AVR442: PC Fan Control using ATtiny13

Features

- **Variable speed based on:**
  - **Temperature sensor (NTC).**
  - **External PWM input.**
- **Stall detection with alarm output.**
- **Implementation in C code to ease modification.**

1 Introduction

This application note describes the operation of 12 volt DC cooling fans typically used to supply cooling air to electronic equipment: These fans are typically based on two-phase Brushless DC (BLDC) motors drawing between 1 and 50 watts of power. Single-phase brushless DC motors are also used in fans, but this is outside the scope of this application note.

Further discussion describes the addition of an Atmel ATtiny13 microcontroller and the benefits this offers, such as variable speed by external thermistor input. An additional input is a PWM pulse width-varying signal, which also controls fan speed.

**Figure 1-1.** The typical PC fan used for cooling computer power supplies.

2 Theory of Operation

12-volt DC cooling fans consist of a rotor-blade assembly containing a permanent magnet, and a 2- or more pole stator. A magnetic sensor, called a Hall sensor, detects the rotating magnetic field and switches 12VDC from one stator coil to another. Varying the supplied DC voltage can vary the speed of most fans. A 12VDC fan might start rotating with 4-5 VDC applied, and increase its speed when increasing voltage is supplied.

Figure 2-1. Two-pole BLDC fan.
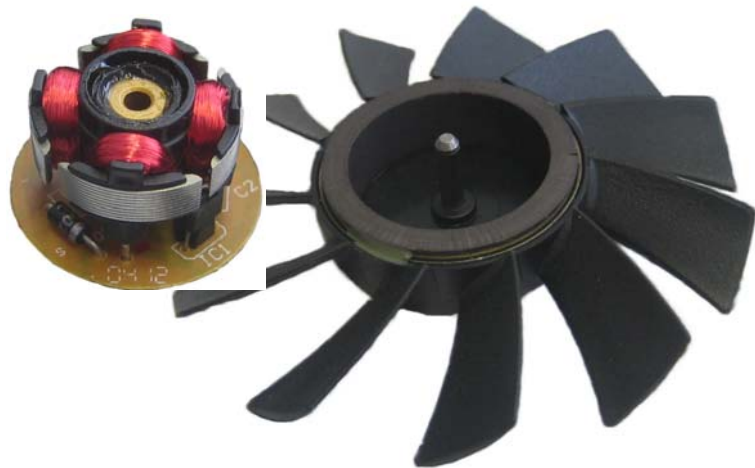
2.1 Dumb Fan Design

Dumb fans have no microcontroller (MCU). The schematic of such a fan could be as simple as one shown in Figure 2-2. Notice that there are 2 coils. Two coils simplify the drive electronics and offer a lower cost of manufacture. There is no provision to control the fan by an external signal. Some fans contain a slightly less dumb control IC such as an LB1668, which can detect a stalled rotor, and disable power to prevent burn up. This type of controllers does however not offer speed control based on e.g. a thermistor input.
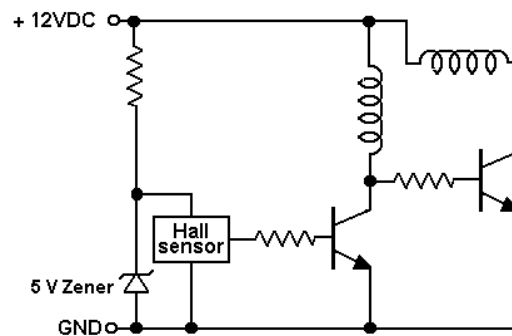
Figure 2-2. Dumb fan schematic

Figure 2-3 shows an actual oscilloscope screen shot, notice how the Hall device supplies one transistor's base drive signal, and the second transistor's base is the electrical inverse. This is the waveforms present when the Tiny13 is generating these signals and running the fan at full power. The Tiny13 controls the speed of the fan by pulse width modulating (PWM) these two base drive signals, described below.

Figure 2-3. Oscilloscope photo of fan waveform with 100% drive
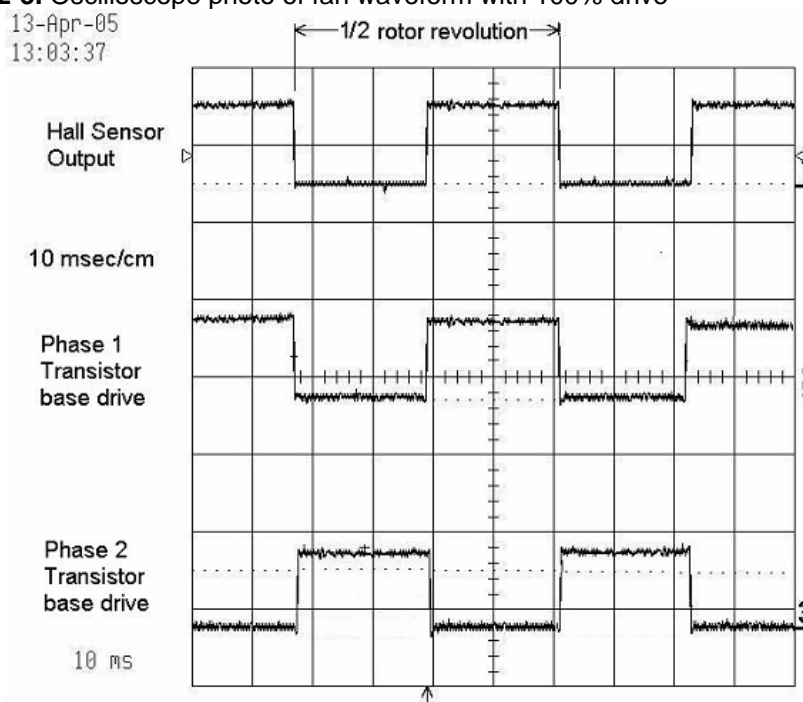
2.2 Commutation

Controlling the currents or voltages in the motor phases in an effort to optimize motor performance can be achieved mechanically or electrically.

2.2.1 Commutator

A commutator is a mechanical device in a brushed DC motor that passes current from the brushes to the windings. The commutator and brushes shown in Figure 2-4 are completely eliminated with the use of a Hall sensor and two transistors. Small motors are well suited to this motor drive approach.

Figure 2-4. Commutator and brushes

2.2.2 Commutation using the ATtiny13

The Tiny13 can take good advantage of the Hall sensor. Commutation is done electrically, in response from the output of the Hall Sensor. The Hall sensor used in this application is a 3 terminal device similar to the one shown in Figure 2-5, requiring approximately 5 VDC and ground. It has one digital output pin which switches between 0 VDC and 5VDC, as a function of a nearby magnetic field.

3

**Figure 2-5.** Hall sensor

2.3 Smart Fan Design

The Tiny13 has two outputs ideal for controlling current to two phases of a motor, PB0 and PB1, shown in Figure 2-6. These are the pins of the two Output Compare outputs, which are controlled by Timer0 and the output Compare registers, OCR0A and OCR0B.

A MCU can add significant benefits to a fan's performance:

- Allow 1 or more control inputs, such as thermistor or PWM input
- Reduce fan noise and power consumption until temperature rises
- Respond to ambient air temperature changes
- Allow custom performance parameters, such as fan speed ramp-up profiles
- Vary fan power by the access of software look up tables (LUT)
- Detect a slow or stalled rotor, and provide an Alarm output

Figure 2-6. Smart fan schematic
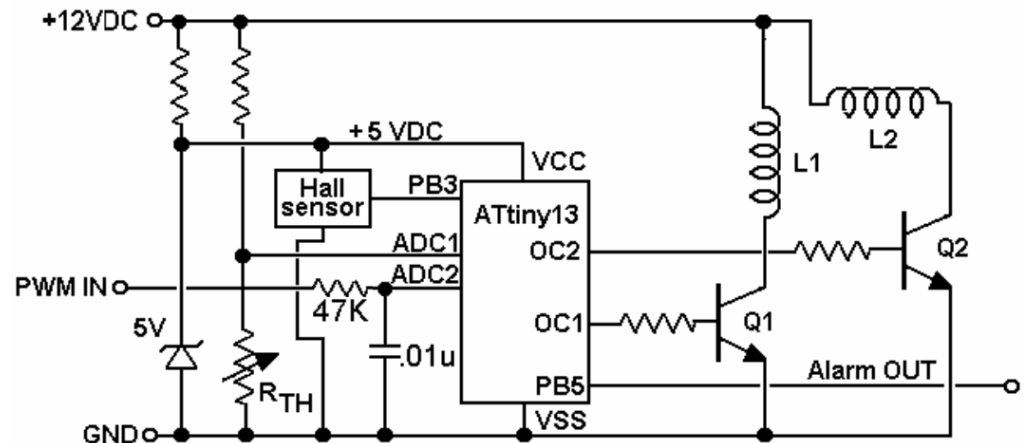
2.3.1 Tiny13 Implementation

The Atmel tiny13 MCU is ideally suited for fan control for the following reasons:

- Output pins source or sink 20 milliamps
- Timer Counter has dual PWM outputs, ideal for a 2 phase fan
- Low supply current even at 4.8 to 9.6 MHz clock speeds
- Advanced MCU core architecture of 32 registers simplifies programming

- Four channel Analog-to-Digital Converter (ADC) allows thermistor and PWM control
- One instruction per clock cycle: 4.8 to 9.8 MIPS (9.8 million instructions/sec)
- Excellent and free AVR Studio 4 Integrated Design Environment (IDE) and DebugWire interface for on-chip debugging.
- Small 5mm by 6 mm surface mount (S8S1) package simplifies PC board layout

2.4 Thermistor Characteristics

A 10K ohm NTC thermistor and a 10 K series resistor was used and the Voltage vs. Temperature curve could look like the one shown in Figure 2-7.

Figure 2-7. Thermistor response
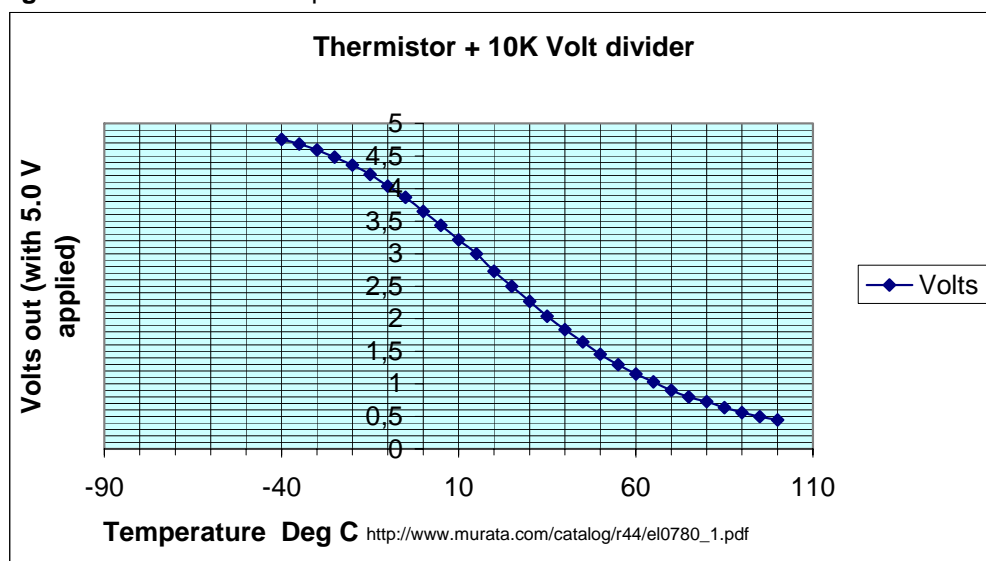
3 Implementation

Described here are the minimum features recommended to implement when running a fan with the Tiny13.

3.1 Basic Control Techniques

- For this application, the Tiny13 was set to run at 4.8 MHz, using its internal RC oscillator. No crystal or resonator is necessary.
- The 10-bit Analog-to-Digital Converter (ADC) is used to read a Negative Temperature Coefficient (NTC) thermistor, connected with another resistor as a voltage divider. Only 8 bits of resolution are necessary for smooth fan speed changes in response to a temperature change.
- A software Look Up Table (LUT) was created in the Tiny13's 1Kbyte flash memory space. This LUT contains 8-bit numbers that represent various power levels to operate the fan motor at.
- The program uses the ADC value to access a location in this table.
- The Tiny13's counter-timer, Timer0, is running at system clock. This gives a timer overflow and PWM period of 53 us. The PWM frequency is then 18,75 kHz, which is above the audible range of hearing.

- The PWM outputs run at a 18,75 kHz frequency, and by using Timer0's Output Compare function, the PWM outputs can operate at a minimum duty cycle of 0%, 255 steps up to 100% duty cycle. 100% corresponds to full power. A typical fan motor could start rotating at 25-30% PWM.

- If the fan rotor is stalled, a software timer (incremented on each interrupt) will time out and shut down the fan power for nominally 10 seconds then re-start the fan.

- An output pin has been designated as an Alarm Output. This alerts the host system of a fault condition, such as a stalled rotor.

Figure 3-1. Program flowchart
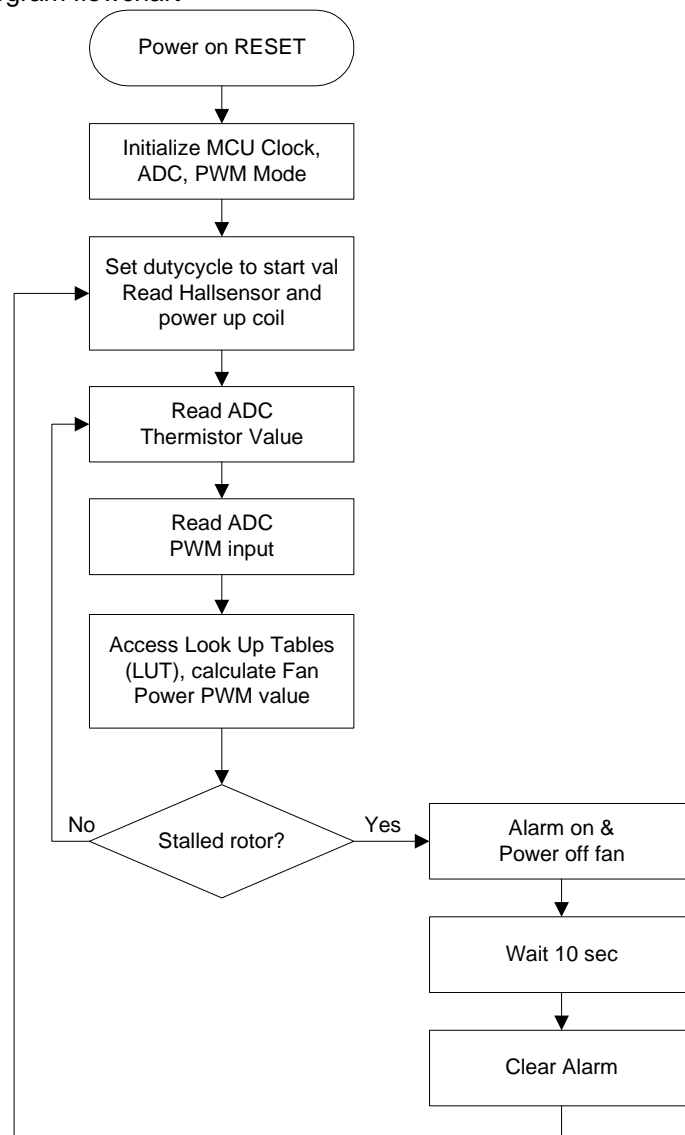
3.1.1 Commutation

Commutation is accomplished by the Hall sensor signal triggering a pin change Interrupt routine, which set OCR0A or OCR0B to be active according to Hall sensor signal level. Figure 3-2 shows the program flow in the pin change interrupt service routine (ISR). The stall time counter is reset so it always counts the time since the last Hall sensor signal.

Figure 3-2. Pin change ISR
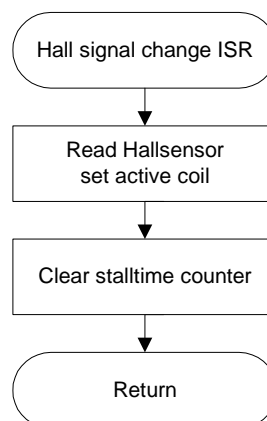
3.1.2 Time delays / stall detection

The compare value is updated only at timer overflow, the buffers are double buffered in PWM mode so it is not necessary with this timing, but it is good coding style to do so. Stall-time and delay counters are incremented, and stall flag is set if stall time is longer than stall limit. Figure 3-3 shows the program flow of the timer interrupt service routine (ISR).

Figure 3-3. Timer overflow ISR
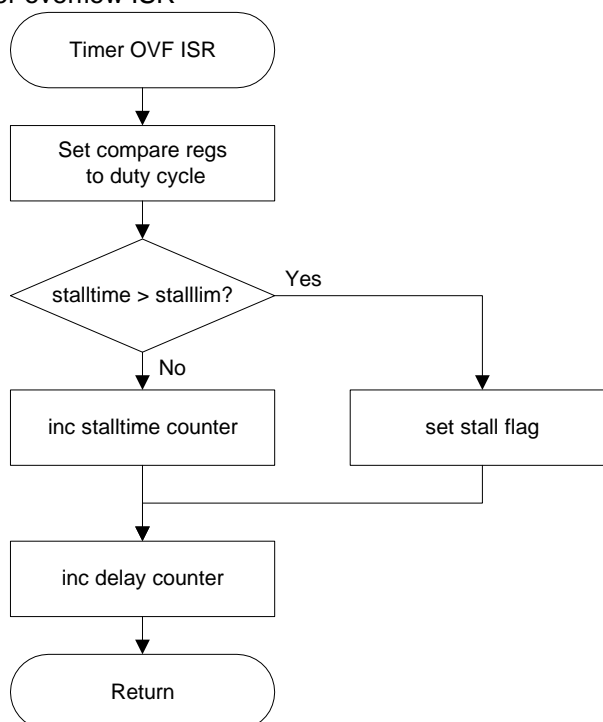
3.1.3 Resulting waveforms

Figure 3-4 shows Hall signal and Tiny13 software controlling PWM outputs running at 47% duty cycle. Note the rotor has four magnetic poles, so one rotor revolution is two Hall sensor cycles.

Figure 3-4. Oscilloscope photo of fan waveform with 47% duty cycle
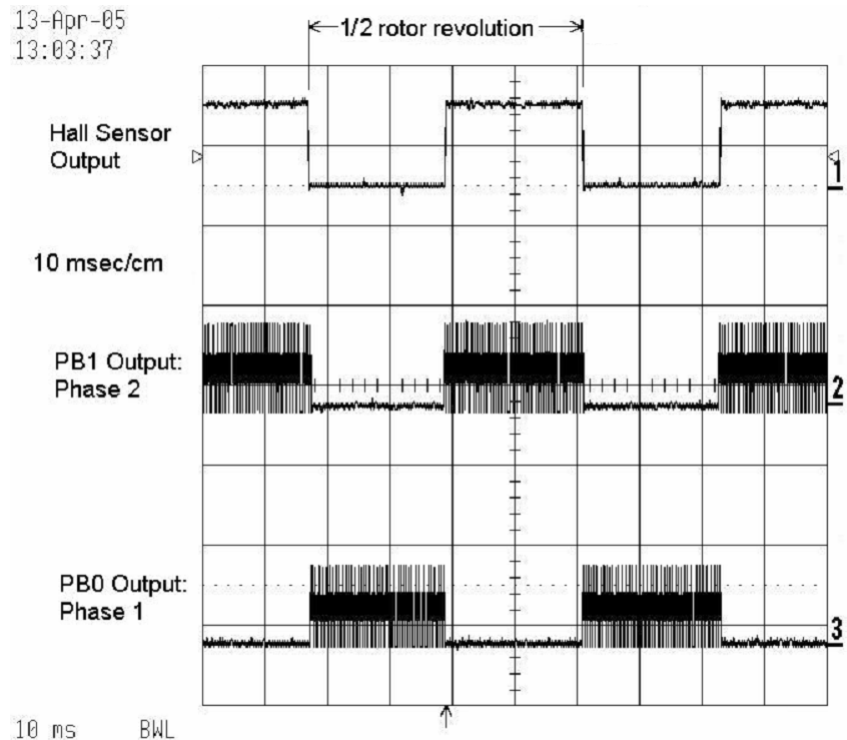
3.2 Advanced Control Techniques

The Tiny13 can accept not only a thermistor input, but also an analog control signal. This signal could be from a host computer or server system, and is called PWM_In for this application note. PWM_In is a 0-5V DC pulse-width modulated signal, low-pass filtered as it reaches an analog input of the Tiny13 as shown in Figure 3-5.

Figure 3-5. Analog filtering of PWM signal
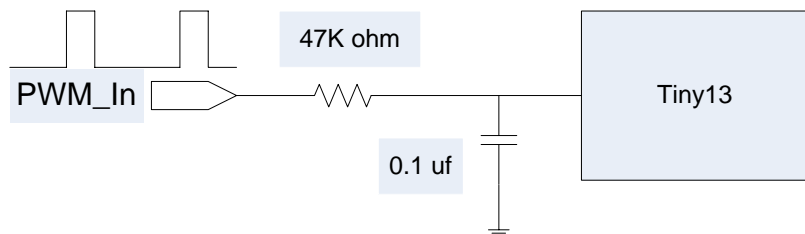
3.2.1 Calculation of PWM output

One successful control technique combines the thermistor ADC input with the PWM_In input and multiplies the result. The technique follows these steps:

1. Use a ADC channel to measure the thermistor voltage, using 8 bit resolution.

2. Using a second ADC channel, the filtered PWM_In signal is digitized into an 8-bit digital value. This 8-bit value is used to access a second LUT, specifically for the PWM_In signal.

3. These two 8-bit digital numbers are multiplied together. A 16-bit digital number is the result, and the least significant 8 bits of this result are ignored.

4. The most significant 8 bits are sent to the Timer0 PWM.

3.2.2 Fan speed results

Figure 3-6 shows the actual motor speed results as a function of the PWM_In signal LUT value multiplied with the thermistor LUT value. The results of the 8 by 8 fixed-point MPY are carefully limited to prevent rollover resulting in erratic motor speeds.

Figure 3-6. Fan speed as function of PWM_In and Vtherm
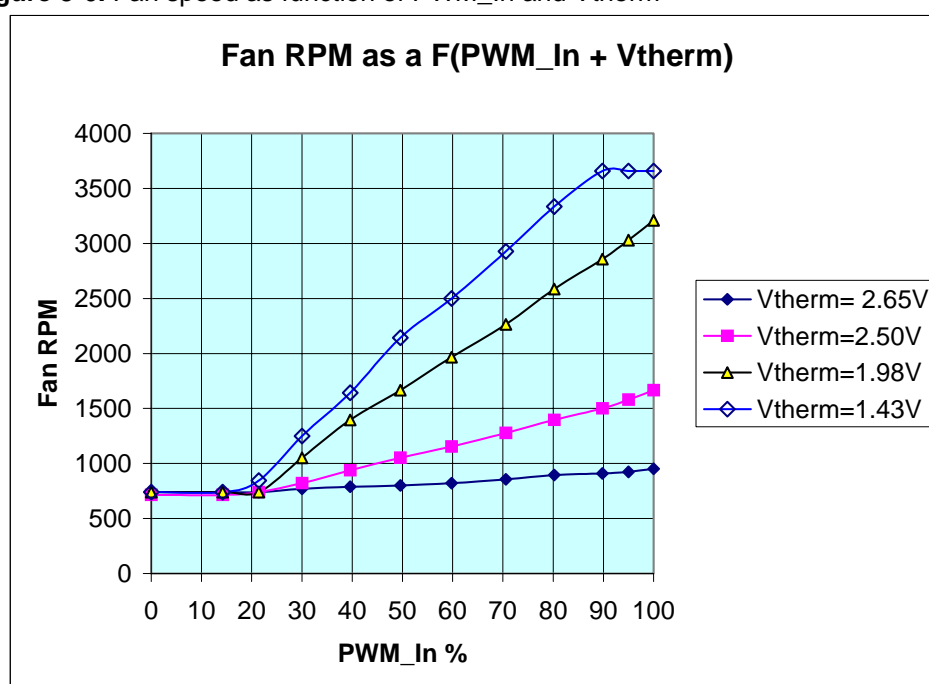
4 Conclusion

The Atmel ATtiny13 has been shown to be an ideal fan motor control MCU based on its high performance core, fast RC oscillator, efficient utilization of flash program memory, and multi-channel ADC. The Tiny13's Timer0 has been used as both a 53us interrupt source, as well as an 8-bit PWM that controls power to the motor.

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