# MICROCHIP

AN538

Using PWM to Generate Analog Output

Pulse Width Modulated (PWM) waveforms which are basically digital waveforms, can be used as cheap Digital-to-Analog (D/A) converters with few external components. A wide variety of microcontroller applications exists 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 used to convert to analog outputs.

Conversion of PWM waveforms to analog signals involves the use of analog low-pass filters. This brief 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 pulse-width modulated 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
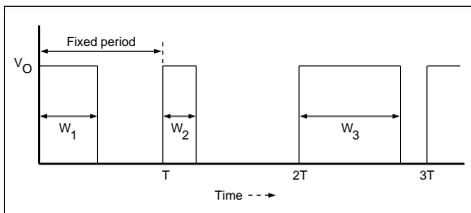
A Fourier analysis of a typical PWM signal (like the one depicted in Figure 1) shows that there is a strong peak at frequency $F_n = 1/T$. Other strong harmonics also exist at $F = K/T$, where K is an integer. These peaks are unwanted noise and should be eliminated. This requires that the PWM signal be low-pass filtered, thus eliminating these inherent noise components (see Figure 2).

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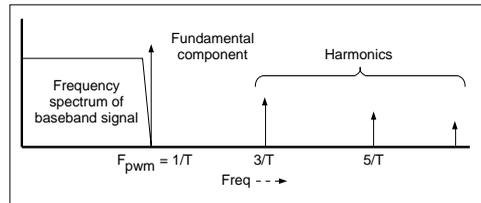
The band-width of the desired signal should thus be

$$f_{bw} \leq (f_{pwm} = 1/T)$$

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
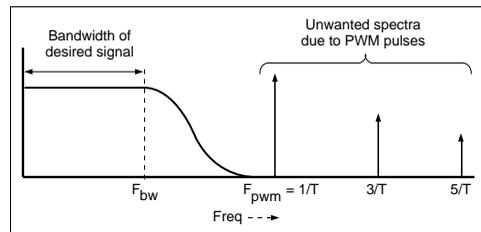
This means, $f_{bw} \ll f_{pwm}$

or $f_{pwm} \gg f_{bw}$

=> $f_{pwm} = K*f_{bw}$ (1)

where, K is a constant such that $K \gg 1$

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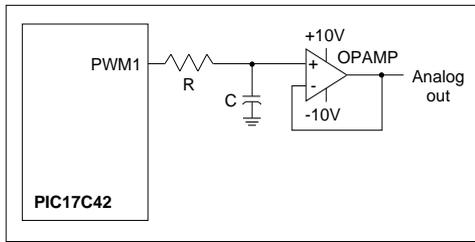
Example : It is required to design a simple RC low-pass filter to obtain an analog output from a pulse width modulated speech signal of bandwidth 4 KHz.

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

$f_{pwm} = K*f_{bw} = 5*4$ KHz = 20 KHz.

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FIGURE 4 - RC FILTER CONNECTED TO
PWM1 OF PIC17C42

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 :

$$R = 4.0 \text{ K}\Omega$$
$$C = 0.01 \text{ µF}$$

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 :

$$(dB)20KHz = -10*\log[1+ (2\pi f.RC)^2] = -14 \text{ dB}.$$

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 more.

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:

$$(dB)62.5KHz = -10*\log[1+ (2\pi f.RC)^2] = -24 \text{ dB}.$$

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

Author: Amar Palacherla
Logic Products Division

WORLDWIDE SALES & SERVICE

AMERICAS

Corporate Office
Microchip Technology Inc.
2355 West Chandler Blvd.
Chandler, AZ 85224-6199
Tel: 602 786-7200 Fax: 602 786-7277
Technical Support: 602 786-7627
Web: http://www.mchip.com/microhip

Atlanta
Microchip Technology Inc.
500 Sugar Mill Road, Suite 200B
Atlanta, GA 30350
Tel: 770 640-0034 Fax: 770 640-0307

Boston
Microchip Technology Inc.
5 Mount Royal Avenue
Marlborough, MA 01752
Tel: 508 480-9990   Fax: 508 480-8575

Chicago
Microchip Technology Inc.
333 Pierce Road, Suite 180
Itasca, IL 60143
Tel: 708 285-0071 Fax: 708 285-0075

Dallas
Microchip Technology Inc.
14651 Dallas Parkway, Suite 816
Dallas, TX 75240-8809
Tel: 214 991-7177 Fax: 214 991-8588

Dayton
Microchip Technology Inc.
35 Rockridge Road
Englewood, OH 45322
Tel: 513 832-2543 Fax: 513 832-2841

Los Angeles
Microchip Technology Inc.
18201 Von Karman, Suite 455
Irvine, CA 92715
Tel: 714 263-1888 Fax: 714 263-1338

New York
Microchip Technology Inc.
150 Motor Parkway, Suite 416
Hauppauge, NY 11788
Tel: 516 273-5305 Fax: 516 273-5335

AMERICAS (continued)

San Jose
Microchip Technology Inc.
2107 North First Street, Suite 590
San Jose, CA 95131
Tel: 408 436-7950 Fax: 408 436-7955

ASIA/PACIFIC

Hong Kong
Microchip Technology
Unit No. 3002-3004, Tower 1
Metroplaza
223 Hing Fong Road
Kwai Fong, N.T. Hong Kong
Tel: 852 2 401 1200 Fax: 852 2 401 3431

Korea
Microchip Technology
168-1, Youngbo Bldg. 3 Floor
Samsung-Dong, Kangnam-Ku,
Seoul, Korea
Tel: 82 2 554 7200 Fax: 82 2 558 5934

Singapore
Microchip Technology
200 Middle Road
#10-03 Prime Centre
Singapore 188980
Tel: 65 334 8870 Fax: 65 334 8850

Taiwan
Microchip Technology
10F-1C 207
Tung Hua North Road
Taipei, Taiwan, ROC
Tel: 886 2 717 7175 Fax: 886 2 545 0139

EUROPE

United Kingdom
Arizona Microchip Technology Ltd.
Unit 6, The Courtyard
Meadow Bank, Furlong Road
Bourne End, Buckinghamshire SL8 5AJ
Tel: 44 0 1628 851077 Fax: 44 0 1628 850259

France
Arizona Microchip Technology SARL
2 Rue du Buisson aux Fraises
91300 Massy - France
Tel: 33 1 69 53 63 20 Fax: 33 1 69 30 90 79

Germany
Arizona Microchip Technology GmbH
Gustav-Heinemann-Ring 125
D-81739 Muenchen, Germany
Tel: 49 89 627 144 0   Fax: 49 89 627 144 44

Italy
Arizona Microchip Technology SRL
Centro Direzionale Colleoni
Palazzo Pegaso Ingresso No. 2
Via Paracelso 23, 20041
Agrate Brianza (MI) Italy
Tel: 39 039 689 9939 Fax: 39 039 689 9883

JAPAN

Microchip Technology Intl. Inc.
Benex S-1 6F
3-18-20, Shin Yokohama
Kohoku-Ku, Yokohama
Kanagawa 222 Japan
Tel: 81 45 471 6166 Fax: 81 45 471 6122

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