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APPLICATIONS NOTE

AN602: DHX Technology Overview

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Introduction

For several years, heat spreaders have been included on enthusiast memory modules to aid in heat dissipation. Dual-path Heat Exchange (DHX™) technology represents a strong effort by Corsair's engineers to devise an optimized thermal solution based on sound technical principles. This paper will provide a description of this technology and show some test results illustrating the superior performance that can be gained through the use of this technology.

Background

Typical desktop computers use memory modules without any heat spreaders, heat sinks, or dedicated airflow. However, for years, enthusiast modules have been fitted with heat spreaders for improved thermal characteristics as well as aesthetics. As system speeds have increased, the need for memory cooling has become more apparent. Let's take a look at why this is the case.

How Heat is Generated

All integrated circuits ("ICs") are composed of a large number of transistors. And, all transistors generate heat. Specifically, transistors generate heat when they are switching, or changing state. This means that the more frequently a transistor is switched, the more heat it generates.

The heat generated by a circuit is known as power dissipation. Power dissipation is calculated using the following equation:

$$P_D = V\,I$$

Where V denotes voltage and I denotes current. So, as voltage increases, power increases also, a fact we should keep in mind for later discussions.

On a memory module, the vast majority of the heat is generated by the RAM ICs themselves. Each of the RAMs contains hundreds of millions of transistors. These transistors generate heat every time a memory cell is accessed, whether it is to read from, write to, or refresh

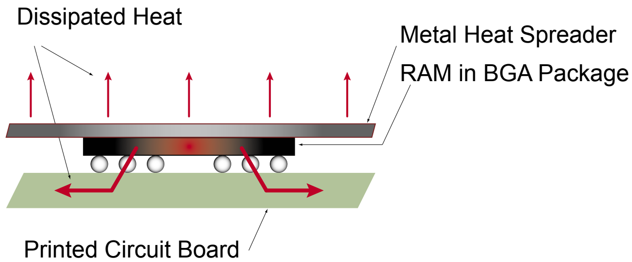

Figure 1. Memory module thermal paths

the memory.

In enthusiast systems, these RAMs are often pushed to the very limits of their functionality. That is, they are pushed in the area of operating speed to the point of failure, and operating voltage is often elevated well beyond specified acceptable values. This method of operation provides very rewarding performance, but generates a substantial amount of heat.

How Heat is Removed

Heat is removed from integrated circuits using both conduction and convection. Conduction is the removal of heat using a stationary conductive material, such as metal. Convection is the radiation of heat into a gas or liquid, which may or may not be moving. In general, conduction is more efficient, but is cumbersome to implement. Convection is more straightforward to implement, and becomes more effective if the fluid medium is circulating.

Figure 1 illustrates the paths from which heat can escape from a RAM module. The RAM ICs are packaged in BGA packages which are mounted face-down on the printed circuit board (PCB). The heat generated by the RAM is conducted from the RAM into the PCB through the solder balls that are used to assemble the RAM to the PCB. The heat is then conducted through the copper power and ground planes of the module into the motherboard.

The heat is also radiated from the back of the RAM into the surrounding air, resulting in convective dissipation. Heat spreaders or heat sinks are often used to improve the efficiency of the convective cooling path.

Benefits of Heat Reduction

Reduced heat brings two big benefits to the memory subsystem. First of all, as transistors get hotter, they get slower. In fact, they are fastest at many degrees below zero. Obviously, cooling to that temperature is impractical and expensive. Secondly, as RAMs get hotter, their lifetime gets shorter. Heat is often used in reliability testing to accelerate failure mechanisms. So the cooler we can keep the RAMs, the longer their theoretical lifespan.

Technology Objectives

The overriding technical objective of developing a new cooling technology was to engineer a thermal solution that allowed enthusiast RAM modules to run cooler. This led to several more specific objectives, as follows:

- The technology had to provide cooler operation, verified with thermal measurements in a controlled environment
- It had to provide additional overclocking headroom, again measured in the lab

- It also had to be implemented in a form factor that would allow modules in adjacent sockets in typical motherboards
- We wanted the new technology to provide enough cooling to allow reliable operation at increased memory voltages.
- Implementation cost had to be minimized, and had to be consistent with enthusiast customer expectations.

DHX Technology Implementation

Based on the stated objectives and the research that we performed, we decided to focus our efforts on conductive as well as convective cooling. By using two cooling paths, we felt we could achieve real performance gains.

DHX Overview

The new cooling approach was named Dual-path Heat eXchange (DHX) technology, in reference to the use of both conductive and convective cooling paths.

The basics of this cooling approach are as follows. Heat is generated by the RAM on the module. Part of this heat is removed via convection through heat sinks attached directly to the RAM packages. Additional heat is removed via conduction through the solder balls of the BGA directly into the metal layers of the PCB. The PCB is also equipped with heat sinks to improve thermal dissipation.

A diagram of the DHX approach is shown in Figure 2. This module cross-section diagram shows the PCB (green), the RAMs in BGA packages (dark gray) and the heat sinks (black and silver). The arrows represent the thermal dissipation paths through the module.

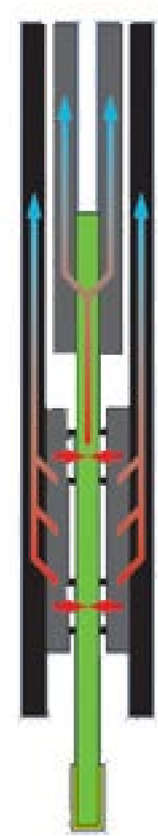

Figure 2. DHX Overview

Printed Circuit Board Design

It was apparent from the start of the project that meeting these objectives would require significant changes to the design of our current modules. Specifically, a new PCB would be required, as well as radically different heat sinks.

We selected our 50-00163A as the base design for our DHX-enabled PCB. This design had been used on several DDR2 modules, and had been shown to have excellent performance at very high frequencies. This design was not altered electrically, but was extended in height. We took advantage of this additional height by extending the

Figure 3. DHX-enabled printed circuit board

copper planes to the top of the PCB and adding large pads to both sides, connected with an array of vias. Figure 3 shows a photograph of the bare PCB.

Heat Sinks

In order to realize our objectives for DHX, we had to go through several iterations of heat sink design. In order to meet cost and performance objectives, we quickly settled on extruded aluminum as the base heat sink technology to work with.

Heat sinks designs were required for both the BGAs and the PCBs. We went through several design iterations to determine the optimal size and shape, with the goal of achieving maximum thermal performance both with and without air flow. Care was taken to keep dimensions within the limited envelope available to us due to system constraints. In addition, we wanted to make sure to take full advantage of both impinging and laminar air flow.

Figure 4. DHX heat sinks

The resulting heat sink designs are shown in Figure 4. This module cross section clearly shows the design elements of the module. The PCB heat sink is nickel plated to allow assembly to the PCB using either solder or epoxy. The memory heat sink has the maximum fin size allowed by the physical envelope, and is black anodized.

Airflow

The final design element to be completed was the air flow unit. The objective of this component is to provide consisting impinging airflow to the memory subsystem. The aspect ratio of the memory subsystem suggested a unit with multiple small fans; the final implementation uses three 40mm fans. The fans run at fairly low RPMs

Figure 5. DOMINATOR Airflow fan assembly

(approximately 5,000 RPM), so the airflow assembly is very quiet, and is nearly inaudible in most of our test systems. A photo of the Airflow unit is shown in Figure 5.

Testing

Our prime objectives for the DHX development project were to verify improved thermal as well as electrical performance. To accomplish this, we designed several tests to be run in the lab. All testing was performed in thermally controlled environment, using a thermal chamber to provide a consistent ambient testing temperature of 33 °C.

Thermal Test: Setup and Procedure

Thermal testing was run on all iterations of the heat sink designs to measure their effectiveness. A set of reference modules was assembled based on the DHX-enabled PCB. These parts were built with high-speed Micron RAMs that were known to [1] exhibit excellent high-speed performance, and [2] run hot.

A thermocouple was attached to the modules at the same location, the fifth RAM from the left edge of the PCB. The modules were run in the oven with a measured ambient temperature of 33 °C. The modules were run at 1067MHz, 5-5-5-15 latency settings, 2.2 volts, in the Asus P5WD2 motherboard. The temperature of the RAM was measured after the third iteration of a stress test routine, typically about 15 minutes of intensive memory operation. This same test procedure was run on a variety of heat sink configurations, with and without the Airflow unit.

Thermal Test: Results

The results of this thermal testing is shown in Table 1. As you can see, the DHX heat sinks provided a substantial improvement, resulting in a net temperature drop of 13 °C. By adding the Airflow assembly, temperature dropped another 4.1 °C, for a total temperature reduction of 17.1 °C.

Table 1. Thermal testing results

Heat Sink	Airflow	Chip Temp	°C Over Ambient
none	none	61.4 °C	28.4 °C
DHX	none	48.4 °C	15.4 °C
DHX	3x 40mm fans	44.3 °C	11.3 °C

Table 2. Overclocking Test Results

Sample	non-DHX	DHX with Airflow	difference
1	816 MHz	832 MHz	16MHz
2	816 MHz	840 MHz	24 MHz
3	804 MHz	828 MHz	24 MHz
4	804 MHz	820 MHz	16 MHz
5	808 MHz	824 MHz	16 MHz

Overclocking Test: Setup and Procedure

Our procedure for our overclock testing was quite simple. First, we took five modules and determined what the maximum overclock was that could be achieved with no heat sinks or fan. Then, we ran the same test with the fully configured DHX heat sink and fan, and measured the delta between the two values.

For this test, the Asus M2N32-SLI Deluxe motherboard was used. Voltage was set at 2.4 volts, latency was set at 3-4-3-9. The RST Pro hardware stress tester was used to determine maximum stable overclock, which was defined as three loops of the RST with no errors.

Overclocking Test: Results

Table 2 shows the results of the overclock testing. In all cases there was an improvement in the maximum overclock that could be achieved; this improvement ranged from 16 MHz to 24 MHz. Similar testing was run on a pair of modules at 4-4-4-12 latency settings; improvement in this case was measured at 24 MHz and 28 MHz on the two modules.

Summary

We were able to meet all our objectives with the DHX design. The additional cooling provided by this technology provides lower temperatures and higher speeds, as planned. We have also realized the corollary benefit of being able to guarantee higher operating voltages based on the cooler temperatures.