WHITE PAPER:

Motorola® ColdFire™ VL RISC PROCESSORS

Enabling the Next Generation of Advanced Consumer Electronics

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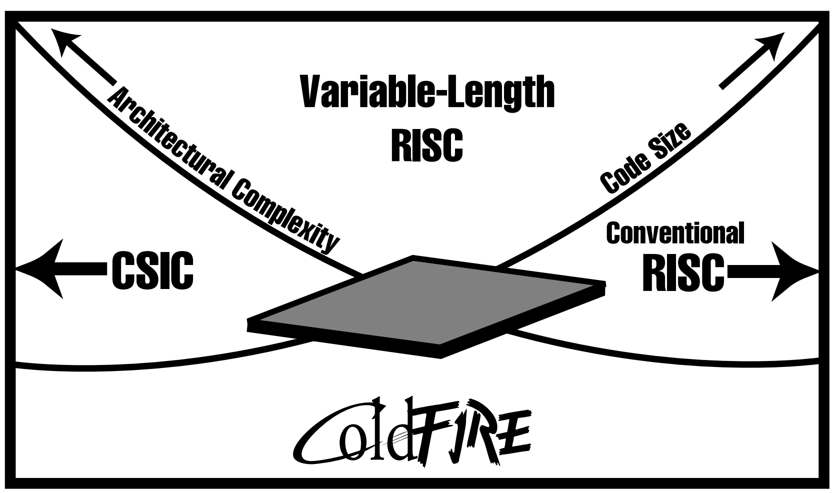
Overview

ColdFire™ VL RISC, Motorola's newest complement to its world class family of 68000 and PowerPC™ microprocessors, was developed as an enabling technology for burgeoning advanced consumer electronics markets. Many of these markets are experiencing shrinking product development cycles and heavy competitive pressure, forcing companies to seek much more cost effective and complete solutions from their vendors for embedded control.

ColdFire occupies the "sweet spot" between complex instruction set computing (CISC) and conventional fixed-length reduced instruction set computing (RISC), striking an optimum balance between code density and transistor count. By using Motorola's unique Variable-Length (VL) RISC technology, ColdFire combines the simplicity and optimal performance of a 32-bit RISC architecture with a memory-saving variable-length instruction set.



ColdFire's sophisticated features, such as a completely synthesizable core for flexibility and a robust debug module, shorten development cycles by speeding the transition from prototype to production. But ColdFire's unique advantage is that it provides the industry's most streamlined migration path to high-performance RISC.

Founded on an optimized subset of the highly successful Motorola 68000 instruction set, ColdFire-based systems leverage the immense body of development tools, software applications, and knowledge amassed over the 68000's 17-year legacy. In the final analysis, ColdFire can solve the fundamental challenges facing today's embedded systems developers by shortening the design cycle and providing a cost-effective path to upgrade the performance of their products.

The Evolving Embedded Market for Consumer Electronics

The embedded processor market is in a state of tremendous growth. The embedded market represents more than 75 percent of the annual shipment of microprocessor units, and the portion continues to grow, outselling desktop varieties by a three-to-one margin. The greatest opportunities exist for 32-bit embedded microprocessors in advanced applications. According to Desktop Strategies, an industry research firm, total shipments of 32-bit microprocessors for embedded control applications are expected to grow to more than 65 million units in 1996.

A fundamental shift in the embedded market is precipitating this rapid growth. New embedded applications represent an evolution in functionality from simple industrial control functions to today's radically innovative products that will form the infrastructure of the coming digital revolution.

Microprocessor-based products have enabled the convergence of computers, communications and consumer electronics, and are fueling the creation of explosive, high-growth markets for embedded processors. Products such as hardcopy imaging devices, interactive TV set-top boxes, personal digital assistants (PDAs) and communicators, digital office equipment, intelligent videophones, and mass storage will greatly expand the market for embedded processors, as well as challenge system designers when making their choice of a microprocessor architecture.

By all accounts, the general and business embedded processor markets are as dynamic as ever. Embedded processors for office automation are expected to grow at a healthy 13 percent pace through 1998, and parts for communications equipment are estimated to increase at 29 percent annually. OEM customers in these markets have four basic selection criteria for processors: time-to-market (i.e., compatibility with third-party software tools and current system software), adequate performance, system cost, and part cost.

The Home-Based Digital Office

The emergence of the small office/home office (SOHO) market is driving the development of a wide array of new consumer-class microprocessor-based products that will reorganize the workplace and revolutionize the way information is processed, stored, retrieved, transmitted, and received. These consumer class products provide the same functionality as comparable corporate-level products, but at consumer-class prices.

The SOHO market has fueled the development of new entry-level office equipment, such as low-cost laser printers, scanners, and other hardcopy imaging peripherals. These products require high performance and energy-efficient designs at a minimal cost to stay competitive. The SOHO market is also driving the development of new classes of office products, such as multifunction peripheral devices (MFPs) that combine hardcopy imaging, scanning, facsimile, and copying into an integrated microprocessor-based system.

The embedded microprocessors in these new intelligent office products incorporate networking to allow computers to communicate with them, through conventional hardwired or wireless serial infrared (SIR) schemes. The processor engines that drive these office equipment networks must be powerful, yet economically priced.

Mass Storage to Handle the Digital Tidal Wave

The digital revolution is spawning enormous databases that continue to expand. Recent estimates put the number of electronic documents in U.S. businesses and government at close to 400 billion, and growing at 70 billion documents every year. But that’s only a foreshadow of the coming deluge expected as major segments of society -- entertainment, education, science, engineering, medicine, and automated manufacturing -- join the digital tidal wave.

The mass-storage market, now about $100 billion per year, could explode into a trillion-dollar market in 10 years. As manufacturers scramble to develop lower-cost, higher-performance, and higher-capacity mass storage systems, they will be looking to upgrade their embedded processors. Given the inherent cost sensitivity and short design cycles in this growing market, new processor platforms must be economical and easy to work with, yet powerful enough to handle vastly improved read/write channels, higher bandwidth, and an enhanced transfer rate between the drive and host.

The PC/TV and a Wired Home

The greatest opportunity for embedded processors in consumer products is starting to emerge in the form of cable TV set-top boxes and combined PC/TV devices. Designed to use the television set for interactive on-line services, these products will give birth to a multi-billion dollar market. Video on demand, on-line gaming, gambling, home banking, and shopping are just some of the applications that will emerge around interactive capabilities. Analysts forecast that interactive home shopping alone, for example, will become a 40-billion dollar market within a decade. Analysts also predict that one-third of all American households will be receiving interactive services by the end of this century.

The processor-intensive multimedia format of these services places great demands on the embedded processor. Multimedia applications require huge amounts of data, especially in the transmission of video, which requires complex compression and decompression algorithms to reduce storage requirements and transmission time. Video games make up more than 75 percent of the consumer market, and next-generation game systems will feature greater interactivity, more realistic graphics rendering, and higher quality multimedia effects. These features will require a boost in processing power without raising the system cost above the consumer class threshold (under $500).

Home appliances such as PCs, TVs, handheld personal communicators, digital video phones, and teleconferencing are some of the new information delivery systems that will define “home improvement” at the turn of the century. The wired home will connect to the information superhighway through the family den via multiple devices, providing huge opportunities for microprocessor sales.

Choosing the Right Processor

The fundamental goal for advanced consumer electronics systems manufacturers is to, at minimal cost, introduce highly functional, high-performance products that will be competitive in the marketplace. The processor platform of choice can have a direct bearing on achieving this goal, but more and more, success depends on other factors. When choosing the ideal processor for new embedded applications, designers must examine issues such as memory subsystem costs, peripheral component costs, power and bus-width requirements, backward compatibility, and the processor’s future migration path.

Above and beyond these, there are other ingredients that have an effect on success in today's market, such as the processor's development environment (i.e., the availability of reliable software tools, development hardware, and knowledgeable engineers) and the support and service provided by the processor vendor.

In addition, advanced consumer electronics markets have become intensely competitive. This has effectively reduced the average life span of new products as well as shrinking the market "window" for new product introductions. Development cycles, which are also being squeezed, are as short as three to six months for many products. In the final analysis, the reduction of product development costs and time-to-market cycles have become factors of primary importance.

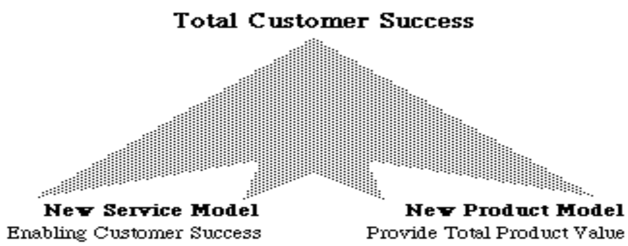
The Changing Buyer-Seller Relationship

The semiconductor industry is in the midst of a transition. As advanced consumer electronics manufacturers scrutinize their own product development efforts, they are beginning to realize that fundamental changes are required in the buyer-seller relationship in order for them to remain competitive in an increasingly aggressive market. Manufacturers are changing the way they do business with their vendors, demanding both a greater service orientation and a different product.

In addition, manufacturers want to establish and maintain closer relationships with their semiconductor suppliers. Partnership qualities expected include understanding and anticipating market dynamics, sharing information -- including business goals, product roadmaps and vision -- and a simple, compatible business interface. Manifestations of this include playing a greater role in the product development process and delivering a total product -- beyond simply supplying silicon. Processor vendors must go beyond the product specification to deliver value -- from engineering research and systems knowledge to world-class documentation. This concept can best be illustrated by looking at the Motorola Semiconductor Products Sector's newest model for success.

New Product and Service Models

The new service model is a complement to the new product model and is distinguished by a change in attitude and approach to responsiveness -- anticipating needs, requirements or problems, instead of simply reacting to them. The heart of this new service model is that vendors will play a greater role in enabling their customers' success.



In the new product model, the product is no longer just silicon, but instead silicon surrounded by a collection of value-added services, in particular world-class software and an engineering organization that both anticipates and responds to market-specific needs. The best way to characterize the new product model is to measure the role that the processor plays in the customer value chain. While historically the quality of the processor itself occupied the most valued link in the chain, today it is the processor plus the quality of the new links -- the product services -- that qualify the vendor as a leader in the minds of customers.

ColdFire -- An Innovative New Platform for a New Generation of Advanced Consumer Electronics

Leveraging years of leadership in the embedded market, Motorola targeted the ColdFire VL RISC processor architecture specifically at new embedded control requirements of advanced consumer electronics, which differ from those of desktop computer systems. The introduction of ColdFire marks an important milestone in the evolution of Motorola's 68000 family of processors. ColdFire represents the next logical step in the evolution of the 68000 -- the platform that ushered in the era of the workstation and desktop computer and is the most prevalent architecture in the embedded market.

ColdFire is Motorola's first advanced 32-bit microprocessor architecture designed specifically for today's high-performance consumer-class embedded applications, including the mass storage and imaging devices previously discussed. Unfettered by desktop computer requirements and starting with a clean slate, Motorola engineers embarked on a critical needs assessment to identify the basic operations required of high-performance processors operating in high-level language environments. These selected operations were used to define a variable-length RISC instruction set that was then implemented using the machine language syntax of the 68000. This approach resulted in an optimized embedded processing architecture that can access the wealth of quality development tools supporting the 68000, while breaking free from historical constraints.

ColdFire's VL RISC design has been optimized for high-performance, yet cost-sensitive, embedded control applications. ColdFire is not designed as a direct replacement for existing Motorola 68000 CPU cores such as the EC000 core, the CPU32 or the CPU32+, but rather to provide a platform aimed at emerging applications in the consumer electronics class. The similarity of the ColdFire programmer's model to previous 680x0 cores facilitates migration of existing applications and tools to ColdFire cores.

The ColdFire architecture is targeted at the consumer-level application -- the toughest class for embedded processors. Microprocessors in this class need to be priced aggressively, but deliver high performance. ColdFire products currently range from $8 to $25.

The Legacy of the Motorola 68000

While ColdFire minimizes core transistor count and code expansion, it fully retains the user programming model of the 68000 Family and its familiar assembly and high-level language coding styles. Programmer familiarity with the 68000 Family means that ColdFire designs will have faster time-to-market cycles. ColdFire VL RISC processors leverage a wealth of robust, high-quality development tools and software available for the 68000 Family (the world's most popular 32-bit embedded microprocessor family) by implementing a streamlined supervisor programming model and a user programming model that is identical to existing 68000 Family processors. No other RISC architecture has this advantage.

ColdFire's tool compatibility is probably its single most important advantage because it provides customers with immediate access to a range of tools and support. Product development costs, usually the greatest non-recurring cost, are minimized and product development schedules are accelerated.

Architectural Overview

In designing the ColdFire architecture, Motorola focused on the key factors for embedded applications: performance, code density, tools compatibility, and fast time-to-market. ColdFire combines RISC architectural features for performance with a powerful subset of the variable-length instruction set found in the 68000 Family for efficient code density and tools compatibility.

ColdFire's high performance is a product of its VL RISC architecture. To attain the highest level of performance, ColdFire features single-cycle instruction execution using hardwired control of the processor's resources, thus eliminating the performance overhead associated with microcoded engines.

ColdFire is a four-stage pipeline processor. By contrast, the 68060 has eight stages, while the 68040 has six. Pipelining increases performance by separating instructions into individual tasks so that multiple instructions can be in various stages of execution at any given time. ColdFire strikes an optimal balance between increased performance and system cost through pipelining, circuit complexity and size.

An overriding design goal for the ColdFire architecture was to minimize the silicon area. For example, while most ColdFire instructions support 32-bit operands, support for 8- and 16-bit operands is provided where needed to meet performance criteria or code density requirements**.** Once again, ColdFire provides an optimal balance between performance and code density versus silicon area.

With the extremely small size of the new class of consumer electronics, the size of each component becomes a critical factor. ColdFire CPU cores are extremely compact. ColdFire's small core die size allows cost-effective integration of on-chip memories (e.g., RAM, ROM, and cache), system modules, and peripherals, which lowers overall system costs.

Core size is also a major factor when it comes to power dissipation, another area of critical concern for advanced consumer electronics -- especially in portable devices. ColdFire's small core minimizes power consumption and maximizes battery life in mobile computing applications.

The ColdFire core is modular and completely synthesizable, meaning it can be quickly customized to include other modules or can be adapted to other fabrication technologies with minimum effort. This synthesis-driven approach enables fast design cycles, simplifies the integration of peripheral functions (like RAM, ROM, cache, and communications interfaces), and allows the use of a wider range of fabrication process technologies, operation frequencies, temperatures, and voltages.

ColdFire's flexible modularity makes it an ideal platform for products that must meet different price/performance points. Customers don't pay for functions they don't need, while higher performance features can be easily added. This flexibility is absolutely essential for embedded systems developers who must adapt their designs to a myriad of possible implementations.

The VL RISC Advantage

ColdFire's most substantial direct cost impact is in the area of memory subsystems. By implementing a VL instruction set architecture, the ColdFire processors optimize application code density for embedded control, thereby reducing memory requirements. Memory subsystem costs contribute a large portion to the overall price of many embedded systems.

Traditional fixed-length RISC microprocessors may appear attractive at first glance -- they provide much more performance per square inch of silicon than their CISC counterparts. This performance is responsible for the trend of some compute-intensive embedded applications to fixed-length RISC platforms.

But raw performance is gained at a substantial cost. RISC processors optimize performance by dedicating a significant portion of their circuitry to code execution accelerators, leaving functions such as managing processor interrupts to software. This can be a serious problem in real-time embedded applications that require the hardware-based peripheral functions such as interrupt handling to address problems in real time.

Fixed-length RISC architectures usually increase performance by maximizing the number of raw instructions that can be executed per second. In contrast, each fixed-length RISC processor instruction generally accomplishes less than a given CISC instruction. In other words, a RISC processor requires more instructions to accomplish a given task than does a CISC processor.

For embedded applications, a pure fixed-length RISC design presents a basic obstacle -- "code density." Because fixed-length RISC processors require more instructions to handle the same task, the code density is lower and fixed-length RISC systems typically require expensive memory subsystems to achieve maximum throughput.

Fixed-length RISC processors typically require 40 to 60 percent more code storage than ColdFire VL instruction set designs for a given task. Memory subsystems and cache size must be increased to handle the code overhead. This adds cost to the application, pricing it out of the range of the new consumer class of advanced electronic products.

ColdFire VL RISC represents an alternative approach that offers the performance advantages and low “real-estate” requirements of RISC coupled with an optimized code density that can operate with a less expensive memory subsystem. Minimized storage requirements for a given application reduce overall system cost. The ColdFire architecture provides a very efficient silicon design.

Family Overview

In the Spring of 1995, the first ColdFire implementation was introduced: the MCF5102 bridge chip. The MCF5102 serves as a “bridge” between the 68000 Family and the next generation of ColdFire products. The completely portable MCF5102 is code-compatible with the 680x0 Family. This affords both new and existing customers a cost-effective migration path to RISC with nearly the same performance as the 68040 at about half the cost. Compatibility with existing 68040 development tools gave system designers immediate access to a range of mature tool support. The MCF5102 provides customers and third-party tool developers with a jump-start in migrating their 68000 legacy software and development tools to the ColdFire architecture. The MCF5102 also executes code which has been compiled or assembled for the next generation of ColdFire, the MCF5200 Series, and provides a high level of sustained performance, ranging from 22 MIPS at 20 MHz to 36 MIPS at 33 MHz. In essence, the ColdFire MCF5102 offers excellent price/performance in addition to 100 percent compatibility with the 68EC040.

ColdFire technology then evolved from the MCF5102 to the MCF5200 Series. The key technological features of the MCF5200 Series include: 1) complete ColdFire ISA compatibility; 2) a range of design optimizations for target applications to provide the lowest-possible cost solution; and 3) a fully synthesizable core that can be integrated with other functions or fabricated in any Motorola process technology (key to reducing development cycles and time-to-market cycle); and 4) close compatability with the 68000 Family, allowing code written for 68000 Family members to run on ColdFire with minor modifications. Specific implementations in the MCF5200 Series include the MCF5202, MCF5203, MCF5204, and the MCF5206.

The MCF5202 combines a ColdFire core with an integrated 2 Kbyte unified cache. A 32-bit multiplexed bus with dynamic bus sizing allows access to 8-, 16-, or 32-bit memory and peripherals in the same system. Motorola's MCF5202 also includes a sophisticated debug interface that supports both background debug mode and real-time trace, so developers can greatly reduce the product development cycle. This interface, as well as JTAG support, is standard on all ColdFire-based processors and enables common emulator support across the entire ColdFire Family. Performance of the MCF5202 is 25 MIPS at 33 MHz.

The MCF5203 incorporates many of the same features as the MCF5202, but is offered with a 16-bit external data bus. Additional logic is also included to specifically support the 16-bit interface to bursting memories, reducing the amount of external logic required, while providing high performance from a 16-bit memory system. At 33 MHz, the MCF5203 achieves 24 MIPS performance.

The MCF5206 is a highly integrated implementation of ColdFire that, in addition to the standard execution core, JTAG port and debug module, includes a DRAM controller, chip selects, an interrupt controller, two timers, DUART, general purpose I/O interface, and Mbus (I^2C-compatible[1] Motorola bus) interface. On-chip memories include a 512-byte instruction cache and a separate 512-byte general purpose SRAM scratchpad, both with one-cycle access to critical code and data. The MCF5206 greatly reduces the time required for system design and implementation by packaging common system functions on-chip and providing glueless interfaces to 8-, 16-, and 32-bit DRAM, SRAM, ROM, and I/O devices. The MCF5206 processor's performance is rated at 17 MIPS at 33 MHz.

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[1] I^2 C is a Phillips proprietary bus

The MCF5204 is comprised of a ColdFire core, a 16-bit data bus, 512-byte direct-mapped instruction cache and 512-byte SRAM with one cycle access to data. Integrated peripheral functions include a serial interface implemented as a programmable full-duplex universal asynchronous receiver/transmitter (UART), and two 16-bit general purpose multimode timers -- one of which provides a separate input and output signal. For system protection, the processor includes a programmable 16-bit software watchdog timer and several bus monitors. In addition, it provides a glueless interface to 8- and 16-bit SRAM, RAM, and I/O devices. The MCF5204 provides 13.5 MIPS at 33 MHz and common system integration at one of the lowest price points in the industry.

Conclusion

Motorola's 32-bit ColdFire VL RISC processor family provides an ideal platform for the burgeoning embedded processor market. Well-suited for general as well as emerging consumer applications, ColdFire is positioned at an optimum price/performance point. ColdFire's ability to leverage the 68000 and the industry's most complete development environment gives customers a unique advantage. In the final analysis, ColdFire represents a low-risk, speedy development platform that will enable customers to get their high-performance products to market quickly and cost-effectively.