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An Integrated Fan Speed Control Solution Can Lower System Costs, Reduce Acoustic Noise, Power Consumption and Enhance System Reliability

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INTRODUCTION

Less than six years ago, thermal cooling in the electronics arena was mainly an issue for high-performance, high-end applications, such as, military, aerospace and large-scale industrial and medical applications. Outside these sectors, thermal cooling was just a premature notion. In the short span of a few years, technological and other developments have made thermal cooling necessary for many applications, thus requiring the development of a new system management category: thermal management.

This article discusses an integrated fan speed solution that provides sophisticated speed control of brushless DC fans, the most popular type of fan used in electronic equipment, and helps designers get around problems like acoustic noise, power consumption, mechanical wear-out and fault detection.

TRENDS AND DRIVERS

On a board level, many more components need cooling today than even six months ago; with the CPUs having begun this trend some years ago. Memory chips never needed cooling, but now SRAM and DRAM packages require their own cooling solutions. Video card processors (mostly the 3D type) and other add-in cards also require cooling, as will the next generation models. Hard drives, DVD players, CD players and chipsets are now candidates for cooling as well. In general, board speeds are becoming faster and boards are becoming smaller and more heavily populated. Package densities are increasing and performing more functions, thus getting hotter.

New developments in digital chip architecture permit higher system clock rates and additional on-chip circuitry, causing the chips to run at higher temperatures. A large portion of the power dissipation is the capacitive charging and discharging during level transitions. Since the power lost is related to the square of the supply voltage, the trend to lower voltages reduces power dissipation. However, higher losses due to higher switching speeds, significantly offset these savings. An example is the 486 microprocessor, which was drawing 12 to 15 watts. As PCs moved into the first Pentium® generation, the microprocessors started dissipating 25W. Today a Pentium® II dissipates about 40W, and there have been reports that the forthcoming 64-bit Merced microprocessor dissipates about 65W.

Thermal cooling is also in demand because of the explosive growth of new embedded applications. Telecommunications equipment, printers, household “smart” appliances, and most importantly, networking equipment (routers, switches and hubs) are only a few of the products now driven by embedded CPUs. More are being added each day, and with the complexity of multiple functions, thermal cooling has become a necessity.

WHY DO WE NEED COOLING?

The air immediately surrounding a chip initially cools its surface. That air eventually warms and rises to the top of the PC or other equipment’s chassis, where it encounters more warm air. If not ventilated, this volume of air becomes warmer and warmer, offering no avenue of escape for the heat generated by the chips.

Typically, a PC chip designed for commercial use can withstand up to 125°C – 150°C junction temperature, although a safety margin of a few degrees might be specified. Exceeding that limit will either cause the chip to make errors in its calculations or fail completely. A chip failure or malfunction impacts the entire system’s operation. Additional cooling also extends component life by limiting the maximum temperatures the components are exposed to. In general, a 10°C temperature reduction will provide a 2:1 increase in MTBF (Mean Time Between Failure).

THERMAL COOLING METHODS

Consistent with the trend of increasing heat dissipation in electronic systems, the thermal cooling methods began moving from passive to active solutions. In the days of the 486 microprocessor, the processor cooling was implemented by a heat sink and an embedded fan was only used to cool down the power supply. Since entering the Pentium era, the processor now produces enough heat to require a stream of cool air from a fan. In addition, new 3D graphic cards generate substantial heat and are also packaged with an embedded fan on top of the graphic chip.

To date, there are three basic approaches to thermal cooling: heat spreaders, heat sinks and fans:

1. Heat spreaders, which are made of a tungsten-copper alloy and are placed directly over a chip, have the effect of increasing the chip’s surface area, allowing more heat to be vented upward. Heat spreaders are frequently designed with a specific chip in mind.
2. Heat sinks spread the heat upward through fins or folds, which are vertical ridges or columns that allow heat to be conducted in three dimensions - length, width, and height - as opposed to the two-dimensional length and width of heat spreaders. Heat sinks maximize the amount of surface area that can be air-cooled.
3. Fans simply focus the available air on a concentrated space. The cooling capability of a fan depends on the volume of air the fan moves, the ambient temperature and the difference between the chip temperature and the ambient temperature. While fans move volume of air, some PC systems also require blowers to generate air pressure.

BRUSHLESS DC FANS

Thermal complexity, thermal content and greater power demands are boosting the popularity of brushless DC (BDC) cooling fans (Figure 1). In addition to the advantages of conventional fans, BDC fans have a significantly higher mechanical reliability. They contain no rotating commutator/brush assembly to shed dust particles, wear out, or act as an ignition source. Additionally, their magnetic coils are stationary and are usually mounted within a rigid frame for superior structural integrity and thermal dissipation. Finally, they lack the rotating magnetic fields of AC motors and the arching of conventional DC motors and, thus, are electrically quiet.

While BDC fans adequately evacuate heat from the system enclosure and are superior to conventional fans, they add other problems. Such problems that designers have to cope with in most applications are:

- Fan Mechanical Wear-out
- Acoustic Noise
- Power Consumption
- Fault Detection

The sections that follow provide an in depth summary of the above mentioned problems and describe the features, operation and advantages of Microchip’s integrated fan speed control solution.

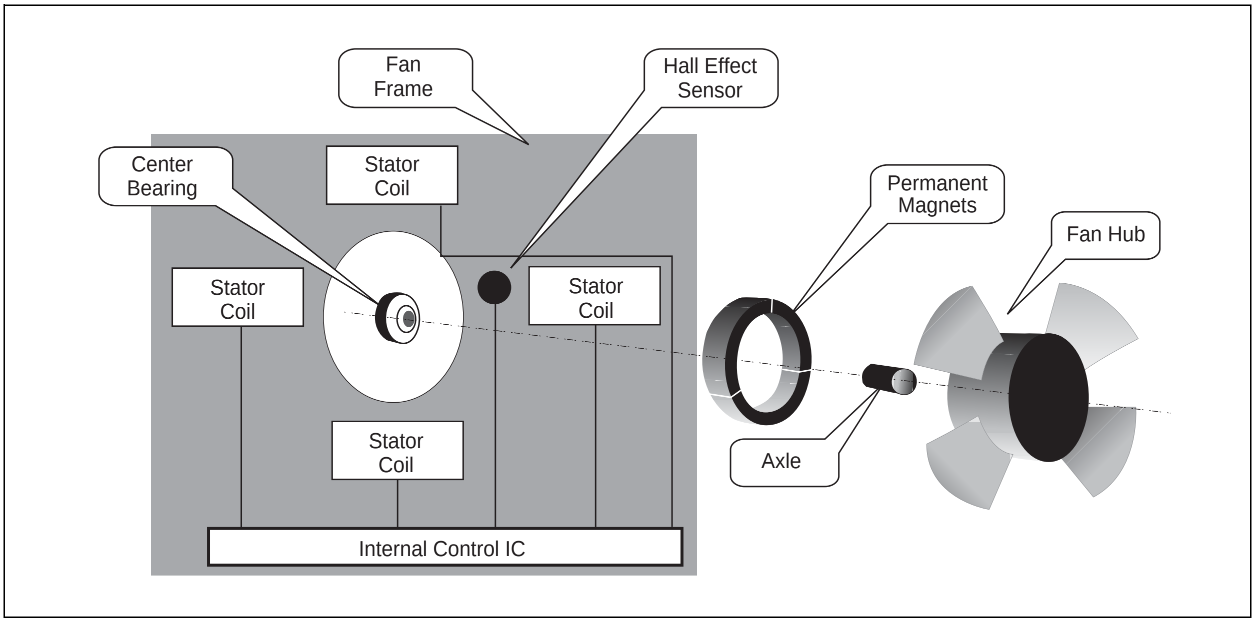

FIGURE 1: *Brushless DC Fan Basics*

FAN MECHANICAL WEAR-OUT

The fan is a complex electromechanical device and, in most cases, requires replacement before the lifetime of its host system expires. In the majority of cases, the fan failure is caused by the failure of the bearing, due to heat and mechanical wear. Other causes include blockage by foreign objects and electrical failures.

Fan failure is a very important issue for the manufacturer in terms of end-product reliability and quality. A fan replacement reduces the customers' perception of product quality and increases their indirect expenditures. The cost of a replacement part (fan), the installation cost and the opportunity cost associated with the non-utilization of the equipment can add up to a significantly higher cost for the user. Therefore, from an economical standpoint, a solution that ensures a longer fan service life is a value-added feature of the equipment and a good marketing tool.

Microchip's fan controller ICs provide sophisticated temperature-proportional, fan speed control. The fan runs only as fast as is required to keep the system cool. This extends the service life of the fan because it is not subject to the stress imposed by continuous full-speed operation and speed changes are gradual (vs. an on/off operation). A typical speed control solution can be expected to have a mean time between failure (MTBF) far greater than a typical fan running at full speed.

Figure 2 demonstrates the fan life versus speed relationship by showing the L10 life values (the time at which one expects 90% of the fan population to survive) of a sleeve-bearing fan running at several speeds and different operating temperatures. A 35% speed reduction more than doubles the L10 life values, independent of the operating temperature. These savings are attributed solely to lower average operating speeds. In addition to these quantifiable benefits, one should expect significantly higher L10 life values from gradual fan speed changes versus conventional aggressive on/off operation. An on/off operation generates shocks, resulting in a hostile environment for the fan's structure and/or bearing system.

Ball-bearing fans perform better in terms of L10 life values. However, they also cost significantly more than sleeve-bearing fans.

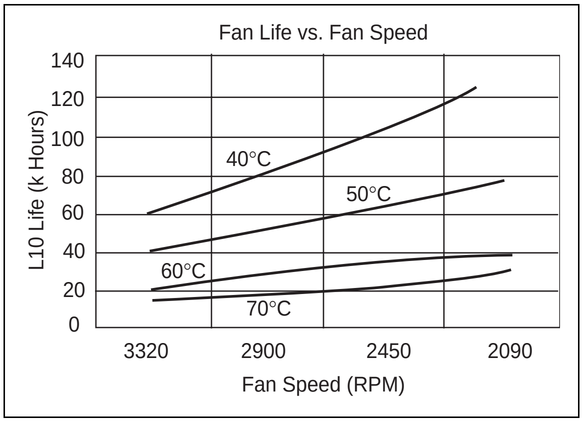

FIGURE 2: *Fan Life vs. Fan Speed*

ACOUSTIC NOISE REDUCTION

Noise is another important factor in the perceived quality of a product. Everything else held constant, a quieter product will always be preferred over a louder one. Noise reduction is a challenging task for designers, yet it is a differentiating attribute for the marketing of the product.

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 operating primarily at lower than full speed, minimizes this noise. The second most dominant source of acoustic noise is due to the BDC fan's torque characteristics. In this case, stator excitation causes a small amount of ripple in motor torque at the frequency of commutation, which again leads to a "ticking" noise.

Correcting noise problems becomes an even greater challenge when moving to multiple-fan applications. If you package several chassis in a rack and put several racks in a room, the combined noise can be deafening. Most designers choose fans for worst case thermal conditions, which has a downside effect under normal thermal operation: additional, unnecessary acoustic noise.

A small change in fan speed causes a significant change in fan noise. The formula used to determine the noise level, when the fan is running at speed S (% of S_{MAX}), is as follows:

EQUATION:

$$L_S = L1 + 50 \log S$$

Where L_S is a weighted noise level at fan speed S and L1 a weighted noise level at full speed.

A typical fan (120 ft3/minute – 4.7") has a full speed noise rating of about 45 dB. Running the fan at half the speed results in a significantly lower noise level of 30 dB. This 15 dB change is perceived by the human ear as an approximately 70% noise reduction, since noise measurement is based on a log scale. This confirms the well known fact that noise is greatly reduced when the fan is operated at lower speeds.

Microchip's temperature-proportional, fan speed control optimizes the fan speed by running the fan only as fast as required by the existing temperature. This solution minimizes acoustic noise, especially since the fan is rarely running at full speed, thus making the operation of electronic systems at home or in the workplace a more pleasant experience for the users.

POWER CONSUMPTION

The large amount of current consumed by the fan itself is another significant problem in today's "microamp-stingy" systems. In a typical application, a 50% decrease in fan speed results in a 50% to 75% reduction in power consumption. This results in significant power savings when less cooling is required.

Naturally, power savings are very important for portable applications, such as, notebooks and measurement equipment, since lower current translates to longer battery life. Nevertheless, low power dissipation is an important issue in every application.

FAULT DETECTION

Failure of a single fan can cause the temperature inside a high density PC (or other piece of electronic equipment) to skyrocket in a short time. In temperature-critical applications, it is very important to detect fan failures and prevent consequent failure of the entire system. As mentioned earlier, an abnormal fan operation or failure can have several causes: bearing wear-out, obstruction of the fan air intake, object lodged in the rotor or electrical failure. These issues are bringing ever-increasing scrutiny to the fan's integrity.

Monitoring the fan's health is a complex, but very important task. Microchip's fan speed control ICs are able to detect a stalled, open or unconnected fan by monitoring the commutation pulses that occur as each pole of the fan is energized. If consecutive pulses are not detected (1 second time frame), a fault signal is generated. This signal can be used to turn on an LED, sound a warning or implement a redundant thermal solution. In redundant systems, duplicate fans are frequently set up under the control of monitoring circuits, which compensate for a failed fan by starting operation of the remaining units.

MICROCHIP'S THERMAL MANAGEMENT SOLUTION

The circuit in Figure 3 illustrates a complete solution to the problem of fan management. The TC646 is a stand-alone, low-cost fan manager that integrates a pulse-width modulation (PWM) fan speed controller (with integrated startup timer) and a fan fault detector. It drives any standard two-wire fan through a low cost transistor (Q_1). The input voltage range (V_{IN}) is 1.25V to 2.65V, corresponding to 0% to 100% fan speed.

The temperature signal is generated with a low-cost NTC thermistor. The output duty cycle (therefore, fan speed) increases with increased voltage on V_{IN}. The fan fault output ($\overline{\text{FAULT}}$) is asserted when consecutive pulses are not detected at the SENSE pin, indicating a stalled, open or unconnected fan. The TC646 automatically suspends fan operation when the measured temperature (V_{IN}) is below a user-programmable (set by R_1 and R_2) minimum setting (V_{AS}), whereby forced air-cooling is no longer required. This little circuit is a fitting mate to any two-wire BDC fan, rewarding the end user with quieter system operation, improved system reliability and more efficient system operation.

In addition to the TC646, Microchip offers two more fan controller ICs with different feature combinations:

1. The TC642: identical to the TC646, except that it has minimum speed mode instead of auto-shutdown mode.

2. The TC648: a PWM fan speed controller with an auto-shutdown mode and over-temperature fault detection.

For more information on Microchip's Fan Speed Control / Fan Systems, refer to the following application notes at www.microchip.com.

AN764 - *Implementing Temperature-based Variable Fan Speed Control in NLX Power Supplies*

AN768 - *Redundant Fan Systems Using the TC642 Fan Manager*

AN770 - *Linear Voltage Fan Speed Control Using Microchip's TC64X family*

AN771 - *Suppressing Acoustic Noise in PWM Fan Speed Control Systems*

AN772 - *Speed Error in PWM Fan Control Systems*

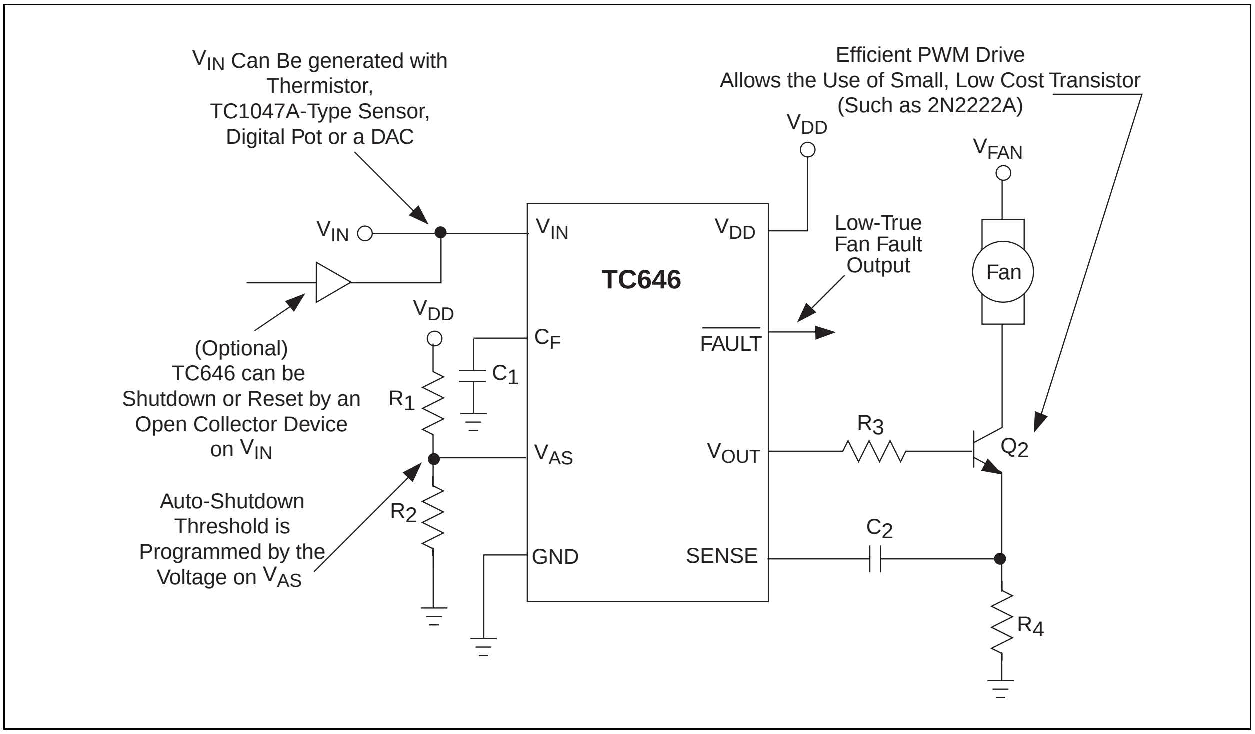

FIGURE 3: *TC646 Thermal Management Solution*

CONVENTIONAL THERMAL MANAGEMENT SOLUTIONS

Discrete/IC Solutions

Many design engineers implement a combination of ICs and discrete components. Although such a solution provides a high level of flexibility, its complexity, cost and space issues make it an unsuitable alternative. In addition, a discrete-based design lacks much of the functionality required by modern electronic systems. For example, a design that requires a switch mode DC/DC controller, two temperature sensors, two transistors, one diode, one inductor and a large number of additional discrete components has the potential to provide only a 3-speed fan control solution, at best.

Smart Fans

Smart, 3-wire and 5-wire fans have become very popular during the last few years. These fans provide a third signal (tachometer output) and an internal or external temperature sensor. Measuring the exhaust temperature, as most smart fans do, can endanger the system's operation because of the time lag between increased, localized heat generation and increased exhaust air temperature. Moreover, 3-wire fans are significantly more expensive than 2-wire fans and are mostly customized products. This means that lead times can stretch up to several weeks. This solution doesn't provide any speed control and, thus, doesn't contribute to a reduction of acoustic noise and power consumption.

Fan Controller Boards

Finally, a lot of manufacturers tend to buy complete solutions, such as, AC and DC fan controller boards. While these boards provide sophisticated control, they are costly and are not optimal for space-critical applications. Hence, they are mostly targeted for large fans and air blowers with airflow of greater than 200 CFM (cubic feet per minute).

CONCLUSION

Thermal management has become a very important factor in the majority of electronic equipment. Designers and Product Managers spend a large amount of time, money and effort to provide efficient thermal management solutions. Microchip's fan controller products deliver fan-noise reduction under normal thermal conditions, significant savings in energy costs and increased system reliability.

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