AN538

Using PWM to Generate Analog Output

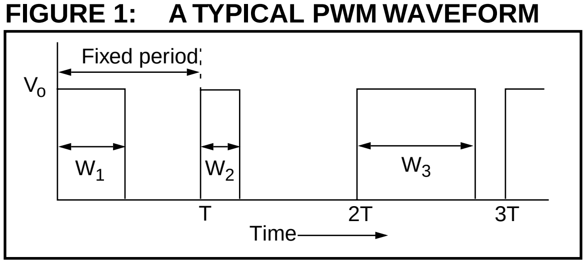
Author: Amar Palacherla
Microchip Technology Inc.

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.

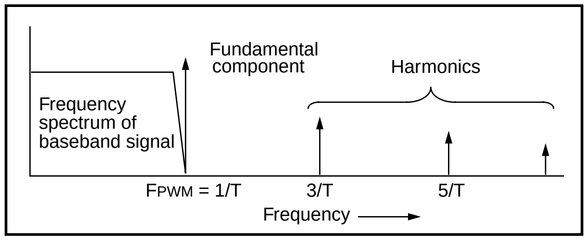
In a typical PWM signal, the base frequency is fixed, but the pulse width is a variable. The pulse width is directly proportional to the amplitude of the original unmodulated signal. In other words, in a PWM signal, the frequency of the waveform is a constant while the duty cycle varies (from 0% to 100%)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

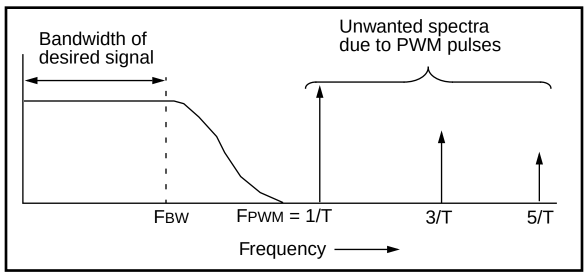


The band-width of the desired signal should be

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

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, $F_{bw} << F_{PWM}$

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

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

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

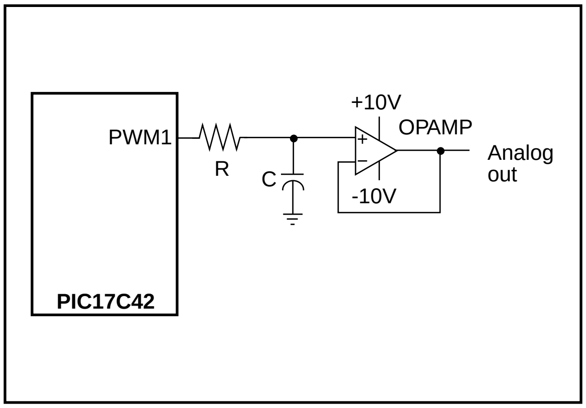
The value of K should be chosen dependant upon the number dB the inherent fundamental noise component of PWM will be rejected. An example follows:

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,

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

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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AMERICAS

Corporate Office
Microchip Technology Inc.
2355 West Chandler Blvd.
Chandler, AZ 85224-6199
Tel: 480-786-7200 Fax: 480-786-7277
Technical Support: 480-786-7627
Web Address: http://www.microchip.com

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

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Tel: 937-291-1654 Fax: 937-291-9175

Detroit
Microchip Technology Inc.
Tri-Atria Office Building
32255 Northwestern Highway, Suite 190
Farmington Hills, MI 48334
Tel: 248-538-2250 Fax: 248-538-2260

Los Angeles
Microchip Technology Inc.
18201 Von Karman, Suite 1090
Irvine, CA 92612
Tel: 949-263-1888 Fax: 949-263-1338

New York
Microchip Technology Inc.
150 Motor Parkway, Suite 202
Hauppauge, NY 11788
Tel: 631-273-5305 Fax: 631-273-5335

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

AMERICAS (continued)

Toronto
Microchip Technology Inc.
5925 Airport Road, Suite 200
Mississauga, Ontario L4V 1W1, Canada
Tel: 905-405-6279 Fax: 905-405-6253

ASIA/PACIFIC

Hong Kong
Microchip Asia Pacific
Unit 2101, Tower 2
Metroplaza
223 Hing Fong Road
Kwai Fong, N.T., Hong Kong
Tel: 852-2-401-1200 Fax: 852-2-401-3431

Beijing
Microchip Technology, Beijing
Unit 915, 6 Chaoyangmen Bei Dajie
Dong Erhuan Road, Dongcheng District
New China Hong Kong Manhattan Building
Beijing 100027 PRC
Tel: 86-10-85282100 Fax: 86-10-85282104

India
Microchip Technology Inc.
India Liaison Office
No. 6, Legacy, Convent Road
Bangalore 560 025, India
Tel: 91-80-229-0061 Fax: 91-80-229-0062

Japan
Microchip Technology Intl. Inc.
Benex S-1 6F
3-18-20, Shinyokohama
Kohoku-Ku, Yokohama-shi
Kanagawa 222-0033 Japan
Tel: 81-45-471- 6166 Fax: 81-45-471-6122

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

Shanghai
Microchip Technology
RM 406 Shanghai Golden Bridge Bldg.
2077 Yan'an Road West, Hong Qiao District
Shanghai, PRC 200335
Tel: 86-21-6275-5700 Fax: 86 21-6275-5060

ASIA/PACIFIC (continued)

Singapore
Microchip Technology Singapore Pte Ltd.
200 Middle Road
#07-02 Prime Centre
Singapore 188980
Tel: 65-334-8870 Fax: 65-334-8850

Taiwan, R.O.C
Microchip Technology Taiwan
10F-1C 207
Tung Hua North Road
Taipei, Taiwan, ROC
Tel: 886-2-2717-7175 Fax: 886-2-2545-0139

EUROPE

United Kingdom
Arizona Microchip Technology Ltd.
505 Eskdale Road
Winnersh Triangle
Wokingham
Berkshire, England RG41 5TU
Tel: 44 118 921 5858 Fax: 44-118 921-5835

Denmark
Microchip Technology Denmark ApS
Regus Business Centre
Lautrup hoj 1-3
Ballerup DK-2750 Denmark
Tel: 45 4420 9895 Fax: 45 4420 9910

France
Arizona Microchip Technology SARL
Parc d'Activite du Moulin de Massy
43 Rue du Saule Trapu
Batiment A - ler Etage
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 München, Germany
Tel: 49-89-627-144 0 Fax: 49-89-627-144-44

Italy
Arizona Microchip Technology SRL
Centro Direzionale Colleoni
Palazzo Taurus 1 V. Le Colleoni 1
20041 Agrate Brianza
Milan, Italy
Tel: 39-039-65791-1 Fax: 39-039-6899883

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