**INTRODUCTION**

Brushless DC fan (BDC) speed can be varied using pulse-width modulation (PWM). The typical PWM control scheme inserts a power switch in series with the fan, as shown in Figure 1. In such applications, an increase in the active duty cycle causes a corresponding increase in fan speed (i.e., fan speed is proportional to \( t_{ON} / (t_{ON} + t_{OFF}) \)). Conventional wisdom states that PWM duty cycle alone determines operating speed (for example, the fan speed runs at 50% of maximum when the PWM duty cycle is 50%). In reality, the fan operates at a higher percentage of full speed for any given duty cycle. The resulting difference between actual fan speed and the corresponding PWM duty cycle (herein referred to as Speed Error) can be problematic in open loop fan control systems.

Speed Error is attributed to both the mechanical characteristics of the fan and the discontinuous nature of PWM speed control. The fan's rotating hub has mass and, therefore, stores rotational energy when the PWM is in its ON state (i.e., when power is applied). The low friction afforded by the fan's center bearings preserve a portion of this stored energy when the PWM is in its OFF state. This residual energy is carried forward into the next PWM ON cycle. Fan speed increases until an equilibrium is struck between mechanical frictional losses and added rotational energy during PWM ON periods. The resulting speed versus PWM duty cycle error is a function of the mass and diameter of the fan hub, the torque characteristics of the fan motor and the losses in the center bearings. Air temperature and humidity also contribute to speed error, but not significantly.

Figure 1 shows the measured speed of three different sized fans that are controlled by a 30 Hz PWM. Fan 1 is a 1 1/2 inch, 12V, 80 mA (max) fan that is typical of CPU chip-cooling fans. Fan 2 is a 3 1/2 inch, 12V, 200 mA (max) fan similar to those used in the typical PC power supply. Fan 3 is also a 12V, 3 1/2 inch fan, but has a 460 mA (max) current spec. The “ideal” response is intuitively what one would expect — percentage of full speed exactly equal to PWM duty cycle. Fan 1, the smallest of the three fans, comes closest to matching this curve (due to its low mass/low torque characteristics). Fan 2 has both greater physical size and greater mass than Fan 1 and, as a result, operates at a higher speed than Fan 1 for every value of PWM duty cycle. Fan 3 is physically the same size and mass as Fan 2, but has higher torque, causing its operating speed to be slightly above that of Fan 2. As shown, all curves converge when the PWM duty cycle is 100%.

![Figure 1: Measured Speed vs. PWM Duty Cycle.](image-url)
COMPENSATING FOR SPEED ERROR IN PWM FAN CONTROL SYSTEMS

Speed error is not a problem when the fan control system is closed loop in nature (such as a fan controller referenced to a local temperature). In this case, a temperature increase is answered by an offsetting increase in fan speed (airflow) until temperature is returned to normal. Another common closed loop fan control technique relies on fan speed feedback (usually a fan tach signal). In either case, the control loop drives the fan hard enough to satisfy the feedback loop.

To compensate for fan speed error in an open loop system, it is first necessary to characterize the fan speed versus PWM duty cycle under typical system conditions. This can be accomplished using either an optical (strobe) tachometer or by monitoring fan current (measuring the time between the fan commutation pulses at various speeds versus full speed). With this characteristic known, the correct PWM duty cycle for a given fan speed can be used in the open loop system. As seen in Figure 1, the result of this typically indicates that the use of a lower duty cycle in order to get the desired fan speed is necessary.

SUMMARY

When using PWM fan speed control, there will be a difference between the PWM duty cycle and the % of full fan speed. This difference will vary based on the fan being used. If the system is to be open loop, the fan speed vs duty cycle relationship should be characterized in order to obtain the desired results.
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**AMERICAS**

**Corporate Office**
2335 West Chandler Blvd.
Chandler, AZ 85224-6199
Tel: 480-792-7200 Fax: 480-792-7277
Technical Support: 480-792-7627
Web Address: http://www.microchip.com

**Rocky Mountain**
2335 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: 770-640-0634 Fax: 770-640-0307

**Boston**
2 Lan Drive, Suite 120
Westford, MA 01886
Tel: 978-692-3848 Fax: 978-692-3821

**Chicago**
333 Pierce Road, Suite 180
Itasca, IL 60143
Tel: 630-285-0071 Fax: 630-285-0075

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

**Kokomo**
2767 S. Albright Road
Kokomo, IN 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**
6205 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
Tel: 61-2-9868-6733 Fax: 61-2-9868-6755

**China - Beijing**
Microchip Technology Consulting (Shanghai) Co., Ltd., Beijing Liaison Office
Unit 915
Beihai 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 Hong Kong 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 India Pvt. Ltd
India Liaison Office
Divyasree Chambers
1 Floor, Wing A (A3/A4)
No. 11, O'Shaugnesssey 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
Canagawa, 222-0033, Japan
Tel: 81-45-471-6168 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 Nordic ApS
Regus Business Centre
Lautrup holj 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 Trapi
Batiment A - ler 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
Via Taurina 1 V. Le Colleoni 1
Centro Direzionale Colleoni
20041 Agrate Brianza
Tel: 33-1-69-53-63-20 Fax: 33-1-69-30-90-79

**United Kingdom**
Microchip Ltd.
505 Eskdale Road
Windsor Triangle
Wokingham
Berkshire, England RG4 1ST
Tel: 44 118 921 5869 Fax: 44-118 921-5820

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