Pulse Width Modulation with Frequency Changing

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Abstract

Pulse width modulation (PWM) is widely used in different applications. PWM transform the information in the amplitude of a bounded input signal into the pulse width output signal, without suffering from quantization noise. The frequency of the output signal is usually constant. In this paper the new PWM system with frequency changing (PWMF) is described. In PWMF the pulse width and also frequency is changed, therefore 2 independents information are simultaneously transmitted, and PWM and frequency modulation (FM) are simultaneously used. But such system needs fast demodulator separately for PWM and FM. The circuit for fast demodulation of PWMF signal is also described and measuring results are presented. All described circuits were constructed and measured.

1. Introduction

PWM, or pulse-duration modulation (PDM), is a technique used to encode a message into a pulsing signal. It is a type of modulation and therefore this modulation technique can be used to encode information for transmission. Pulse-width modulation uses a rectangular pulse wave whose pulse width is modulated resulting in the variation of the average value of the waveform. If we consider a pulse waveform *f(t)*, with period *T* low value y_{min}, a high value y_{max} and a duty cycle *D*, the average value of the waveform is given by:

$$\bar{y} = \frac{1}{T}\int_0^T f(t)dt \qquad (1)$$

where *f(t)* is a pulse wave, its value is y_{max} for $0<t<D.T$ and y_{min} for $D.T<t<T$. The above expression then becomes:

$$\bar{y} = \frac{1}{T}\left(\int_0^{DT} y_{max}dt + \int_{DT}^{T} y_{min}dt\right) = D\cdot y_{max} + (1-D)y_{min} \qquad (2)$$

This latter expression can be fairly simplified in many cases where $y_{min}=0$ as $\bar{y} = D\cdot y_{max}$ and for $y_{max}=1$ as $\bar{y} = D$. From this, it is obvious that the average value of the signal $\bar{y}$ is directly and linearly dependent on the duty cycle *D* (or width *w*), where $D\in\langle 0, 1\rangle$.

Different methods for PWM modulation can be classified if we consider the sampling process [1, 2]. The simplest way to generate a PWM signal is the intersective method, which requires only a sawtooth or a triangle waveform (easily generated using a simple oscillator) and a comparator. For the demodulation of the PWM signal the classical concept employs a simple low pass filter. Another possibility is described in [3, 4]. There the demodulation is made in two steps. First the PWM signal is transformed into a pulse amplitude signal (PAM). As a result we have an equidistant pulse train where the amplitude of the pulses contains the information. In the second step the PAM signal is processed with a low pass filter. This reconstructs the original signal waveform. These two step demodulation is exactly the reverse way to the uniform sampling process. The main disadvantage is lowpass filter because slow response. The similar (speed limitation) is for FM signal.

In this paper is described new approach for fast demodulation of PWM signal and also for FM signal. The new system therefore allows transmit simultaneously PWM an FM signals as 2 independents information in one PWMF signal and also fast demodulation. The fast demodulator can be also separately used as PWM demodulator, FM demodulator and demodulator for asynchronous sigma-delta modulator (ASDM) [5-12].

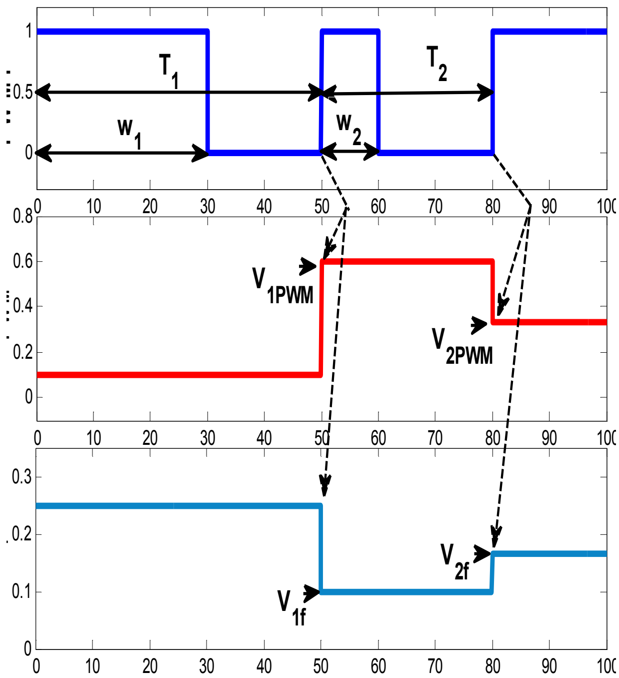

Fig. 1. The principle of PWMF modulation and fast demodulation (in every cycle – on rising edge of PWMF). Top - PWMF modulated signal, middle - PWM signal demodulation, bottom - demodulation of frequency modulation.

2. Principle of Pulse Width Modulation with Frequency Changing

Signals with pulse-width modulation are very easy to demodulate. In addition to a number of other components, their spectrum contains also the baseband spectrum of the original modulating signal. A low-pass filter is therefore sufficient to separate the useful signal. This method, however, has a drawback in that the power of the original baseband spectrum in the spectrum of the modulated signal is small. The second drawback is slow low-pass analog filter (which reduces bandwidth of transmitted signal) and needs of output buffer amplifier. Another possibility is use a converter which converts the width-modulated rectangular pulse to an amplitude-modulated pulse (usually applying the linear charging of the capacitor for the duration of the width-modulated pulse). This amplitude-modulated signal is then demodulated with the help of a demodulator with pulse-stretcher. This approach can be modified by using counters and digital-analog (D/A) converter. This principle is used for demodulation. It is important to note that PWMF signal change booth – pulse width and also frequency.

In this paper the new approach is used for demodulation of PWM in every period (every rising edge). The principle of 2 independent information transmissions by means of PWMF and demodulation is shown in Fig. 1. On the top 2 period of modulated signal are shown, where first period is T_1=50 and width w_1=30 and second period is T_2=30 and width w_2=10. In the middle, the demodulation of PWM signal is displayed. The new values v_{1PWM} and v_{2PWM} are updated on every rising edge of PWMF signal. On the bottom, the demodulation of frequency modulated signal is shown. The new values, corresponding frequency of PWMF signal are also updated on every rising edge of PWMF signal.

The value of demodulated PWM signal of period T_1 with width w_1 is v_{1PWM} (updated on the end of period T_1)

$$v_{1PWM} = \frac{w_1}{T_1} = \frac{30}{50} = 0.6 \tag{3}$$

and for period T_2 with width w_2 is v_{2PWM} (updated on the end of period T_2)

$$v_{2PWM} = \frac{w_2}{T_2} = \frac{10}{30} = 0.333 \tag{4}$$

The value of demodulated FM signal of period T_1 (for gain coefficient k_f=5) v_{1f} is (updated on the end of period T_1)

$$v_{1f} = k_f \frac{1}{T_1} = 5\frac{1}{50} = 0.1 \tag{5}$$

and for T_2 is v_{2f} (updated on the end of period T_2)

$$v_{2f} = k_f \frac{1}{T_2} = 5\frac{1}{30} = 0.166 \tag{6}$$

The circuit and measuring results for conversion of PVM signal to voltage and FM signal to voltage in one period (updated on every rising edge) is described in next part.

3. Circuit for Fast PWM Demodulation

For fast demodulator of PWM the IC's LTC2644 was used [13 - 15]. The simplified block diagram of LTC2644 is shown in Fig. 2. The LTC2644 measures the period and pulse width of the PWM input signals and updates the voltage output DACs after each corresponding PWM input rising edge The input frequency is between 30 Hz and 6.25 kHz (12-bit), 25 kHz (10-bit) or 100 kHz (8-bit). The DAC outputs update and settle to 12-bit accuracy within 8µs typically. The most important is that slow analog filter was eliminated. The LTC2644 has a full-scale output of 2.5V using the 10ppm/°C internal reference. It can operate with an external reference, which sets the full-scale output equal to the external reference voltage. Each DAC enters a pin-selectable idle state when the PWM input is held unchanged for more than 60ms. The part operates from a single 2.7V to 5.5V supply and supports PWM input voltages from 1.71V to 5.5V

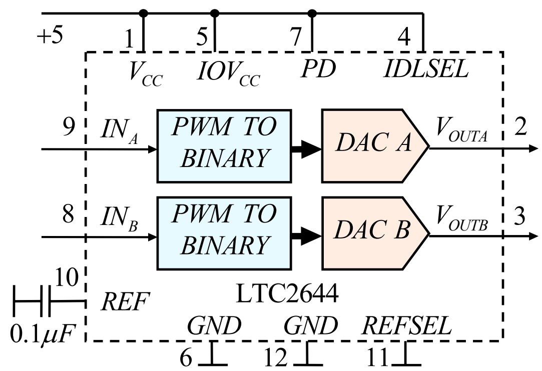

Fig. 2. The circuit diagram of 2 channel PWM/V converter LTC2644. PWM inputs are 8 and 9, voltage outputs are 2 and 3

The demodulated output voltage V_{DEM} can be calculated by the following equation

$$V_{DEM} = V_{REF}\frac{t_1}{T} \quad [\text{V, s}] \tag{7}$$

where V_{REF} is 2.5 V internal reference voltage (or external reference voltage) and t_1 is width of PWM signal and T is period of PWM signal. The measured example of PWM demodulation on every rising edge of input signal is shown in Fig. 3.

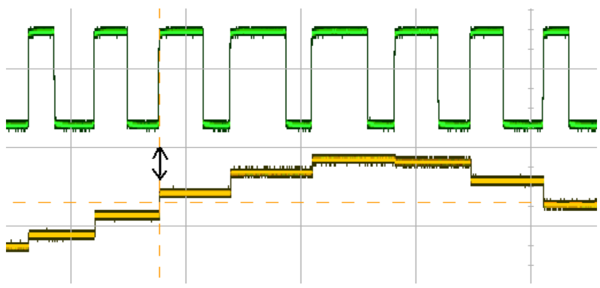

Fig. 3. Th scope of measured the PWM demodulation in every cycle of PWM signal (time evoluation of signals). The PWM signal (top), demodulated voltage output (bottom). The output of the demodulator is updated every rising edge of input signal.

3. Circuit and Measuring Results

In this part the circuits and measuring results are presented. The PWMF modulator based on LTC6992 is displayed in Fig. 4 [16]. V_{PWM} is analog input voltage for PWM modulation and V_{FM} is analog input voltage for FM modulation. Applying a voltage between 0V and 1V on the MOD pin sets the duty cycle. The frequency range is from 3.81 Hz to 1 MHz.

For fixed PWM frequency (without FM modulation) a single resistor, R_{SET}, programs the LTC6992's internal master oscillator frequency. The output frequency is determined by this master oscillator and an internal frequency divider, N_{DIV}, programmable to eight settings from 1 to 16384 (by means of R_1 and R_2) [16]. For $R_{FM}\to\infty$ (fixed PWM frequency) the output PWM frequency is given

$$f_{out}=\frac{5\cdot 10^{10}}{N_{DIV}}\cdot\frac{I_{SET}}{V_{SET}};\, N_{DIV}=1,4,\ldots 16384 \quad \text{[Hz,V,A]} \quad (8)$$

where $I_{SET}=V_{SET}/R_{SET}$ and $V_{SET}\approx 1$ V, therefore

$$f_{out}=\frac{5\cdot 10^{10}}{N_{DIV}}\cdot\frac{1}{R_{SET}};\, N_{DIV}=1,4\ldots 16384 \quad [\text{Hz},\Omega] \quad (9)$$

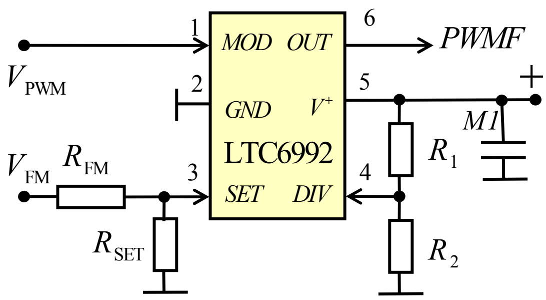

Fig. 4. The circuit diagram of PWMF modulator with LTC6992 IC's. V_{PWM} is analog input voltage for PWM modulation and V_{FM} is analog input voltage for FM modulation.

When the frequency modulation is also used, total current I_T from pin 3 (*SET*) is

$$\begin{aligned} I_T &= I_{SET}+I_{FM}=\frac{V_{SET}}{R_{SET}}+\frac{V_{SET}-V_{FM}}{R_{FM}} \\ &= V_{SET}\left(\frac{1}{R_{SET}}+\frac{1}{R_{FM}}\right)-\frac{V_{FM}}{R_{FM}}=k_1-\frac{V_{FM}}{R_{FM}} \end{aligned} \quad [\text{V, A, }\Omega] \quad (10)$$

where k_1 is constant and output frequency is

$$\begin{aligned} f_{out} &= \frac{5\cdot 10^{10}}{N_{DIV}}\cdot\frac{I_T}{V_{SET}}= \\ & \frac{5\cdot 10^{10}}{N_{DIV}V_{SET}}\cdot\left[V_{SET}\left(\frac{1}{R_{SET}}+\frac{1}{R_{FM}}\right)-\frac{V_{FM}}{R_{FM}}\right]; \quad \text{[Hz, V, A]} \quad (11) \\ & N_{DIV}=1,4,\ldots 16384 \end{aligned}$$

The block diagram of circuit for PWMF modulation/demodulation (with isolation barrier) of 2 separate signals is presented in Fig. 5. For FM demodulation, on the first monostable pulse generator (MPG) is used and output of MPG is connected to one of PWM/V demodulator. The MPG converts FM to PWM. For PWM to voltage the LTC2644 (see Fig. 2) is used. Results are shown in next figures.

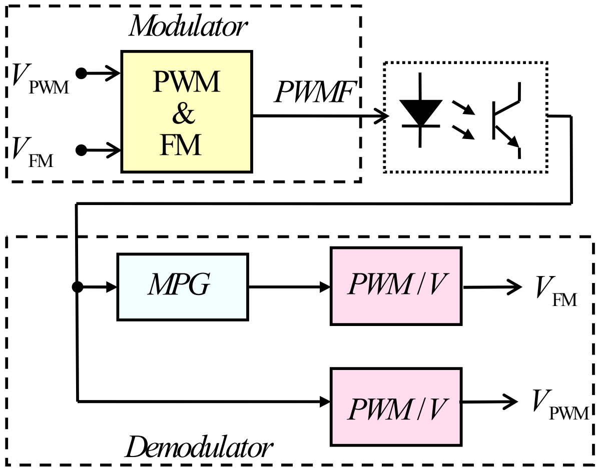

Fig. 5. The circuit diagram of PWMF modulator/demodulator with galvanic separation. PWM & FM – modulator (LTC6992), MPG – monostable pulse generator on every rising edge of PWMF, PWM/V – demodulator (LTC2644).

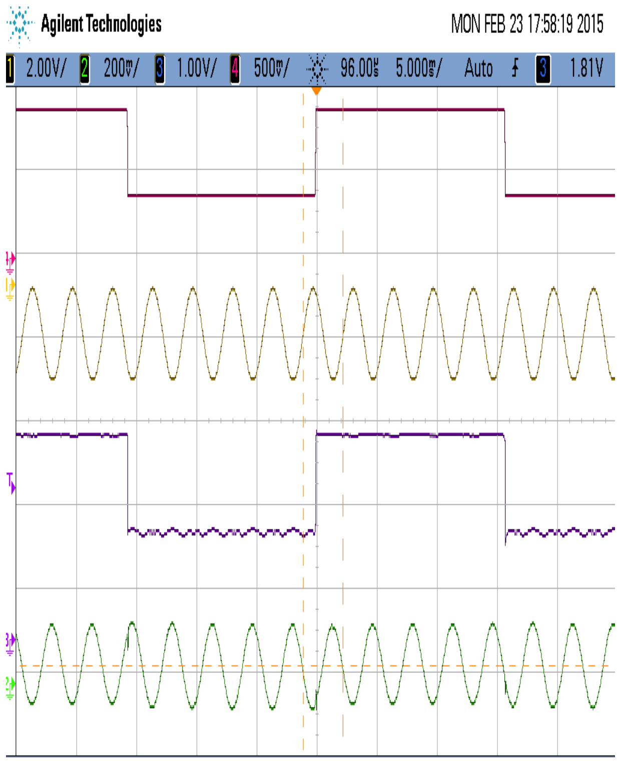

Fig. 6. The example of transmission 2 signals by means of PWMF. First (Top) – PWM modulator input signal, Second – FM modulator input signal, Third - demodulated PWMF signal, PWM output, Botton – demodulated PWMFsignal, FM output.

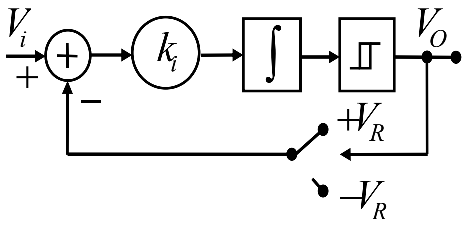

Fig. 7. The block diagram of the first order asynchronous sigma-delta modulator

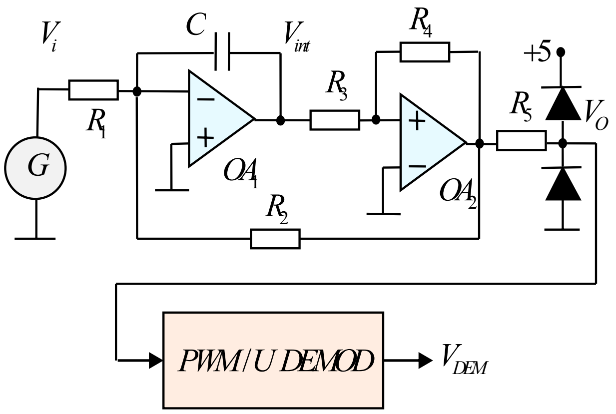

Fig. 8. The circuit diagram of the simple, first order asynchronous sigma-delta modulator and demodulator (For demodulator LTC2644 is used, see Fig. 2). $R_1=R_2=R_3=R_5=10$ kΩ, $R_4=100$ kΩ, C=100 nF, $V_R=$ 10.5 V, *Hys*=2.3 V, OA=TL072

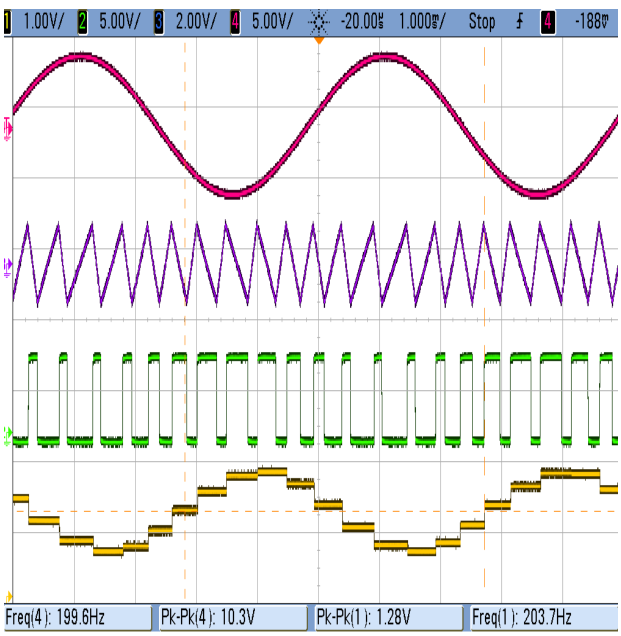

Fig. 9. The example of analog signal transmission by means of ASDM. From top to bottom: Input signal V_i; output of the integrator V_{int}; output of the modulator V_0; demodulator output (bottom)

In the Fig. 6 the modulation and demodulation of the PWMF signal is shown. The first input signal (square wave, frequency=35 Hz) analog signal (on the top) is connected on PWM input of PWM & FM circuit, the second input signal (sine wave, frequency = 300 Hz) is connected on FM input of PWM & FM circuit, the third, is demodulated output V_{PWM} of PWMF signal and bottom is demodulated output of V_{FM} signal.

The fast demodulator (Fig. 2) can be used also for demodulation of ASDM signal, generated by system shown in Fig. 7. An ASDM block diagram (Fig. 7) includes several functional blocks: the summation block, integrator, hysteretic comparator and a switch [17]. The circuit diagram of the simple, first order asynchronous sigma-delta modulator is displayed in Fig. 8 and the signals of ASDM modulator and demodulator are displayed in Fig. 9.

The demodulated output voltage V_{DEM} can be calculated by the following equation

$$V_{DEM} = V_{REF} \frac{t_1}{T} \qquad \text{[V, s]} \qquad (12)$$

where V_{REF} is 2.5 V internal reference voltage (or external reference voltage) and t_1 is width of PWM signal and T is period of PWM signal. This demodulator is not sensitive for input frequency changes (It is important to note that for ASDM output signal – booth, the PWM and frequency are changing).

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5. Conclusions

In this paper was described new approach for fast demodulation of PWM signal and also for FM signal. In conventional PWM, the frequency of the digital output is fixed while its duty cycle changes in proportion to the analog input. In PWMF representation, the digital output has its output frequency and the duty cycle changing (respectively through two different inputs).The new system therefore allows transmit simultaneously PWM an FM signals as 2 independents information in one PWMF signal. The demodulator measures the period and pulse width of the PWM input signals and updates the voltage output DACs after each corresponding PWM input rising edge. The demodulator is not sensitive for input frequency changes. The DAC outputs update and settle to 12-bit accuracy within 8μs typically. The most important is that slow analog filter was eliminated. The fast demodulator can be also separately used as PWM demodulator, FM demodulator (the MPG circuit must be added, see Fig. 5) and demodulator for asynchronous sigma-delta modulator (ASDM). The demodulators are produced in 2 or 4 channel version. The presented systems were described, simulated, constructed and measured. Presented results illustrate a good match.

6. Acknowgledment

This work was supported by the European Regional Development Fund and the Ministry of Education, Youth and Sports of the Czech Republic under the Regional Innovation Centre for Electrical Engineering (RICE), project No. CZ.1.05/2.1.00/03.0094 and by the Internal Grant Agency of University of West Bohemia in Pilsen, the project SGS-2015-002 and partly also by free samples of IC's from Linear Technology.

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