

Preface: Packaging

In 1993, IBM began replacing bipolar emitter-coupled logic (ECL) in its large mainframe computers with complementary metal-oxide semiconductor (CMOS) logic because of the very high integration density of CMOS, its high switching speed, lower switching current, and excellent reliability. Advances in CMOS microprocessor technology have had a spillover effect on packaging technology. The increased functionality and density of CMOS-based control chips, along with the use of surface-mount technology, have resulted in the denser packaging required to support multichip modules (MCMs). Refrigeration-cooled CMOS microprocessor chips in MCMs have not only removed heat from the chips but have also improved their switching speeds. Small energy-efficient switch-mode power supply units with MOSFET switches now replace bulky and energy-inefficient phase-controlled power supplies. Concurrent with improvements in performance and the increased circuit densities of microprocessor chips, power and cooling subsystem designs have made high-end servers more reliable and sufficiently compact to be packaged within a single frame.

The following five papers in this issue of the *IBM Journal of Research and Development* discuss packaging of large computer systems. The first paper, by Singh et al., is an overview of the power, packaging, and cooling of the IBM eServer z900. The four major subsystems of the server are the bulk power assembly, the central electronic controller (CEC) cage, the input/output (I/O) cage, and the modular refrigeration unit (MRU); the packaging and function of each are described in detail. High reliability and system availability are achieved by introducing redundancy so that a failed component is field-replaceable without interrupting the operation of the system. Finally, the electromagnetic compatibility and noise requirements, and immunity to shock, vibration, and earthquakes are discussed.

The second paper deals with the vapor compression refrigeration cooling of the z900 series CMOS mainframe and its three predecessors, the S/390 G4 to G6 mainframes. Schmidt and Notohardjono discuss the advantages of using a closed-cycle refrigeration unit for sub-ambient cooling of microprocessors, and the associated changes in microprocessor performance and leakage current. The refrigeration system design choices and optimization efforts are described in detail. Among the issues discussed are the refrigerator's cooling ability, reliability, cost, and physical space, and its electrical power requirements.

When microprocessor chips are cooled below the dew point of the ambient by using a refrigeration system, moisture condensation can occur on the outer surfaces of the chip module and the circuit board on which the module is mounted. The third paper, by Ellsworth et al.,

models the cooled module and circuit board using 3D finite element analysis to study how strategically placed heaters can maintain the temperature of their surfaces above the dew point while requiring minimal increase in the total heat load the refrigeration unit must remove from the module. The two viable design options which were finally considered involved heaters with or without insulation on the back side of the card. The design option with no insulation on the back side of the card was selected because it required fewer parts.

As the number of transistors on a chip increases, the number of connections between a multichip module and the circuit board also increases, requiring sockets with higher interconnection densities. In the fourth paper, Corbin et al. describe a very attractive new type of connector, the land grid array (LGA) socket, which permits direct electrical connection between a module substrate and a circuit board through a conductive interposer. Connection is achieved by aligning the contact array of the two mating surfaces and the interposer, and mechanically compressing the interposer. The paper summarizes the state of the technology and presents in some detail the development, analysis, and testing of a mechanical subsystem required to successfully implement LGA sockets in mid-range and high-end server systems.

The fifth paper, by Knickerbocker et al., describes in detail an advanced multichip module used in the high-performance UNIX-class eServer. The MCM holds four copper metallized chips, each with 170 million transistors, and provides thermal cooling capability of 156 watts per chip. Using 7018 flip-chip solder connections, each chip is attached to a high-performance glass-ceramic substrate with 1.7 million internal copper vias and 190 meters of copper wiring. The 1-mm pitch of the more than 5100 off-module I/O connections allows the overall module size to be a compact $85 \times 85 \text{ mm}^2$ and allows 8- to 32-way systems to operate at 1.1 GHz or 1.3 GHz.

These five papers offer the reader insight into the disciplines of power, packaging, and cooling that are essential to the design and manufacture of commercial computers with high reliability, essentially zero downtime, minimal floor-space and power requirements, no objectionable electromagnetic radiation or acoustical noise, and the ability to withstand electromagnetic radiation, mechanical shock, and vibration within specified limits.

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