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Speed Error in PWM Fan Control Systems

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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%.

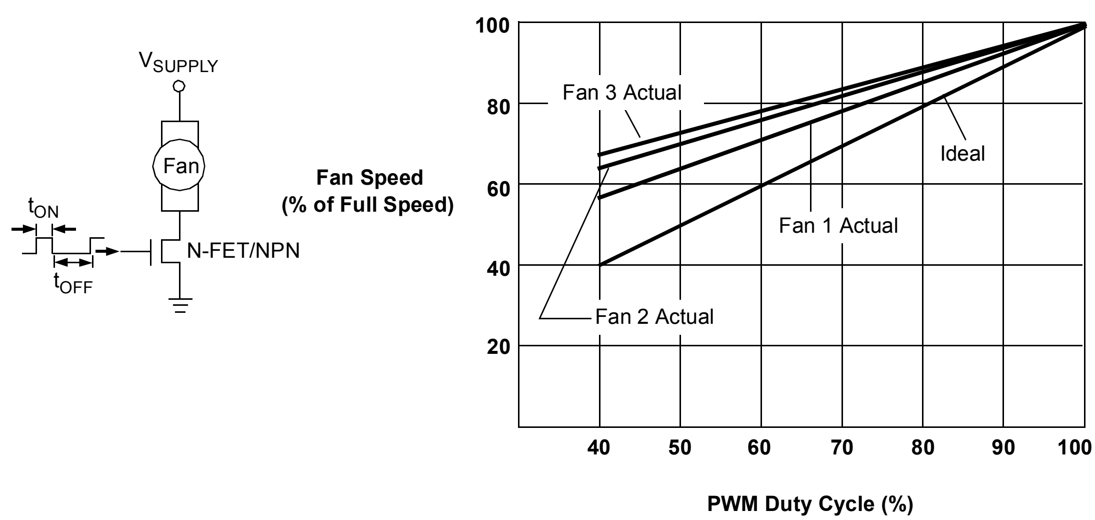

FIGURE 1: *Measured Speed vs. PWM Duty Cycle.*

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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12/05/02