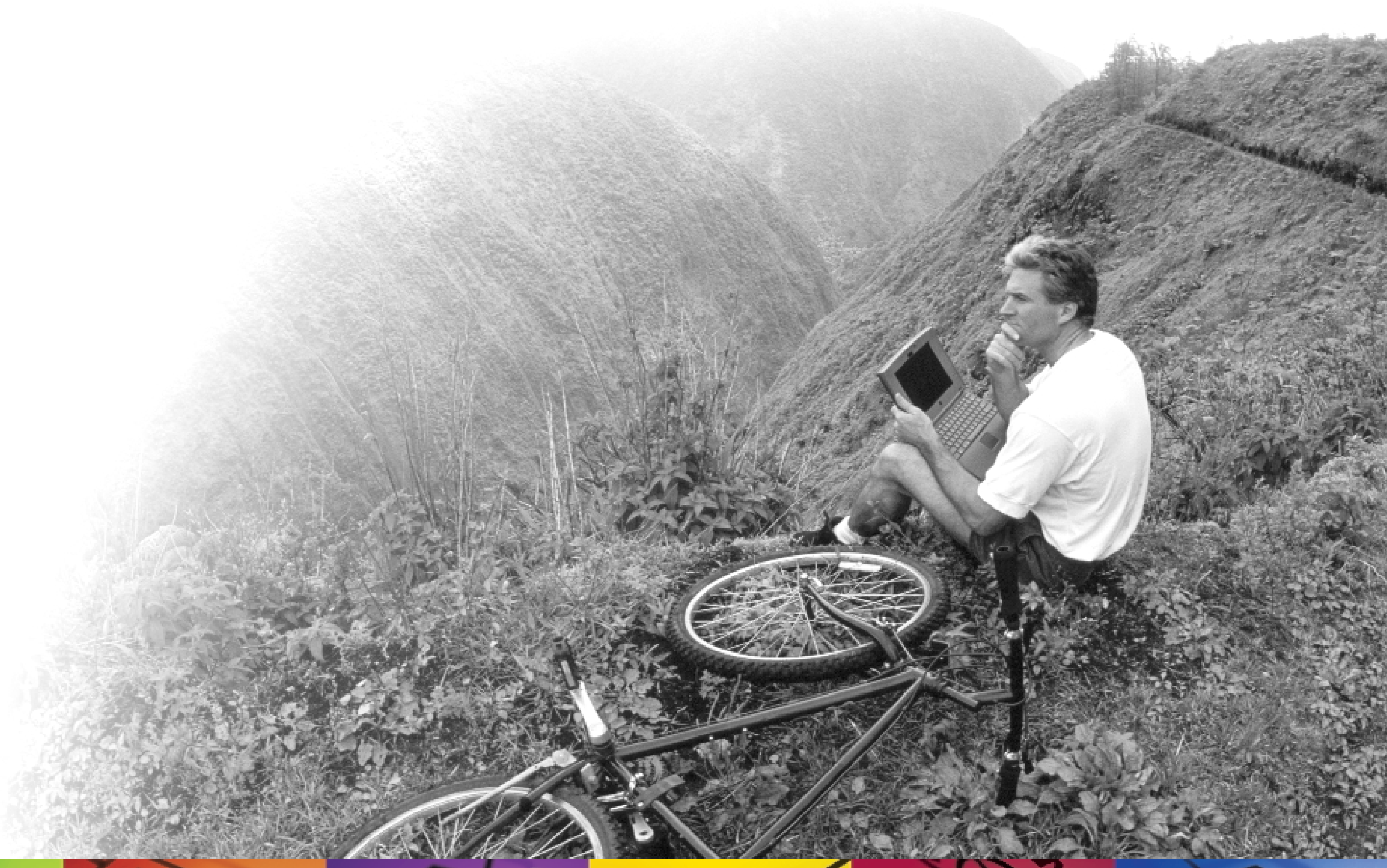
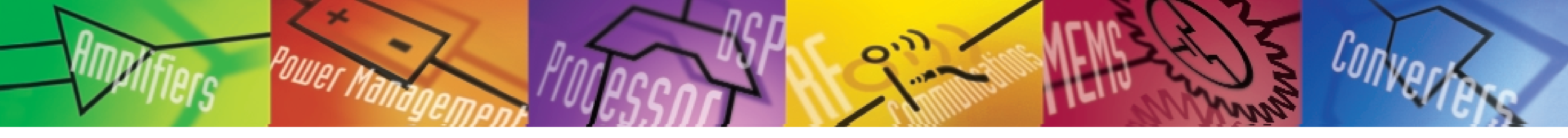
The Rise of Embedded Media Processing





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The Rise of Embedded Media Processing

An Inflection Point in Technology Causes a Fundamental Shift in the Application of Semiconductors

Despite the economic downturn of the last three years, the semiconductor industry is expected to return to the healthy growth rates that it has enjoyed since the mid-1970s. But what will be the growth drivers and enabling technologies that will move the industry forward?

The growth driver in the 1980s was the PC. In the 1990s, cellphones, high speed modems, and the Internet all fundamentally changed the way people transact business, interact with one another, and entertain themselves. Companies that provided the key products and technologies for these changes have become household names—Intel®, Microsoft®, Motorola, Nokia, Ericsson, and Cisco.

Analog Devices, Inc. (ADI) has detected the emergence of a subtle yet fundamental shift in our industry triggered by a confluence of factors that together strongly favor growth in the use of embedded processors. The emerging market for high speed, multimedia products of all descriptions is fueling a shift in the application of semiconductors, as many of these products benefit from Internet connectivity and extraordinary digital signal processing performance. Another factor is the continuing progress in semiconductor process technology, which improves performance and reduces chip cost, but now also dramatically increases the cost of IC design. Microprocessor architectural innovation now allows the hardware and software aspects of microcontrollers, digital signal processing, and media processors to be tightly integrated.

These factors define a new market context, one in which there is a clear demand for embedded signal processing that is flexible, low cost, and easy for OEMs to implement into media-rich wired and wireless applications. To address this need for a programmable architecture capable of processing greater volumes of data and signals at higher speeds, Analog Devices has developed a programmable micro-architecture that combines control and high performance signal processing into a single core. Based on this design, Analog Devices' new Blackfin® architecture provides a homogeneous model for the software engineer, while also reducing the complexity of a multicore system.

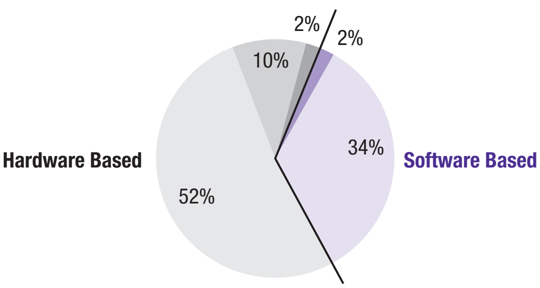
Analog Devices' new Blackfin Processor family affords designers and developers the opportunity to create and rapidly deploy innovative, higher quality multimedia, networking and communications applications, while reducing costs and utilizing a familiar RISC programming model. This paper addresses the market trends, technological imperatives, and design rationale driving the industry toward an embedded-processing alternative.

New Vanguards Spearhead Long-Term Growth

Drivers are emerging to sustain long-term growth in the semiconductor industry. The growth rates for digital signal processor (DSP) and analog semiconductor ICs are significantly outperforming those of microprocessors, memory ICs, and the overall semiconductor industry. The price and performance of signal processing devices have improved to the point where high performance signal processing is at the heart of every product that processes audio, images, and wireless signals.

Renaissance in Digital Signal Processing

2002 Digital Signal Processing Market—$13.3 B
Source: Forward Concepts



- 52% FASICs and Customer-Designed ASICs
- 10% DSP ASICs
- 2% Building Blocks
- 2% MPUs/Media Processors
- 34% Programmable DSPs ($4.86 B in 2002)
  - 3% Automotive
  - 7% Consumer
  - 11% Wired
  - 12% Computer
  - 13% General Purpose
  - 54% **Wireless**

A confluence of emerging market dynamics, advances in signal processing technology, and micro-architectural innovation is putting pressure on the digital signal processing market to move away from the traditional means of performing digital signal processing.

Despite the industry buzz over digital signal processing, the actual reported revenue of traditional DSPs, Texas Instruments™ catalog DSPs and Analog Devices' general-purpose DSPs—combined—represents only 13 percent of the digital signal processing market—and only five percent of all DSPs.

Today, only about one-third of the entire signal processing market comprises software based architectures such as programmable DSPs and microprocessors. Traditional hardwired solutions make up the bulk. These include merchant-market FASICs, customer-designed ASICs, ASICs with digital signal processing IP cores, and digital signal processing building blocks.

As the rise in embedded media processing gains momentum, newer software based micro-architectures that combine control and signal processing are expected to expand into hard real-time video processing and VLIW media processors.

One of the most promising applications for signal processing will be making the Internet—and electronic equipment in general—more useful and accessible to general users by providing always-on, high speed connectivity that is portable and enriched with high quality voice, audio, and video. A vast array of consumer products requiring very intensive, high performance signal processing is expected to bolster the growth of semiconductors as other product categories mature. The proliferation of signal processing based products and applications is gaining momentum and is being led by wireless, multimedia-capable appliances, wireless LANs, home-network gateways, and other consumer, automotive, and industrial products.

Before describing the agents for change affecting this shift, a review of the current signal processing landscape and its segmentation between fixed-function versus programmable solutions will provide useful context. According to DSP market research firm Forward Concepts, 60 percent of the entire $13.3 billion digital signal processing market is comprised of fixed-function, hardwired solutions. The majority of these are merchant-market function and algorithm-specific ICs (FASICs), followed by customer-designed ASICs that employ digital signal processing technology but are not programmable by the OEM buyer, and digital signal processing building blocks consisting mostly of FPGAs and PLDs. In contrast, the programmable segment represents only 40 percent of the market and consists of software based micro-architectures, such as programmable DSPs, media processors and microprocessors (see "Renaissance in Digital Signal Processing").

Representing the lion's share of hardwired signal processing solutions are more than 80 merchant-market FASIC suppliers serving up everything from DSL and cable-modem modulator/demodulator chips to decoder chips found in MP3s and most DVD players. These chips perform specific functions, whether in an Internet audio player or in wireless communications infrastructure. In the past, FASICs and customer-designed ASICs delivered signal processing functions with performance beyond the capability of software based, programmable DSP micro-architectures.

During the 1990s, the proliferation of telecom standards and features in handsets drove semiconductor growth as programmable DSP performance enabled the processing of GSM®, CDMA, and now EDGE Wireless℠ standards. (Enhanced Data GSM Environment, a faster version of GSM service using TDMA technology.) However, despite the resulting industry buzz over digital signal processors, the large majority of the digital signal processing market is served by fixed-function FASICs and cellular-handset chipsets.

Yet, general-purpose DSPs are the place where innovators start. When designing a new category of device or adding new classes of functionality, designers usually begin with a high performance, generally available DSP. The fact remains, however, that for every DSP-savvy algorithm programmer, there is a significantly larger pool of system designers programming more mainstream micro-architectures.

That is why conventional microprocessors and microcontrollers still outsell DSPs in unit volume by a factor of five to one, according to the World Semiconductor Trade Statistics Inc. (10 to one if programmable DSPs used in handsets are excluded). Although both exhibit similar growth rates, DSP penetration remains moderate despite a clear and growing trend toward signal processing differentiation in many different equipment segments.

As demand for design flexibility and time-to-market advantages increasingly defines the competitive landscape, and as process technologies enable higher performance architectures, software based system designs are gaining momentum for applications that in the past were serviced by fixed-function FASICs and customer-designed ASICs. Even today, media processors (typically VLIW DSPs) are already employed in high end consumer electronics, such as HDTVs and set top boxes. Together with high end MPUs, these software based solutions represent only two percent of the entire DSP market. A market shift is imminent, however, as blended RISC/DSP micro-architectures now have enough signal processing performance to enter the broader markets serving voice, video processing, and hard real-time media processing applications.

Agents of Change

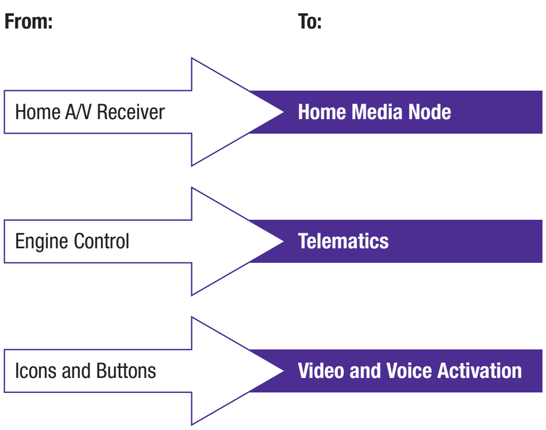
1. Emerging markets
As agents of change, many traditional embedded applications are undergoing a metamorphosis; they are imbued with rich audio and video data types—in some cases for entertainment, but in many cases for business productivity, security, or safety applications. (See "Life As We Know It Will Change.") These applications are network-connected media devices, which play to the strengths of programmable processors with leading-edge signal processing performance. Just as in mobile handsets—where programmable DSPs expedited the adoption of constantly evolving GSM voice-CODEC standards—programmable processors like the Blackfin Processor will accelerate the move to multi-standard, networked-media devices.

Whether for video or audio, multi-format and multi-standard support will be critical ingredients in the success and utility of portable and handheld devices. However, fixed-function ICs don't offer such flexibility to support multiple formats, including Microsoft Windows Media®, MPEG-2, MPEG-4, and H.264; and conventional embedded processors cannot meet the demanding signal processing requirements of systems dedicated to media processing.

2. Microprocessor innovation
The dramatic improvements in cost and performance of processors are more a result of architectural innovation than shrinking semiconductor process lithography, although both are important. (See "An Inflection Point Signals a Shift.") The performance of Analog Devices' fixed-point DSPs has been growing steadily as the architectures evolved from supporting the voice-band modems of the last decade to enabling today's native video-processing applications. At the same time, semiconductor process technology and architectural innovation drove a corresponding log-linear drop in cost-per-unit performance.

Ten years ago, Analog Devices launched a price/performance breakthrough with one-dollar-per-MMAC (millions of multiply-accumulate cycles) performance that catapulted its sub-$10 DSPs into mainstream popularity. Today Analog Devices' one-cent-per-MMAC Blackfin Processors have set yet another price/performance breakthrough. This new level of price/performance creates an alternate and compelling value proposition for many customers of fixed-function DSPs and embedded processors.

Life As We Know It Will Change

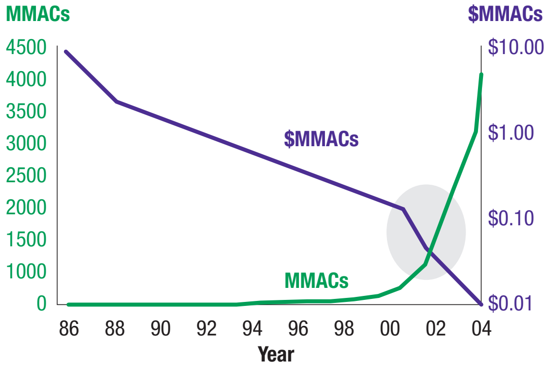


In the 1980s, PCs fundamentally changed the way people transacted business. In the 1990s, cellphones, high speed modems, and the Internet altered how people interact with one another and entertain themselves. Now, embedded processing is causing the current generation of electronic equipment—from wireless systems and engine control to home entertainment, cellphones, and PDAs—to undergo a metamorphosis that imbues them with rich audio, video, and wireless capabilities.

Processing requirements in this emerging world are very different because rather than relying on hardwired fixed-function ASICs, terminal devices will need to retain programming ability much like PCs today.

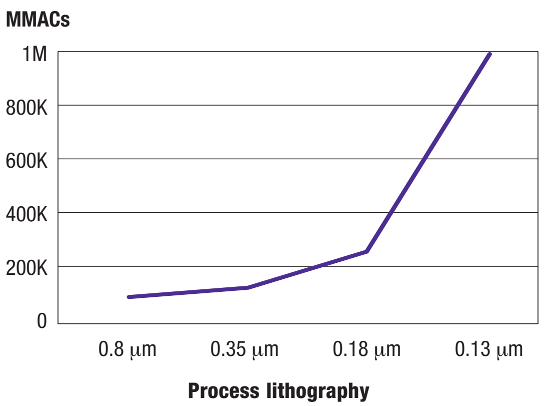
An Inflection Point Signals a Shift

ADI fixed-point architectures



Digital signal processing performance has increased exponentially while the cost per MMAC has dropped from $1 ten years ago to only a penny today. Meanwhile, development costs for ASICs continue to rise unabated.

Units to justify ASIC development
ADI estimates



Hardwired ASICs are fine-tuned to the application and optimized for-performance and power consumption; they are used to reduce costs when performance/protocol requirements stabilize and when costs can be minimized with high unit volumes. However, as newer process lithography descends below 0.15 microns, the sales of a particular ASIC design must grow exponentially in order to cover development costs. A 90-nanometer design will cost more than $1 million for mask sets alone, so companies are moving aggressively to rethink their technology decisions and move to a software based design model.

While MMAC price/performance improves, the cost of designing fixed-function ICs or ASICs grows exponentially as manufacturing technology evolves. Like every aspect of ASIC development, mask costs have skyrocketed, increasing from under $100,000 to millions of dollars per mask set as lithography descends toward 90 nanometers and below. For example, the unit volume necessary to justify an ASIC design has quadrupled as minimum geometry shrinks from 0.18 micron to 0.13 micron—and that trend shows no sign of abating.

Many fixed-function DSPs based on current ASIC technology are facing a brick wall in terms of development costs. By some estimates, only one in 10 ASIC designs can justify the costs associated with leading-edge process technology. Coupled with the relentless changes in standards and new features, companies are rethinking their technology decisions by aggressively moving to programmable processors. When they have made that move, changes, updates, and modifications can then be done in software rather than hardware.

3. New micro-architecture advances embedded processing

Embedded controllers are already used widely in portable and mobile devices of all types and are ubiquitous to the point of controlling anything having buttons, LEDs, or an LCD display. Embedded control is also found in cars, performing engine- and cabin-control functions as well as displaying electronic readouts.

Starting at the chip level, creative circuit design and architectural innovation have a major impact on the economics and architecture of embedded system design, as Analog Devices has demonstrated many times in its history. The new, innovative micro-architecture developed jointly by Intel and Analog Devices perfectly illustrates this point. The objectives for this new design were to, first, achieve breakthrough digital signal processing performance with hooks that facilitate hard real-time, full-motion-video processing; second, to combine the best capabilities of microcontrollers, microprocessors, and DSPs into a single programming model; and, third, to achieve best-in-class power efficiency. This brought to life the Blackfin Processor family of new products, enabling designers to run communications, multimedia, and the user-interface programs on a single, easy-to-program platform.

With the goal of delivering very high clock speeds and requiring very low power, Analog Devices focused on the physical design and handcrafting of data paths—a hallmark of the company's design skills—to reach results unachievable through simple process migrations.

Native support for 8-bit data (the format common to red-green-blue pixel processing algorithms) and specialized video processing instructions make it possible, for the first time, to cost effectively and power efficiently process DVD-quality video with software. In addition, integrated video instructions eliminate complex and confusing communications between the processor and a separate video IC.

Back to the Future—Shift to Embedded Media Processing Looks Familiar

Analog Devices has always been a significant force in analog and digital signal processing technologies. Anticipating the expanded use of signal processing beyond conventional DSPs in small-volume applications, Analog Devices' strategic collaboration with Intel bore fruit in an innovative, hybrid RISC/DSP architecture called Micro Signal Architecture (MSA). The joint development married Analog Devices' decades of experience in signal processing with Intel's expertise in application and control processing.

This embedded processor architecture blends the best qualities and features of a RISC Processor™, powerful DSP and high performance media processing. The efficient architecture, which combines the processing power of a dual-MAC, 16-bit DSP engine with a clean, 32-bit RISC instruction set, ably handles both control processing and media processing. These types of processing were traditionally accomplished only in separate RISC and DSP cores. The instruction set, which is tailored for media applications, includes image and video processing instructions, such as "sum of absolute differences," an algorithm critical to MPEG-4 video encoding and decoding.

The Blackfin architecture presents a familiar RISC processor paradigm, which embeds media processing in consumer-oriented handheld devices. On the one hand, it performs traditional digital signal processing tasks like those found on the C55 series from Texas Instruments (TI). On the other, it executes command and control tasks akin to Motorola processors, such as ColdFire® or PowerQUICC™, and Intel's XScale™ processors, which are RISC processors of 68K, PowerPC®, and ARM® heritage, respectively. The Blackfin's linear pipeline architecture executes the hard real-time tasks in true DSP fashion, but also sports the programmability, memory management, memory protection, and event interrupt/exception handling of a RISC microprocessor. (See "A Better Blend.") Unlike microprocessors with MAC blocks bolted on, or a DSP coupled to an ARM processor,

A Better Blend
The Blackfin Processor architecture blends the best attributes of digital signal processing with a RISC-based micro-architecture, enabling more efficient control processing and media processing features.

Vendor	**Texas Instruments**	**Analog Devices**	**Intel**
Example Product	TMS320VC5510	ADSP-BF533	PXA250
Architecture	C55X	Blackfin/MSA	XScale/ARM
Category	DSP	MSA	RISC
Max Clock Speed (MHz)	300	600	400
Dynamic Power Management	Clock Branch Disable, IDLE Modes	Clock Branch Disable, IDLE Modes, Voltage/Frequence Scaling	Clock Branch Disable, IDLE Modes
Signal Processing Features			
Pipeline Style	Linear	Linear	Out of Order
Internal SRAM	Yes	Yes	No
Lockable Deterministic Cache	Yes	Yes	Yes
Circular Buffer Addressing	Yes	Yes	No
Zero Overhead Looping	Yes	Yes	No
Cycles for MAC	1	1	2
Control Processor Features			
Inst/Data Cache	Yes/No	Yes	Yes
Operating Modes	Normal (ex. Supervisor), Emulator	User, Supervisor, Emulator	User, Supervisor, Emulator
Memory Mgmt Unit (MMU)	No	Yes	Yes
Real-Time Clock	No	Yes	Yes
Watchdog Timer	No	Yes	Yes
Event Handling	Interrupts	Interrupts/Exceptions	Interrupts/Exceptions
Performance Counters	No	Yes	Yes
Media Processing Features			
Video Bilinear Interpolation	No	Yes	No
Data Packing/Unpacking	No	Yes	Yes
Motion Estimation (SAA)	No	Yes	No
Byte Alignment	Yes	Yes	Yes

the Blackfin Processor is designed as a cohesive and efficient single-core embedded processor tailored for control, media, and signal processing. Proficient at signal processing and endowed with all the important control features of a RISC processor, the Blackfin Processor has a programming environment that will appear familiar to RISC programmers accustomed to orthogonal instruction and register sets and a high level programming language.

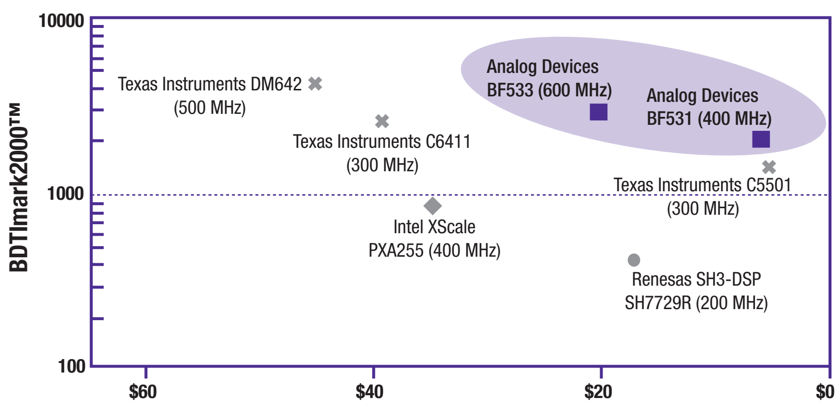
Analog Devices' long tradition of pushing the boundaries of possibility has resulted in its products sparking the imaginations—and designs—of customers in unexpected ways. Indeed, Analog Devices has been innovating in digital signal processing since 1982, and shipping product since 1984. Even so, the scope of customer innovations enabled by the 2001 introduction of ADI's first Blackfin product, the ADSP-BF535, exceeded the company's already high expectations. Such was the case with innovation in automotive telematics demonstrated at the 2002 Electronica show in Munich, Germany, where a 300-MHz Blackfin Processor simultaneously ran a GPS system while performing MP3 decoding, speech recognition, and speech-to-text processing.

The newest generation of Blackfin products—the ADSP-BF531, ADSP-BF532, and ADSP-BF533—is now poised to spark a fresh round of innovations among designers as it squeezes more performance into the same size package—but at a lower price than offered by competitive options. The performance of Blackfin's purely native signal processing is two times better than the highest performance conventional DSP-based solution available today.

Benchmark: Blackfin Infiltrates New Waters

Embedded media appliances for consumers depend on low cost, yet highly efficient architectures. Hence the typical one-dimensional benchmarking of raw clock speed in MHz alone is of little use if the processor's command and control resources are not in place to ensure that signal data is always ready for processing. Analog Devices' second-generation Blackfin ADSP-BF531 and ADSP-BF532 exhibit twice the performance at half the price of conventional programmable DSP chips. For example, using the BDTImark2000 to measure performance, the ADSP-BF532 provides twice the performance for the same price of the TI C5502. The ADSP-BF533 and ADSP-BF532 perform high quality media processing at a fraction of the price demanded by expensive, high end digital media chips (such as the TI DM642). As a result, rather than facing a $50-to-$100 price tag, manufacturers of consumer appliances and handsets save a bundle with chips that perform speech processing and fully native video processing for $5 to $10.

High End Without the High Cost



BDTi BENCHMARK PARTNER The BDTImark2000 provides a summary measure of DSP speed. For more info and scores see www.BDTI.com. Scores © 2002/2003 BDTI.

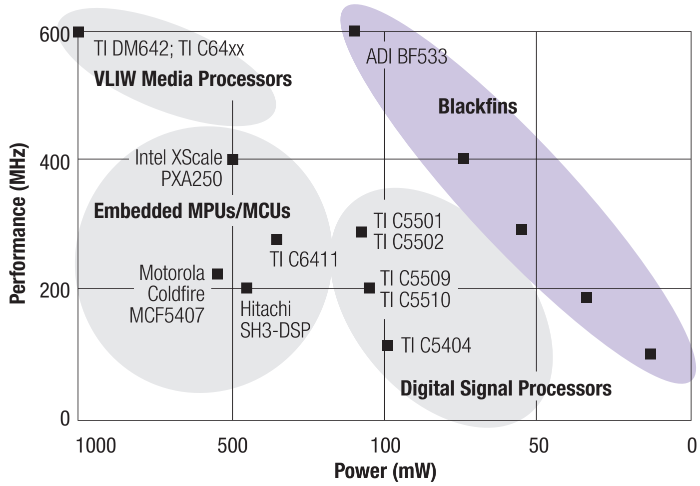
Breakthrough Performance

Blackfin Processors have broken through a performance level where full media processing, performed natively in software, is now feasible but at a fraction of the price of a VLIW DSP or media processor. (See "Benchmark: Blackfin Infiltrates New Waters.")

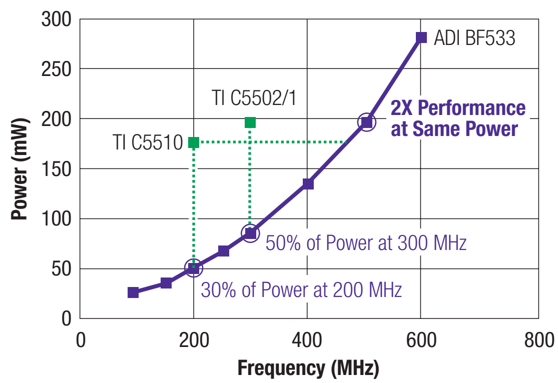
Given the scope of utility desired in portable devices, power efficiency is a criterion of equal importance to performance. Besides architectural innovation and a 0.13 micron process that endow a smaller chip with greater performance, the newer Blackfin Processor's miserly power consumption is further minimized through built-in dynamic power management. This capability allows a handset designer to continuously vary the Blackfin Processor's system voltage and operating frequency, fine-tuning it for real-time applications according to the needs of the processor's task; i.e., depending on whether operation is in standby, voice, or video-processing mode. (See "Dynamic Power Management.")

For example, the power consumption of a Blackfin Processor is only a small fraction of that exhibited by a TI C55-series DSP operating from 200 MHz to 300 MHz. And, at a given level of power consumption, the ADSP-BF533 can operate at over twice the speed.

Dynamic Power Management



Rigged with a dual-MAC architecture, dynamic power management, and an efficient memory hierarchy, the new lineup of Blackfin Processors maintains its edge in signal processing performance against alternatives that include DSPs, embedded microcontrollers and MPUs, and VLIW media processors.



Source: Texas Instruments Promotional Materials

For example, a Blackfin ADSP-BF533 operating at 200 MHz consumes only 50 mW, about 70 percent less power than a traditional DSP from TI, the C5510. Stated differently, for the same power consumption, the Blackfin Processor can operate at over twice the speed.

Beyond Benchmarks

Looking beyond the claims of software based media processors provided by benchmark comparisons, the percentage of processor utilization deserves a closer look. For example, consider the ADSP-BF533 Blackfin Processor, performing media processing in a fully software implemented D1 video (full DVD quality at about the size of a VGA screen). Running under Windows Media® Player (WMV 9), only 86 percent of a Blackfin Processor operating at 600 MHz is tasked—that's processing continuous video at 30 frames per second (fps).

In other examples, 74 percent of the ADSP-BF533's processing power is used for H.264 video and about 50 percent for MPEG-4. For cellphones and PDAs displaying CIF-format video, it's less than 25 percent. Audio CODECs, processing high sample rates for Windows Media (WMA 9) and MP3 players, are barely noticeable to a ADSP-BF533. At 600 MHz, only 10 to 20 percent of the processor is being used. The processor has significant remaining bandwidth for execution of additional algorithms or tasks. Of course, scaling back the frequency will save additional power without adversely affecting performance. Such benchmarks set the bar for real world embedded signal processing in media players running the gamut from 50 MHz to 600 MHz, where maximum performance per milliwatt per dollar is the gating factor.

Mainstream Programmers Stick Together

Optimizations for computation efficiency—rather than simplicity of programming—have made the classic DSP instruction set cumbersome and prohibited it from running mainstream embedded operating systems. For example, a 2002 survey of system developers by Wilson Research Group and CMP Media estimates that up to 75 percent are currently using, or seriously considering, an embedded OS in their next design. The emergence of open source code for Linux and application-optimized OSs further contributes to the growing appeal of embedded OSs at the expense of conventional DSPs.

In the past, many system developers were forced into a trade-off that sacrificed OS-friendly features of embedded microprocessors for signal processing performance. By taking a clean-slate approach to digital signal processing with built-in operating-system support, Analog Devices has turned what was once a barrier against programmable DSPs into an enabler.

Most programmable DSPs, such as the TI C6x and C5x series, do not support mainstream operating systems. Microprocessors like the PowerPC, XScale, and ColdFire do, but they lack high performance signal processing capability.

As with any world-class microprocessor, software support for mainstream OSs is a key attribute of the Blackfin's underlying architecture. Some of the mainstream OSs supported include Linux, Java™, ThreadX®, and systems from Fusion Software Engineering, LiveDevices Ltd., Metrowerks Corp., and Accelerated Technology®. Each tends to have gravity in different market segments, providing Blackfin based platforms with a broad range of applicability in different design communities, including consumer media, audio and video, automotive telematics, and hard real-time media processing.

The choice of a development platform is important in winning time-to-market competitions. For example, typical current solutions employ a multicore implementation—a conventional DSP processor and a microcontroller integrated into a single chip. But neither core is optimized for the application, and ASIC accelerator blocks are typically added just to provide the processing power to meet real-time requirements. The unavoidable reality remains; a programmer faces a hardware Frankenstein created with unrelated parts that have been stitched together, making the software challenge far more difficult. Programmers face a rigid (fixed in silicon) heterogeneous multiprocessor with awkward interprocessor communication and two separate development environments. Bringing up a product based on such a platform poses risks as protocol issues surface between the heterogeneous processors and the ASIC accelerator blocks. The realization of these issues typically surfaces toward the end of the project, when time-to-market pressure is at the highest point.

Since the initial introduction of the Blackfin architecture, Analog Devices has cultivated a large ecosystem of development tools, third-party DSP Collaborative™ developers, platform-ready reference designs, and training aids. Robust code generation and development tools are available from Analog Devices, Green Hills Software® and Metrowerks, to name but a few.

Embedded Processing Like Never Before

Technology has reached an inflection point where the spiraling costs of hardwired ASICs and FASICs signal a market shift toward software based micro-architectures. Signal processing performance of RISC processors stands poised to break into real-time media processing, and embedded processing is morphing electronic equipment to deliver rich audio, video, and wireless capabilities.

Analog Devices is leading the evolution, with its Blackfin Processor family, which embodies a new, yet familiar class of embedded processors for media-enabled appliances. Larger growth is anticipated in the use of mainstream architectures, displacing ASICs, FASICs, and traditional programmable DSPs as an easier-to-use and more economical solution to the signal processing challenge. The bottom line for embedded processors like the Blackfin Processor is a compelling and measurable competitive advantage in system cost, flexibility, and time to market.

Embedded Processing Support

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