AN3530

PID Fan Speed Control for 4-Wire Fans

Introduction

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In today's electronics, air moving fans provide a critical service in that they cool the system power electronics. However, just running the fan at full speed has a disadvantage in that it can produce significant audio noise. Therefore, most modern systems regulate the speed of the fan so they can balance the requirements of cooling and noise abatement.

Given that the fan speed is also significantly affected by restrictions on the airflow, both into (dirty air filter) and out of (blocked outlet ports) the fan, some form of fan speed regulation is typically needed to maintain consistent cooling. This application note will cover a relatively simple, low-cost solution for managing the fan speed, using a software-based Proportional Integral Differential (PID) fan speed control.

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1. Design Specifications

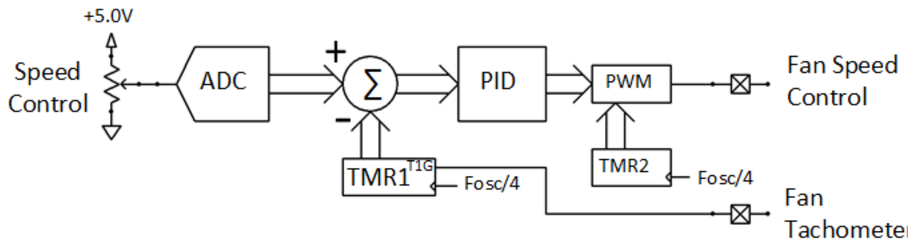
To implement a speed control for a common DC brushless fan, the following items are required:

- A 4-wire fan with both a tachometer output and speed control input
- A frequency counter peripheral to measure the tachometer output (fan speed)
- Either an analog drive (0-12V) or a digital PWM (0-12V)
- A Proportional/Integrator/Differentiator (PID) to provide phase/gain compensated feedback

2. Hardware Theory of Operation

The microcontroller used in the design will be a PIC16F15244 that incorporates a 10-bit PWM, 10-bit ADC and 16-bit gated timer. The PWM will provide the control signal to the fan. The ADC will monitor the control potentiometer, comprising a simple speed control user interface. And, the 16-bit gated timer will monitor the fan speed by measuring the period (1/frequency) of the tachometer output from the fan. The PID algorithm that closes the feedback loop will be a PID algorithm implemented in firmware. Figure 2-1 shows the block diagram of the speed control system.

Figure 2-1. PID Fan Speed Control System



Another option for measuring the speed of the fan is to combine TMR0 and TMR1 to create a frequency counter. While this removes the requirement for a 16-bit divide to get the frequency, it has the problem that the resolution of the speed measurement would be very limited. When the fan is running at 14000 RPM, it only produces 56000 pulses per minute or 933 Hz. Assuming 10 measurements per second, that is only a count of 93 at maximum speed. Given the sample rate is only 10 Hz, the update rate for the PID would also be significantly limited, requiring 10s to 100s of seconds to settle in response to a change.

The ADC periodically measures the output voltage of the potentiometer to obtain the designed speed. The output of TMR1 is then subtracted from the ADC result to get an error value.

The error value is then loaded into the software PID controller. This software function generates a straight multiple of the error (the P component of a PID). The software also integrates the error function over multiple cycles to generate the I component of the PID. Finally, the software PID also differentiates the error function over multiple cycles to generate the D component of the PID. The three values, P, I and D, are then summed and output to the PWM.

The PWM is generated based on the output of TMR2. TMR2 runs continuously, resetting to zero when the maximum period is reached. The PWM module monitors the output of TMR2, setting the PWM output when TMR2 rolls over and then clearing the PWM output when the duty cycle register matches the TMR2 output.

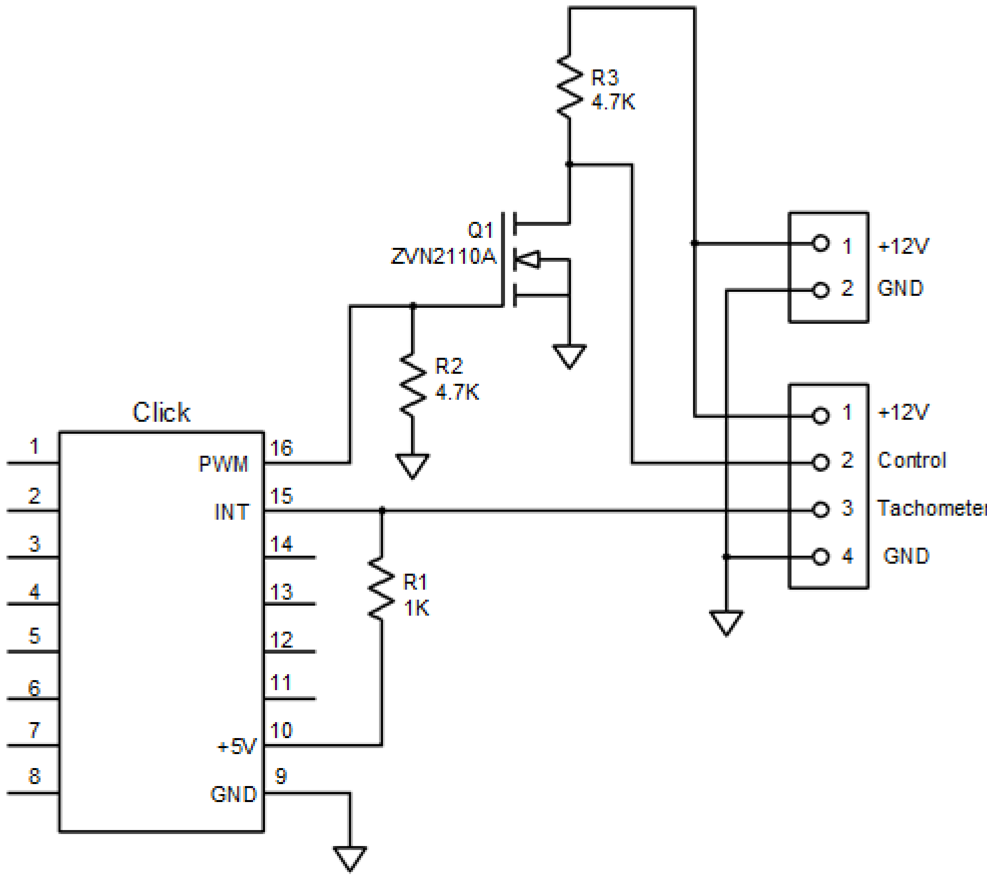
2.1 Tachometer Input and Fan Speed Drive

The tachometer output of the fan is an open collector, so to electrically connect the tachometer output to T1G will require a pull up to 5.0V. Connecting the fan speed control to the PWM will require a similar interface; the PWM output is connected to a ZVN2110 N channel MOSFET to create an open collector output, and then a pull up to 12V provides the high side output for the fan.

Note:
Because the MOSFET will invert the output of the PWM peripheral, the 0-99.9% duty cycle range of the PWM will be converted into a 100-0.1% duty cycle. The firmware must account for this to provide the correct control range for the fan.

To implement the system for this example, a prototype Click board was modified with the MOSFET output transistor and the two pull-up resistors. The schematic of the board is shown below.

Figure 2-2. Prototype Click Board with Fan Interface

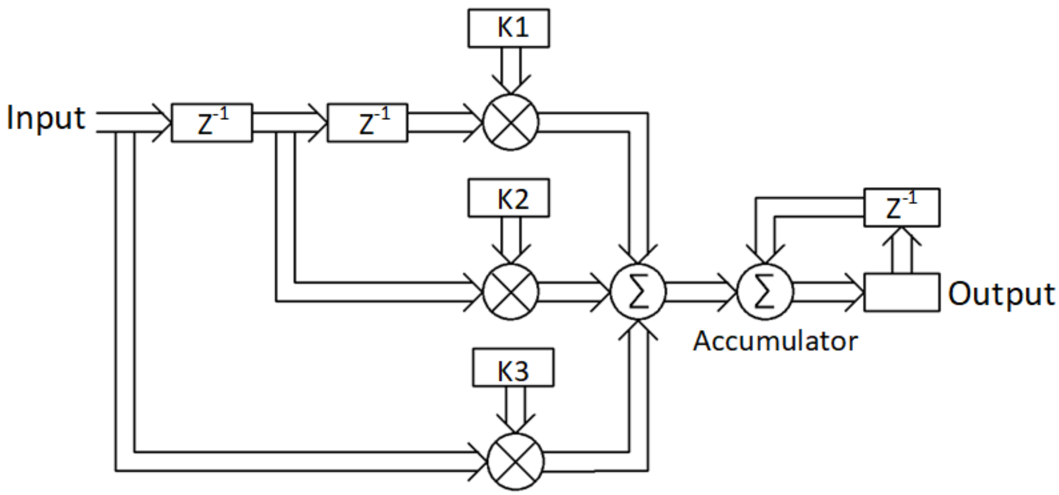


3. PIC Control

In control theory, a PID controller takes the difference between the desired and actual outputs and converts them into three terms: proportional, integral and differential. The proportional term is a simple multiplication of the difference. The integral term is a summation of the current and previous inputs. And, the differential term is the difference between the current and previous inputs. The proportional term drives the output toward a minimal difference between desired and actual outputs. The integral term drives the output toward a zero difference between the desired and actual output by integrating long term non-zero error terms. The differential term acts as a stabilizing factor, which slows the approach to a zero error to prevent overshoot.

For an in-depth explanation of a PID system, refer to TB3136: PID Control on PIC16F161X by using a PID Peripheral for a derivation of the discrete-time PID function. In this application note, it skips to the end and shows the final function. See Figure 3-1.

Figure 3-1. PID System Function



Each (Z^{-1}) is a single sample time delay, i.e., the value is from the previous calculation. This, combined with the accumulate function on the output, provides the proportional, integral and differential terms for the PID.

Note: The K_p, K_i and K_d terms don't translate directly from the frequency domain. Instead, the following are the constants for the time domain version of the PID function. The term "T" is the sampling period of the discrete-time system. For this design, T = 100 ms, the sample time for the tachometer frequency counter circuit.

$$K1 = K_p + K_i T + \frac{K_d}{T}$$

$$K2 = K_p - \frac{2K_d}{T}$$

$$K3 = \frac{K_d}{T}$$

4. Tuning the PID

To tune a PID system, there are two basic approaches; manual tuning and simulation. While simulation has a definite appeal, creating sufficiently accurate simulations is not a trivial task and well beyond the scope of this application note. Therefore, a manual tuning procedure is the only procedure that will be presented here.

There are several strategies for manual tuning of PID controllers. The following is a simple technique that usually produces reasonably stable results.

- Connect a scope to the PWM output
- Start with K_p, K_i and K_d at zero
- Increase K_p until the system oscillates. This will appear as two overlapped pulses
- Increase K_d until the oscillations stop
- Increase K_i until the fan speed is within an acceptable tolerance desired
- Switch the setpoint between the minimum and maximum speeds, at 30-40 second intervals
- If the speed overshoots or undershoots, increase K_d until the system is critically damped
- Increase K_p until the acquisition time is acceptable
- If oscillation occurs, increase K_d until the oscillations stop
- If necessary, tune K_i until the fan speed is back within the acceptable tolerance
- Repeat 6-10 until response time, stability and speed tolerance are acceptable

Note: Different fans, ducting and power supply voltages will affect PID tuning. To determine the production values for K_p, K_i and K_d, tune multiple systems (different fans, power supplies, ducting) to establish a range for each of the constants and then chose values that will remain within the specification over the range of systems.

To tune the project, three 10k potentiometers were added to the design and connected to RC2, RC3 and RC4. Originally, they drove the K_p, K_i and K_d constants of the PID. After tuning, it was discovered that the K_d constant is not needed and, therefore, has no effect on the stability of the system. At that point, RC2 was redefined at the target speed. The lack of effect from the K_d constant is likely due to the uni-directional drive of the PWM, which can increase the speed. However, slowing is due to inertia and the load on the fan, so the derivative term does not have a means of actively slowing the speed of the fan. Subsequent discussions with a co-worker with experience in fan design indicated that the manufacturers of digitally controlled fans do not use the derivative term either.

5. Conclusion

In this application note, a simple low-cost PID fan speed control subsystem was demonstrated. Using a PWM and gated timer peripherals, plus a simple software PID feedback speed control, the design easily fits within most PIC® microcontrollers with the necessary peripherals. Furthermore, the subsystem is sufficiently self-contained and can be combined with CPU supervisory, RTCC or serial EEPROM functions within a common microcontroller, making a true system supervisor on a chip.

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ISBN: 978-1-5224-6265-1

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