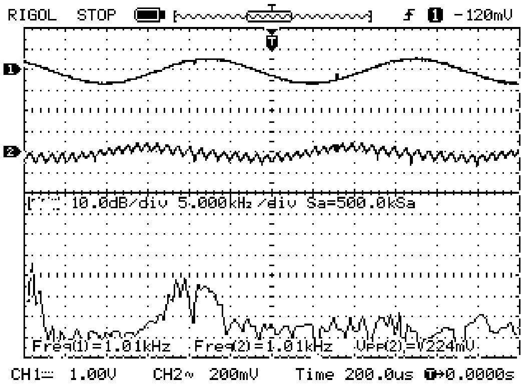

Fig. 7(c) Demodulated FM signal by adjust V_{GC} =4.4V

Fig. 7 experimental results of FM demodulation with voltage gain control (V_{GC}) where the upper trace is the message signal, which is modulated by FM signal, the middle trace is the demodulation of a message signal and the lower trace is the spectrum components of PWM signal, which is generated by using the principle of zero crossing.

By considering (10), if we adjust V_{GC} to 3.7v, 4v, 4.3V, 4.6V and 4.9V, the result is AT_pk . It is the amplitude of output message signal from the mathematic analysis, it defines representing the value AT_pk equal A_T. By comparing it with the amplitude from the experimental results A_O, the result is shown in table1.The graph relationship of V_{GC}, A_T and A_O are shown in Fig. 8. The voltage V_{GC} is varied shown on the x-axis. The graphs show that the trend is consistent. When the voltage V_{GC} is increased, the amplitude of information is reduced. The results are consistent with the mathematical analysis as well.

TABLE I Compares the voltage V_{GC} and the amplitude

V_{GC} (Volt)	A_T (Volt)	A_O (Volt)
3.7	0.6067	0.38
4.0	0.4702	0.34
4.3	0.3917	0.30
4.6	0.3385	0.25
4.9	0.2992	0.20

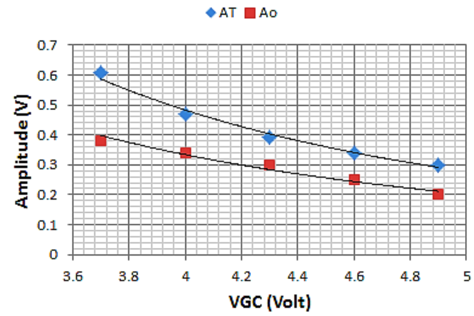

Fig. 8 V_{GC} versus the amplitude A_T and A_O

4. Conclusion

In this paper, the FM demodulation based on FM to PWM conversion is proposed. The proposed scheme can be adjusted the positive pulse width by electrical methods. Then signal is passed low-pass filter to eliminate high frequency. The result is a message signal. The proposed circuit is simple and small. The important advantage is that the proposed scheme can adjust the gain in order to detect the various message signals. It consist of exclusively monostable multivibrator and low pass filter. Furthermore, the mathematical analysis also showed the influence of the positive pulse width to the amplitude of demodulated signal.

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