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Using PWM to Generate Analog Output

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Pulse Width Modulation (PWM) modules, which produce basically digital waveforms, can be used as cheap Digital-to-Analog (D/A) converters only a few external components. A wide variety of microcontroller applications exist that need analog output but do not require high resolution D/A converters. Some speech applications (talk back units, speech synthesis systems in toys, etc.) also do not require high resolution D/A converters. For these applications, Pulse Width Modulated outputs may be converted to analog outputs.

Conversion of PWM waveforms to analog signals involves the use of analog low-pass filters. This application note describes the design criteria of the analog filters necessary and the requirements of the PWM frequency. Later in this application note, a simple RC low-pass filter is designed to convert PWM speech signals of 4 kHz bandwidth.

In a typical PWM signal, the base frequency is fixed, but the pulse width is a variable. The pulse width is directly proportional to the amplitude of the original unmodulated signal. In other words, in a PWM signal, the frequency of the waveform is a constant while the duty cycle varies (from 0% to 100%) according to the amplitude of the original signal. A typical PWM signal is shown in Figure 1.

FIGURE 1:   A TYPICAL PWM WAVEFORM
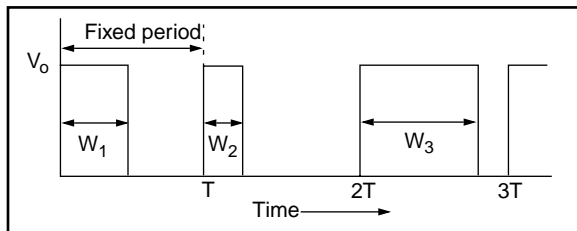
A Fourier analysis of a typical PWM signal (such as the one depicted in Figure 1) shows that there is a strong peak at frequency $F_n = 1/T$. Other strong harmonics also exist at $F = K/T$, where K is an integer. These peaks are unwanted noise and should be eliminated. This requires that the PWM signal be low-pass filtered, thus eliminating these inherent noise components as shown in Figure 2.

**FIGURE 2:   FREQUENCY SPECTRUM OF A PWM SIGNAL**
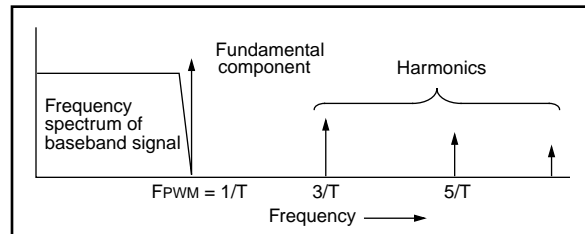
The band-width of the desired signal should be

$$F_{\overline{bw}} <= (F_{PWM} = 1/T)$$

If F_{BW} is selected such that $F_{BW} = F_{PWM}$, then the external low-pass filter should be a brick-wall type filter. Brick-wall type analog filters are very difficult and expensive to build. So, for practical purpose, the external low-pass filter should be as shown in Figure 3.

FIGURE 3:   EXTERNAL LOW-PASS FILTER
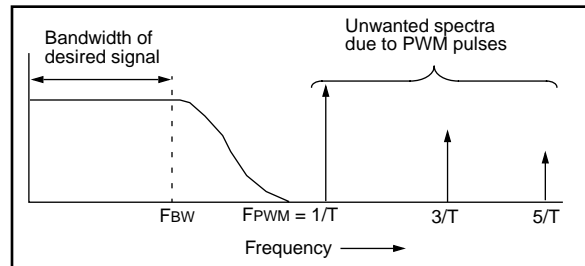
This means, $F_{bw} << F_{PWM}$

$$or \; F_{PWM} >> F_{BW}$$

$$=> F_{PWM} = K \bullet F_{BW} \qquad (1)$$

where, K is a constant such that $K >> 1$

The value of K should be chosen dependant upon the number dB the inherent fundamental noise component of PWM will be rejected. An example follows:
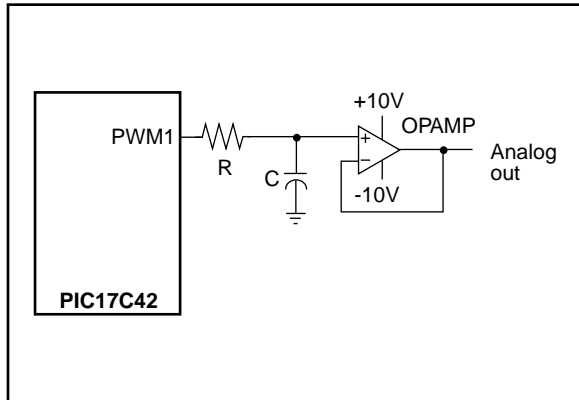
Example: It is required to design a simple RC low-pass filter to obtain an analog output from a pulse width modulated speech signal of bandwidth 4 kHz.

From *eqn (1)*, choosing arbitrarily K = 5,

$$F_{PWM} = K \bullet f_{BW} = 5 \bullet 4 \; kHz = 20 \; kHz.$$

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FIGURE 4: **RC FILTER CONNECTED TO PWM1 OF PIC17C42**

Choosing, the -3 dB point at 4 kHz, and using the relation RC = 1/(2 • π•f), we get R = 4 kΩ, if C is chosen as 0.01 µF:

R = 4.0 kΩ

C = 0.01 µF

Since the PWM frequency is selected as 20 kHz, the fundamental noise peak to be filtered is at 20 kHz. Now, lets calculate by how many dB the main peak of PWM signal is cut-off at 20 kHz:

$$(dB)\ 20\ kHz = -10\bullet log[1+ (2\pi f.RC)2] = -14\ dB.$$

For many applications, this rejection of -14 dB will not suffice. Therefore instead of a simple RC low-pass filter, a higher order active low-pass filter may be necessary. Or, if the microcontroller is capable of modulating at higher PWM frequencies, the rejection of noise will be greater.

For example, using 8-bit resolution, the PIC17C42 can generate PWM frequency of 62.5 kHz.

At this frequency the attenuation of the PWM frequency is:

$$(dB)62.5\ kHz = -10\bullet log[1+ (2\pi f.RC)2] = -24\ dB.$$

The higher frequency of the PIC17C42 PWM outputs makes it easier to generate analog output.

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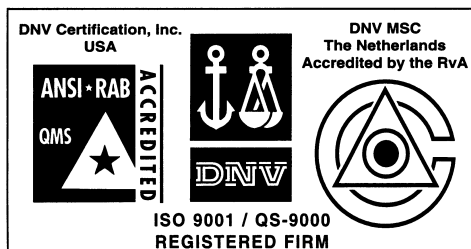
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