

Suppressing Acoustic Noise in PWM Fan Speed Control Systems

Author: Kyle Gaede
Microchip Technology Inc.

INTRODUCTION

Fan speed control extends fan service life and decreases acoustic airflow noise and average fan current. The most efficient way to implement fan speed control is to use low frequency pulse width modulation (PWM). However, PWM fan speed control can sometimes introduce unwanted acoustic noise at a frequency equal to that of the PWM itself. This is especially noticeable when PWM control is used with higher operating current (>300 mA) fans and at low operating speeds. This application note discusses the source of this acoustic noise and a method to suppress it.

BRUSHLESS DC (BDC) FAN BASICS

BDC fan motors operate in much the same way as mechanically commutated DC electric motors. The basic components of the BDC fan motor are the stator, rotor assembly, rotor position sensor and on-board commutation control chip (Figure 1). The stator is a wound, stationary set of electromagnets connected in a multi-phase configuration. It resides in the fan's frame for better heat dissipation and greater fan frame rigidity. The rotor assembly consists of a soft iron core with permanent magnetic poles that is assembled into a hollow plastic hub with attached fan blades. The rotor assembly is attached to an axle that rides on a pair of center bearings installed in the fan frame such that the rotor's permanent magnets rotate freely about the outside circumference of the stator. The rotor position sensor is typically a Hall effect device, directly actuated by the stator's magnetic poles. The commutation control chip uses the signal from the rotor position sensor to time the sequential switching of each stator phase so that a rotating electromagnetic field is established around the stator. The rotor is set in motion by the magnetic coupling between this rotating electromagnetic field and its own magnetic poles.

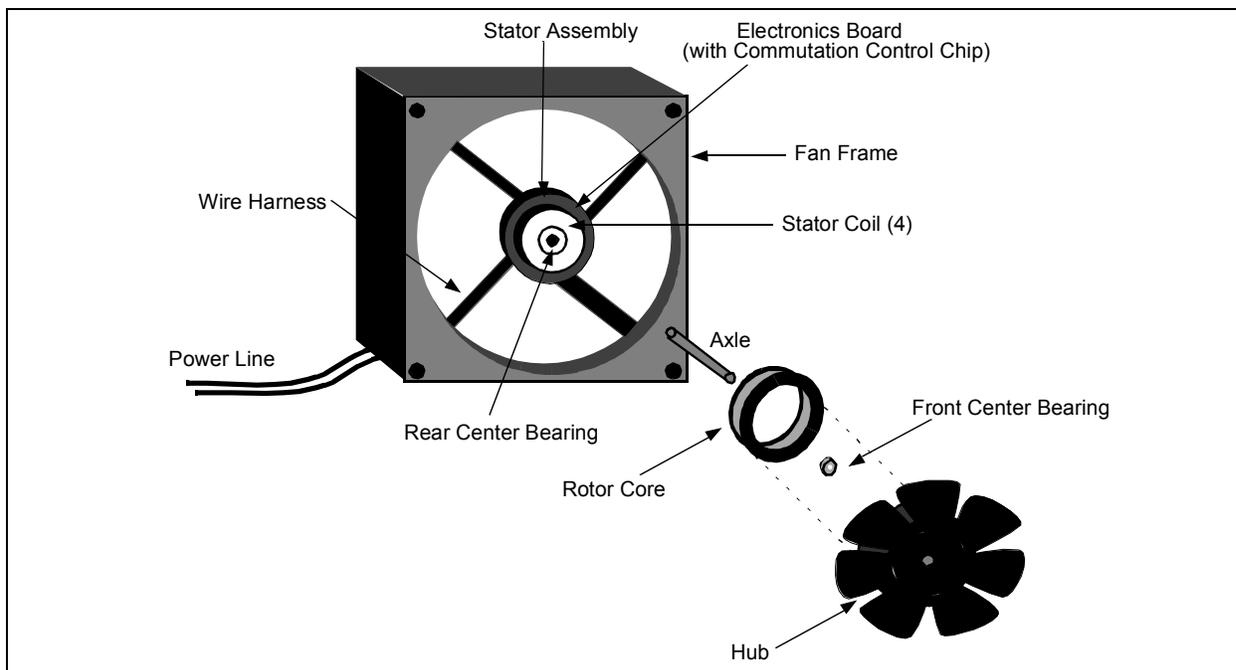


FIGURE 1: Typical BDC Fan.

ACOUSTIC NOISE SOURCES

The most dominant source of acoustic fan noise is turbulent airflow, which is caused by fan operation at full speed. Employing fan speed control (where the fan is operated primarily at lower than full speed) minimizes this noise. The second most dominant acoustic noise is due to BDC fan's torque characteristic. As shown in Figure 2 and Figure 3, stator excitation is a square wave that is switched "on" 45° before peak torque position and switched "off" 45° after peak torque position. This excitation causes a small amount of ripple in motor torque at the frequency of commutation. Each small torque "burst" causes a minute flexing of the entire fan structure and results in a faint (but audible) "ticking" noise while the BDC fan is operating (Figure 2).

Acoustic PWM noise is generated in exactly the same way. When the PWM pulse turns on, a step change in torque occurs within the fan, the profile of which matches the rise time of the PWM pulse (Figure 3). This impulse torque is articulated by the fan structure as audible noise. This is true mostly in larger fans (i.e., fans with operating currents in excess of 300 mA), since they generate a greater amount of torque and have larger size and mass. This effect is also more pronounced at low operating speeds (i.e., low PWM duty cycle): the lower the PWM duty cycle, the greater the percentage of time the fan is "off" (quiet) and the more noticeable the acoustic noise caused by the PWM becomes.

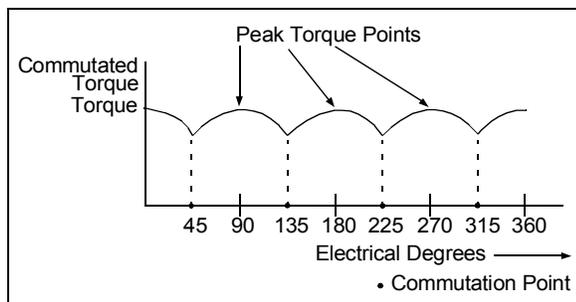


FIGURE 2: BDC Fan Torque Characteristics (Fan Running Continuously).

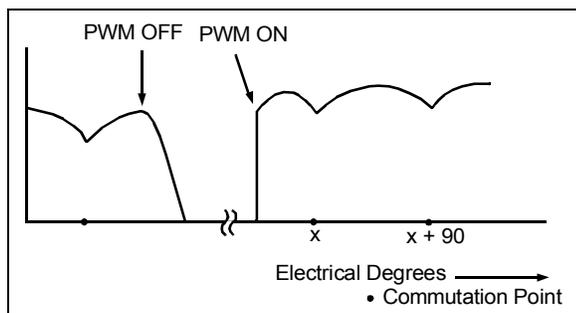


FIGURE 3: BDC Fan Torque Characteristics (PWM Control).

SUPPRESSING PWM NOISE

As previously explained, PWM acoustic noise is caused by the impulse torque generated by the fan motor during each active PWM cycle. Reducing this acoustic noise involves slowing the slew rate of the PWM switching, thereby "smoothing" the PWM impulse torque profile. The circuit in Figure 4 depicts any PWM fan controller (such as Microchip's TC646) driving a low-side switching transistor. The added small base capacitor reduces the slew rate of the driving waveform (and, therefore, the slew rate of the output switching). The value of the capacitor must be determined experimentally, since it is a function of the fan mounting, supply voltage, operating current and torque characteristics. In general, the RC product of the base drive resistor and capacitor should be 1.0 ms to 4.7 ms for a base drive resistor in the range of 1 kΩ to 10 kΩ.

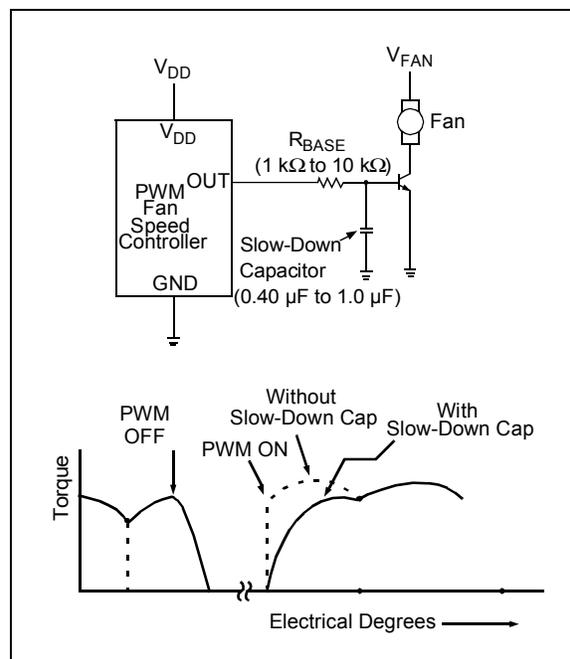


FIGURE 4: PWM Acoustic Noise Suppression Technique.

DRIVING INDUCTIVE LOADS

Inductive kick is another problem that can arise in fans with larger drive currents. As stated earlier, the stator motor is made up of electromagnetic coils. Because all inductors have the property $V = L(di/dt)$, the inductor current cannot go to zero instantaneously. The motor coil, which happens to be energized at the time the switch opens, reverses polarity in an attempt to maintain constant current. The voltage on the ground terminal of the fan can increase to 70V or more. This high voltage can result in damage to the drive transistor. The slow down capacitor prevents this because the transistor is not turned off instantaneously. The slower transition time gives the inductor current time to ramp down before turnoff (see scope plots in Figure 5, Figure 6 and Figure 7).

In Figure 5, trace 1 shows the fan's ground wire voltage, while trace 2 shows the base of the switching transistor. Figure 6 shows the same traces on a different time scale. Figure 7 shows the same fan with the addition of the slow down cap. The large voltage spike is gone and the acoustic noise is reduced dramatically. These plots were taken using the TC646EV and a 400 mA fan.

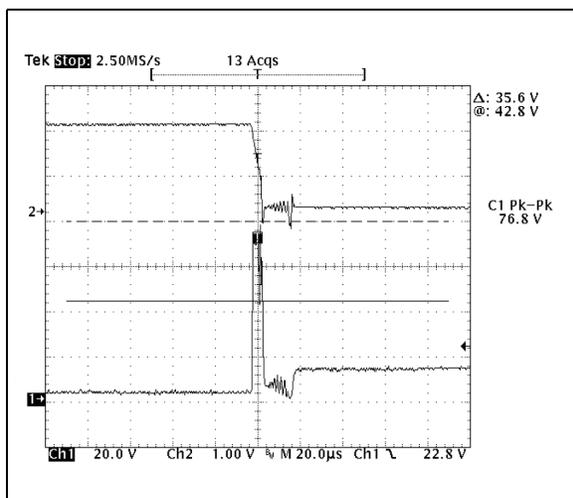


FIGURE 5: Inductive kick voltage spike. No slow down capacitor, 20 μ s time scale.

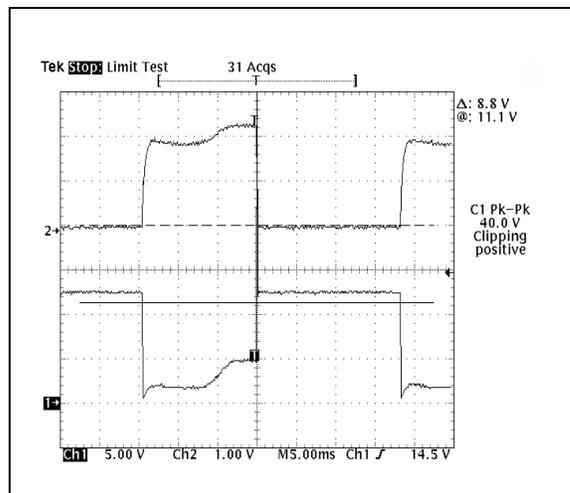


FIGURE 6: Inductive kick voltage spike. No slow down capacitor, 5 ms time scale.

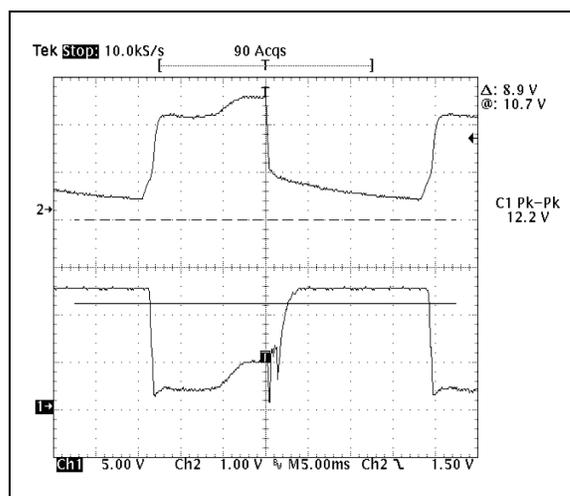


FIGURE 7: Using a 10 μ F slow down capacitor with 1.1 k Ω base resistor. Notice the lack of voltage spike and more rounded edges of Trace 1.

SUMMARY

PWM noise, as well as inductive kick, can be reduced or eliminated by slowing the slew rate of the PWM drive signal to the fan. Even a small reduction in slew rate results in a significant reduction of the PWM noise. The noise-suppression circuit implementation is simple, requiring only the addition of a small capacitor to the base of the PWM switching transistor. For very large fans (more than 500 mA operating current), DC speed control may be required (refer to AN770, "Linear Voltage Fan Speed Control Using Microchip's TC64X Family" (DS00770), for implementing such a circuit).

AN771

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WORLDWIDE SALES AND SERVICE

AMERICAS

Corporate Office

2355 West Chandler Blvd.
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Tel: 480-792-7200 Fax: 480-792-7277
Technical Support: 480-792-7627
Web Address: <http://www.microchip.com>

Rocky Mountain

2355 West Chandler Blvd.
Chandler, AZ 85224-6199
Tel: 480-792-7966 Fax: 480-792-4338

Atlanta

3780 Mansell Road, Suite 130
Alpharetta, GA 30022
Tel: 770-640-0034 Fax: 770-640-0307

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Dallas

4570 Westgrove Drive, Suite 160
Addison, TX 75001
Tel: 972-818-7423 Fax: 972-818-2924

Detroit

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

Kokomo

2767 S. Albright Road
Kokomo, Indiana 46902
Tel: 765-864-8360 Fax: 765-864-8387

Los Angeles

18201 Von Karman, Suite 1090
Irvine, CA 92612
Tel: 949-263-1888 Fax: 949-263-1338

San Jose

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

Toronto

6285 Northam Drive, Suite 108
Mississauga, Ontario L4V 1X5, Canada
Tel: 905-673-0699 Fax: 905-673-6509

ASIA/PACIFIC

Australia

Microchip Technology Australia Pty Ltd
Suite 22, 41 Rawson Street
Epping 2121, NSW
Australia
Tel: 61-2-9868-6733 Fax: 61-2-9868-6755

China - Beijing

Microchip Technology Consulting (Shanghai)
Co., Ltd., Beijing Liaison Office
Unit 915
Bei Hai Wan Tai Bldg.
No. 6 Chaoyangmen Beidajie
Beijing, 100027, No. China
Tel: 86-10-85282100 Fax: 86-10-85282104

China - Chengdu

Microchip Technology Consulting (Shanghai)
Co., Ltd., Chengdu Liaison Office
Rm. 2401-2402, 24th Floor,
Ming Xing Financial Tower
No. 88 TIDU Street
Chengdu 610016, China
Tel: 86-28-86766200 Fax: 86-28-86766599

China - Fuzhou

Microchip Technology Consulting (Shanghai)
Co., Ltd., Fuzhou Liaison Office
Unit 28F, World Trade Plaza
No. 71 Wusi Road
Fuzhou 350001, China
Tel: 86-591-7503506 Fax: 86-591-7503521

China - Hong Kong SAR

Microchip Technology Hongkong Ltd.
Unit 901-6, Tower 2, Metroplaza
223 Hing Fong Road
Kwai Fong, N.T., Hong Kong
Tel: 852-2401-1200 Fax: 852-2401-3431

China - Shanghai

Microchip Technology Consulting (Shanghai)
Co., Ltd.
Room 701, Bldg. B
Far East International Plaza
No. 317 Xian Xia Road
Shanghai, 200051
Tel: 86-21-6275-5700 Fax: 86-21-6275-5060

China - Shenzhen

Microchip Technology Consulting (Shanghai)
Co., Ltd., Shenzhen Liaison Office
Rm. 1812, 18/F, Building A, United Plaza
No. 5022 Binhe Road, Futian District
Shenzhen 518033, China
Tel: 86-755-82901380 Fax: 86-755-82966626

China - Qingdao

Rm. B503, Fullhope Plaza,
No. 12 Hong Kong Central Rd.
Qingdao 266071, China
Tel: 86-532-5027355 Fax: 86-532-5027205

India

Microchip Technology Inc.
India Liaison Office
Divyasree Chambers
1 Floor, Wing A (A3/A4)
No. 11, O'Shaughnessey Road
Bangalore, 560 025, India
Tel: 91-80-2290061 Fax: 91-80-2290062

Japan

Microchip Technology Japan K.K.
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 135-882
Tel: 82-2-554-7200 Fax: 82-2-558-5934

Singapore

Microchip Technology Singapore Pte Ltd.
200 Middle Road
#07-02 Prime Centre
Singapore, 188980
Tel: 65-6334-8870 Fax: 65-6334-8850

Taiwan

Microchip Technology (Barbados) Inc.,
Taiwan Branch
11F-3, No. 207
Tung Hua North Road
Taipei, 105, Taiwan
Tel: 886-2-2717-7175 Fax: 886-2-2545-0139

EUROPE

Austria

Microchip Technology Austria GmbH
Durisolstrasse 2
A-4600 Wels
Austria
Tel: 43-7242-2244-399
Fax: 43-7242-2244-393

Denmark

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

France

Microchip Technology SARL
Parc d'Activite du Moulin de Massy
43 Rue du Saule Trapu
Batiment A - 1er Etage
91300 Massy, France
Tel: 33-1-69-53-63-20 Fax: 33-1-69-30-90-79

Germany

Microchip Technology GmbH
Steinheilstrasse 10
D-85737 Ismaning, Germany
Tel: 49-89-627-144 0 Fax: 49-89-627-144-44

Italy

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

United Kingdom

Microchip Ltd.
505 Eskdale Road
Winnesh Triangle
Wokingham
Berkshire, England RG41 5TU
Tel: 44 118 921 5869 Fax: 44-118 921-5820

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