AIRBORNE DEMONSTRATION OF A MINIATURIZED COMMERCIAL SUPERCOMPUTER

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Abstract

Military systems are exploiting rapid advances in commercial electronics by adapting off-the-shelf products to meet a large segment of processing needs. However, this approach presents some unique challenges in remote sensor platforms that are characterized by limited volume and extremely high throughput [1]. Only the most advanced computing architectures available in the commercial market are capable of providing the performance necessary to assume the role traditionally filled by special purpose processors custom designed for these applications. This paper describes an ongoing project to miniaturize a Cray vector supercomputer for demonstration in a signal collection application onboard the Rivet Joint RC-135 aircraft.

Introduction

As illustrated in figure 1, microelectronics and advanced packaging play a key role in achieving a form factor suitable for remote sensing platforms [2]. The current J90 computer utilizes conventional packaging to fit four processors and 1 Gbyte of memory on a pair of boards measuring 13" x 16" and 16" x 19". The repackaged design has been partitioned into four types of multichip modules (MCMs) that will reduce the footprint to a single 9" x 10" double-sided printed circuit board. Three of the four MCM types have completed fabrication and prototype test. The 24-layer printed circuit board is designed with processor and network modules on one side and stacked memory modules on the other. The finished unit will include a self-contained liquid spray cooled chassis to manage the thermal load without contributing significantly to size and weight. Features of the computer are highlighted below:

- Parallel Vector Architecture
- 200 MFLOPS/Processor
- 4 Processors/Board
- 4 - 32 Processors/Chassis
- 0.25 - 8 Gbytes Memory
- Memory Bandwidth: 50 Gbytes/sec
- I/O Bandwidth: 0.1 - 1.6 Gbytes/sec

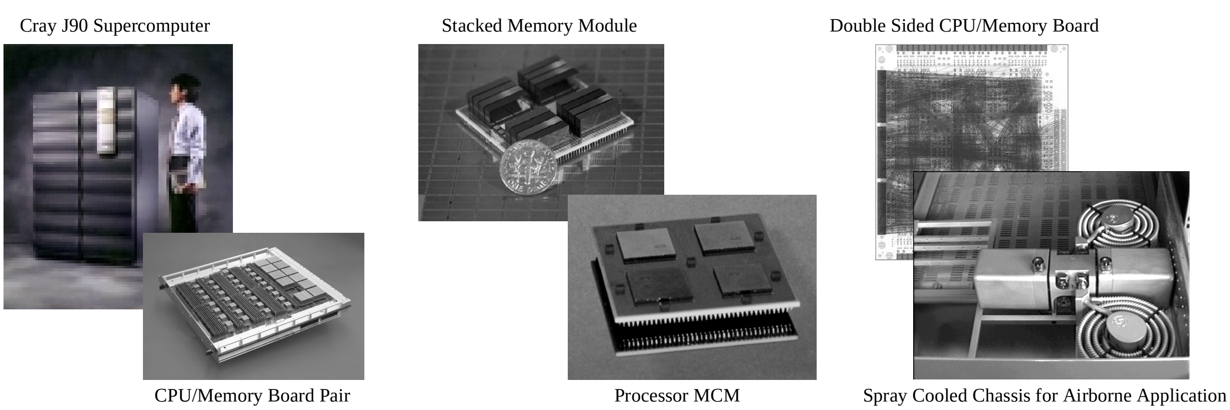

Figure 1. New packaging technologies provide the vehicle to rehost existing commercial architectures in a form factor suitable for embedded processor applications (19 inch rack).

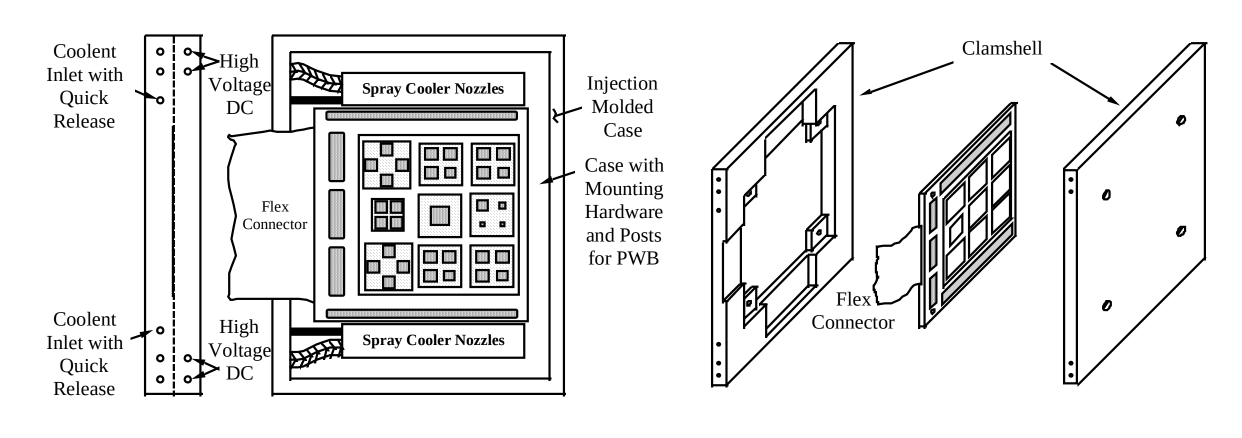

Figure 2. The system element is enclosed in an injection molded clam shell with integrated spray nozzles and power converters to produce a self-contained assembly.

System Element and Integration Platform

Figure 2 illustrates the packaging concept for a self-contained "system element" that represents the minimum unit of replication for the computer. Each system element contains four processors and 1 Gbyte of memory. At the core of the system element is a double-sided printed circuit board fully populated with multichip modules. An array of pads is provided on the left side of the card for external signal I/O. Large contact pads at the top and bottom edges provide power to the card. The entire assembly is mounted in a clamshell housing with an integrated spray cooler.

As shown in figure 3, a conventional "chips last" process is used to fabricate the MCMs. A multilayer interconnect is constructed over a ceramic substrate that has been patterned for a 1520-contact area array grid. The die are mounted flip-chip to the top surface of the multilayer interconnect. Heat is extracted from the back of the die and distributed over the full available surface area of the module with a synthetic diamond substrate. The complete assembly is attached to the printed circuit board using a column grid array on the bottom of the ceramic substrate.

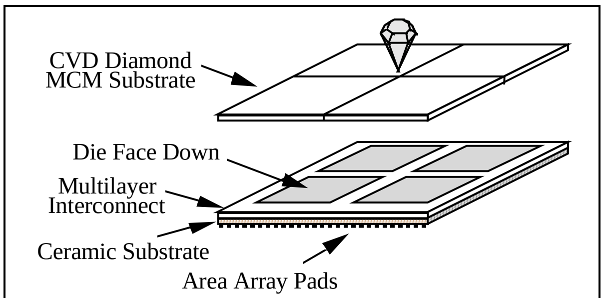

Figure 3. The MCM is mounted face down with the back of the chips in direct contact with the diamond.

One J90 processor MCM will dissipate up to a total 35 Watts of power among the four die. The diamond substrate provides an effective mechanism for distributing the heat load of the individual chips over a larger surface area to improve thermal transfer to the spray coolant [3] [4]. As a comparison, figure 4 illustrates the difference between the thermal performance of a diamond and aluminum oxide (alumina) substrate under an equivalent heat load. The two substrates are compared in three different environments; air-free convection, air-forced convection, and edge conduction. As shown in the figure, the diamond substrate maintains a lower temperature under all three conditions. The edge conduction example provides the most dramatic example of heat transfer with a single ice cube applied to the edge of both substrates.

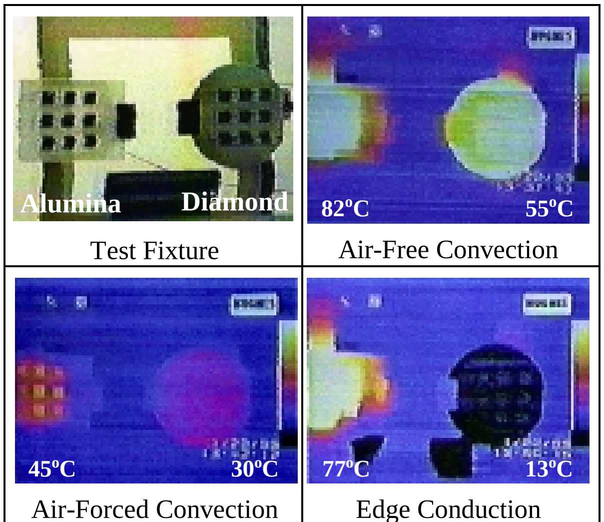

Figure 4. Infrared images illustrate the sharp contrast in thermal conductivity between diamond and alumina substrates under a 10 Watt heat load.

Spray cooling is used to remove the heat from the exposed surface of the diamond substrate [5]. A liquid-to-gas phase change process is sustained by continuously coating the diamond surface with a uniform thin film of Flourinert®, the preferred heat transfer fluid. This is accomplished by replenishing the fluid with a fine spray as it evaporates. The vapor is returned to an external condenser to complete the closed-loop system. This technique can achieve a heat transfer coefficient two orders of magnitude greater than the air-forced convection used in most office computer equipment. It is even an order of magnitude better than the liquid-forced convection popular in more sophisticated electronics.

As shown in figure 5, the system element clamshell is attached to an "integration platform" that provides the coolant reservoir and condenser for the spray cooler. The heat exchanger used to condense the Flourinert® is mounted to a standard 5 inch muffin fan. The fluid pump is located in the hub of the condenser coils. Each fan can manage a 500 Watt heat load.

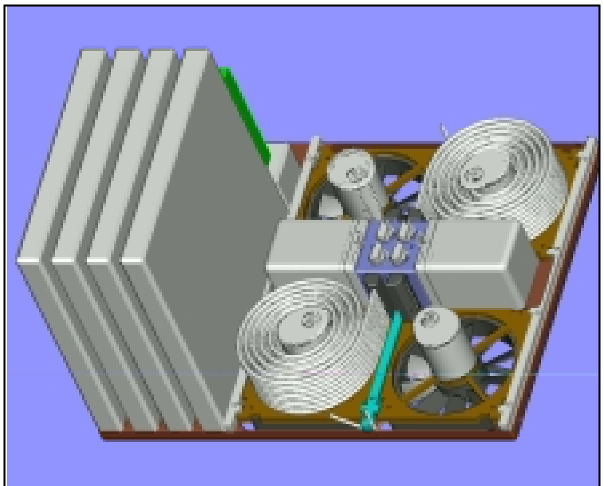

Figure 5. The rack mountable integration platform supports up to four system elements (16 processors).

Size and Weight Comparison

Figure 6 illustrates the size reduction achieved by repackaging a four processor configuration of the existing J90. The comparison allocates the overall structure of each unit to three common elements; electronics, heat removal and heat transfer. The electronics component consists of the volume occupied by the assembled printed circuit board exclusive of mounting or thermal management hardware. The volume allocated to heat removal for the conventional J90 represents the space consumed by finned heat sinks attached to the individual devices. The counterpart in the integration platform is the volume consumed by the clamshell that delivers coolant to the electronics. Heat transfer to the environment is accomplished with fans in both implementations. The existing J90 utilizes a large blower to produce the required airflow across the finned heat sinks while the integration platform uses a muffin fan mounted to a condenser and reservoir.

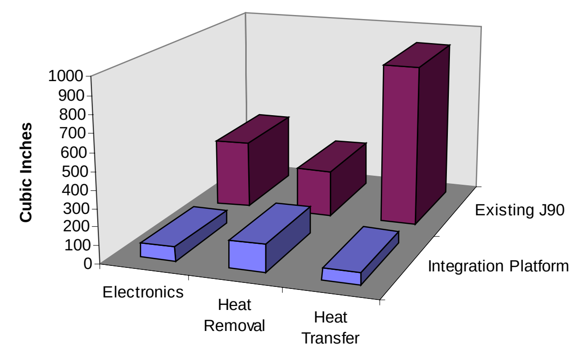

Figure 6. An overall 5:1 size reduction is achieved with the integration platform.

A weight comparison between the existing J90 and the integration platform reveals an even greater benefit than the size reduction. As shown in figure 7, the primary contributor to weight reduction is the electronics component. The integration platform eliminates a large percentage of the dense printed circuit board and ceramic packaging materials used in the existing unit. The clamshell is actually a little heavier than the sum of all of the finned heat sinks, resulting in a slight weight increase for heat removal. However, the efficiencies of spray cooling result in a condenser unit that is much lighter than the fan needed to transfer heat in the existing air cooled cabinet.

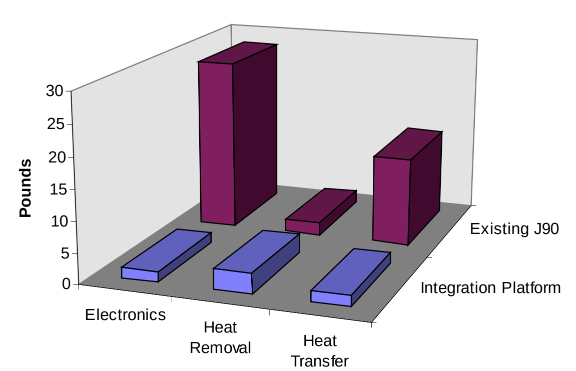

Figure 7. An overall 6.6:1 weight reduction is achieved with the integration platform.

Demonstration

A flight demonstration of the integration platform is planned onboard the Air Force Rivet Joint aircraft shown in figure 8. Rivet Joint is a signal collection platform that is used to geolocate electromagnetic transmissions.

Figure 8. The Rivet Joint collection platform processes signal intercept data onboard the aircraft.

The planned demonstration will utilize an existing antenna array and receiver front-end on the aircraft as a data source. Figure 9 illustrates the insertion of the J90 integration platform in the receiver processing chain. The wideband and narrowband processors search for signals and perform analog measurements of signal parameters. The parameter measurement assembly digitizes the analog encoded data and forms a descriptor word for each pulse.

The vector processor will host pulse deinterleaver and emitter geolocation algorithms that are currently implemented in a combination of custom hardware and loosely coupled general purpose processors. These algorithms associate pulse descriptor words that are common to a single emitter and utilize angle of arrival information to compute a position. In addition to leveraging the cost and maintainability benefits of commercial technology, the modified architecture will also provide an element of flexibility and mission adaptability not available with custom hardware.

Acknowledgment

Development of the J90 system element and integration platform is sponsored by the National Security Agency (NSA) under the Embedded High Performance Computer with Diamond-Based Technologies program (contract MDA904-94-C-6210). The authors would like to acknowledge the many technical contributions of team members from E-Systems Raytheon, Cray Research, Diamonex, Isothermal Systems Research (ISR), and Norton Diamond Film.

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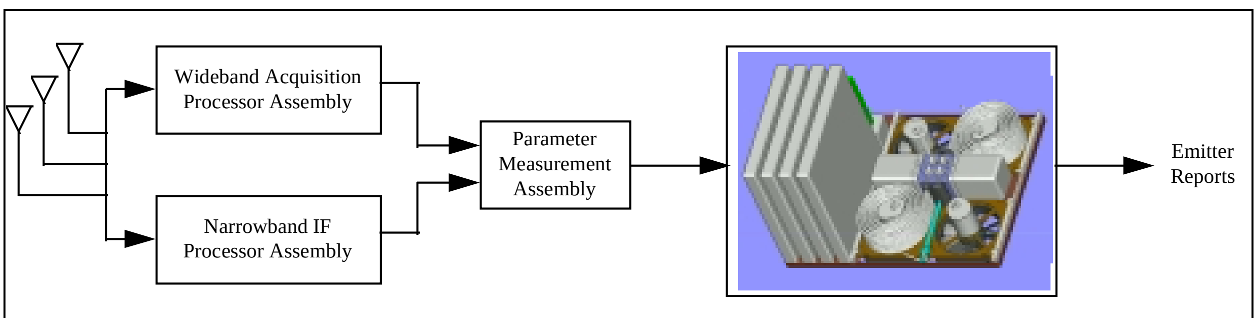

Figure 9. The J90 integration platform will host pulse deinterleaver and emitter geolocation algorithms.