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Choosing the Right Architecture for Real-Time Signal Processing Designs

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ABSTRACT

This paper includes a feasibility report that examines the benefits of seven of the most popular architectures (ASIC, ASSP, configurable, DSP, FPGA, MCU and RISC/GPP) in a direct-comparison format using the following criteria:

- Time to Market
- Performance
- Price
- Development Ease
- Power
- Feature Flexibility

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1 Introduction

Real-time signal processing and the applications that utilize it are changing the electronics market. Consumers are inundated with new products and technologies that are smarter, faster, smaller and more interconnected than ever, but which ultimately leave them wanting more. They want greater speed, effectiveness and portability, and they want it now.

Clearly, this puts tremendous pressure on design engineers who are asked to satisfy these varied demands. They must reduce cost and power consumption while increasing performance and flexibility. And they must do all of this in increasingly complex development environments and within a design cycle that is ever shrinking.

In addition, designers are also faced with a myriad of core technologies, all claiming to best execute real-time operations for a given application. Once the realm of digital signal processors (DSPs) only, the market is now crowded with options that further muddy the once clear waters of real-time signal processing.

MCUs, ASSPs, GPPs/RISCs, FPGAs, ASICs and configurable processors have joined DSP to stake their claim to a piece of the real-time pie. So how do you know which one will meet your real-time signal processing requirements? The purpose of this paper is to examine the benefits of the different architectures and compare the design trade-offs between them.

First, the criteria will be explained, and then applied to each of the seven options. Each option will be graphed according to its relative strengths and weaknesses based on these criteria and then discussed individually.

2 Criteria and Measurement

A recent Texas Instruments survey indicated that of the signal processing architectures considered by today's developer, the following alternatives were the most popular: ASIC, ASSP, configurable, DSP, FPGA, MCU and RISC/GPP.

Additional studies, including Cahner's "Mind of the Engineer" and Beacon Technology Partners' "Breaking Down the Barriers to Embedded Development," suggested that today's developer fulfills a number of criteria when choosing their signal processing architecture.

The criteria which were used to evaluate the options and their relative importance are as follows:

- Time to Market — High importance
- Performance — High importance
- Price —High importance
- Development Ease — High importance
- Power — Medium importance
- Feature Flexibility — Low importance

The architectural options were then evaluated against the criteria by means of the following decision table:

Table 1. Decision Table for Designers of Real-Time Applications

	Time to Market	Performance	Price	Development Ease	Power	Feature Flexibility	Summary
ASIC	Poor	Excellent	Excellent	Fair	Good	Poor	Fair
ASSP	Fair	Excellent	Good	Fair	Excellent	Poor	Good
Configurable	Poor	Excellent	Good	Poor	Good	Fair	Fair
DSP	Excellent	Excellent	Good	Excellent	Excellent	Excellent	Excellent
FPGA	Good	Excellent	Poor	Excellent	Poor	Good	Fair
MCU	Excellent	Fair	Excellent	Good	Fair	Excellent	Good
RISC	Good	Good	Fair	Good	Fair	Excellent	Good

The architectural considerations are listed on the left side of the table. The criteria used to evaluate these various options are listed along the top, according to importance of the criteria and the effectiveness of individual choices in meeting them.

Following is an in-depth discussion of each of these signal processing alternatives and how they address the issues of today's developer.

2.1 Discussion of Real-Time Signal Processing Options

2.1.1 ASIC (Application-Specific Integrated Circuit)

ASIC was judged poor in the matter of time to market. Configurable processors and ASICs are similar because the long cycle time required to complete and test an ASIC or configurable processor, fab the wafers unique to your design, and validate your solution can be many months to years. Whether configuring from gates or higher-level processor elements, they are only slightly different in degree of difficulty. Therefore, configurables gain a slight edge over ASIC in the poor time to market rating.

ASIC was judged excellent in the matter of performance. For ASIC, like FPGA, you can tune hardware gates specific to your application offering high application-specific performance.

ASIC was judged excellent in the matter of price, the only alternative to do so. In fact, dedicated standard cell logic gates with no overkill or underkill are the most efficient and smallest semiconductor chip size, thus likely offer the lowest recurring price. Also, ASIC commoditization can drive down the price per gate of ASIC chips.

ASIC was judged good in the matter of power. ASIC can achieve decent power efficiency when the design is specifically targeted for power efficiency, similar to the position on configurable. However, most ASIC-oriented designs are focused on performance or recurring cost (price) reasons, not power.

ASIC was judged fair in the matter of development ease. Although ASIC can be perceived as inexpensive, it is in fact the most expensive when it comes to overall development cost. This is attributed to the amount of logic design that has to be done by the customer to create the application on the chip, coupled with the ever increasing cost of silicon processing, with multiple hundreds of thousands of dollars per full reticle revision of silicon. In terms of development help, ASIC provides general support, but does not offer any application-specific help due to general lack of application-specific content knowledge at ASIC suppliers.

ASIC was judged poor in the matter of feature flexibility. With ASIC, once you commit to your logic for your ASIC, you have to start over and redesign to add features. And this means creating a new iteration of silicon.

2.1.1.1 ASSP (Application-Specific Standard Product)

ASSP was judged fair in the matter of time to market. However, the following compromise is often encountered: if the market already exists and the product already exists, the time to market could be good to excellent. However, in many new markets, the certainty of features required to make an application-specific dedicated product is late and thus time to market is poor. The composite rating thus would be fair.

ASSP was judged excellent in the matter of performance. For ASSP, assuming that it is specifically tuned to a particular application, it should offer high application-specific performance.

ASSP was judged good in the matter of price. ASSP is assumed to be application specific so much that it has less scale volume for cost efficiency; therefore price is good but slightly behind DSP.

ASSP was judged excellent in the matter of power. ASSP should score well on power, as it is optimized to the application-specific function. However, since it may be more optimized towards cost instead of power, it does not rate as high as DSP.

ASSP was judged fair in the matter of development ease. This assumes that it will have some challenges achieving differentiated features that may slow down development somewhat. In terms of development help, ASSP is expected to have application-specific knowledge, but only turnkey-oriented solutions. Thus, they are not likely to have good development help.

ASSP was judged poor in the matter of feature flexibility. ASSPs are by nature going to be somewhat poor in flexibility as they are inherently specific to their application, and in particular, to their unique solution approach to the target application. This specific focus and optimization is a tradeoff for flexibility.

2.1.1.2 Configurable Processor

Configurable was judged poor in the matter of time to market related to immaturity of the offerings, and relatively poor ease of development (see below).

Configurable was judged excellent in the matter of performance. Configurable processors, assuming they are specifically tuned to a particular application, should offer high application-specific performance.

Configurable was judged good in the matter of price. Configurable is still expected to offer a good price option, but lower scale and early life stage will keep if from being low price.

Configurable was judged good in the matter of power. This processor is designed to be configured somewhat for power efficiency assuming importance for the application.

Configurable was judged poor in the matter of development ease. With configurable processors, the wide-open functionality leaves much configuration effort to the product developer. Also, such products are immature and are likely to have development issues. Both factors relate to poor development cost. Given the newness of the architectures and small scale of the developers, configurable processors are bound to have numerous product and tool bug problems that consume a designer’s attention and cause support issues. It also cannot claim adequate application-specific knowledge.

Configurable was judged fair in the matter of feature flexibility. It can clearly be reconfigured to change features, but typically it will be before field placement. Consequently, aftermarket feature flexibility would be low.

2.1.1.3 DSP (Digital Signal Processor)

DSP was judged excellent in the matter of time to market. DSP, RISC processors and MCUs are all programmable processors and thus can utilize software programmability to achieve different functions and features, saving time to market versus similar hard-coded logic implementations. Within these three, for real-time signal processing, DSP is rated the best, or excellent, due to best and most relevant product, toolset and value web match to real-time applications.

DSP was judged excellent in the matter of performance. For DSP in particular, the multi-MAC VLIW architectures such as TI's TMS320C6000™ offer very high MIPS and MMACS signal processing performance resulting in increasing density of channels per chip that is competitive to FPGA, ASIC or ASSP.

DSP was judged good in the matter of price. DSP is not as cost-effective as ASIC or MCU, but not far off from MCU.

DSP was judged excellent in the matter of power. DSPs are very power efficient, especially when you consider DSP platforms designed specifically for low power, handheld applications such as TI 's TMS320C5000™.

DSP was judged excellent in the matter of development ease. With respect to development help, DSP suppliers have networks of third parties that add value in all aspects, from consulting to software, hardware platforms to systems. Also, powerful and easy-to-use tools, complemented by technical support networks and applications engineers that understand the real-time world are ready to help customers achieve their real time designs.

In terms of development cost, DSP programmability allows for faster development cycles for the desired function versus developing application-specific chips or ASICS. With proper use of high-level programming and/or use of standard code modules, one can cut development time significantly, and thus save development cost.

DSP was judged excellent in the matter of feature flexibility. DSP is a programmable processor and thus can utilize software programmability to achieve different functions and features, saving time versus similar hard-coded logic implementations. For real-time signal processing, DSP is rated the best among programmable processors (DSP, RISC, MCU) due to the existence of the best and most relevant toolset and value web to achieve real-time signal processing relevant functions.

2.1.1.4 FPGA (Field Programmable Gate Array)

FPGA was judged good in the matter of time to market. FPGAs avail field-ready modifications to achieve functions. Their flexibility is not as high as software programmable alternatives, thus they fall below DSP, MCU and RISC in their rating for time to market. However, they have better support and faster cycle time than ASSP, configurable processors or ASIC, and thus can claim faster time to market than those alternatives.

FPGA was judged excellent in the matter of performance. With FPGAs, developers can tune hardware gates specific to the application, delivering high application-specific performance.

FPGA was judged poor in the matter of price. FPGA is by far the most expensive alternative discussed here, achieving a poor rating.

FPGA was judged poor in the matter of power. FPGA is the bottom of the pack in power efficiency, an inherent trait in FPGA circuit technology as well as the overhead power of unused gates in the array. Technology advances will lower FPGA power, but likely not enough to change its place in the relative ranking on power efficiency.

FPGA was judged excellent in the matter of development ease. FPGA would rate the best on development cost assuming two situations: that the toolset for FPGA programming is not too expensive; and, assuming the developer is dealing primarily with hardware, that the engineer is involved in the development. If development leans towards software engineers, then FPGA would increase in effort and relative cost. In terms of development help, the FPGA tools and support structure for FPGA-based designs seems to be well established and acceptable to OEMs.

FPGA was judged good in the matter of feature flexibility. It can be field reconfigured for additional features or changes. However, this act of hardware reprogramming of an FPGA is more difficult and the achievable feature sets are more limited than software programmable solutions like DSP.

2.1.1.5 MCU (Microcontroller)

MCU was judged excellent in the matter of time to market. DSP, RISC processors and MCUs are all programmable processors and thus can utilize software programmability to achieve different functions and features, saving time to market versus similar hard-coded logic implementations. Within these three, for real time signal processing, MCU is rated second best, since it has a broad product, toolset and value web, although it is not a strong match for real time-applications.

MCU was judged fair in the matter of performance. Compared to a RISC/GPP, the MCU has lower mathematical processing resources and typically slower operating frequency.

MCU was judged excellent in the matter of price. MCU typically has a small chip size and thus a relatively low price; as such it comes in second behind ASIC.

MCU was judged fair in the matter of power. Typically MCUs are general in nature, making them less power efficient than DSPs, ASSPs or what configurable should be able to achieve. However, they typically use less silicon resources than RISC or FPGAs, rendering them more power-efficient than those alternatives.

MCU was judged good in the matter of development ease. MCU programmability of existing chips allows for faster development cycles for the desired function, versus having to develop application-specific chips or ASICS. With proper use of high-level programming and/or use of standard code modules, development time can be significantly reduced, saving development cost. In terms of development help, most MCU suppliers have a network of support as well, although it does not score excellent because much of that network is not experienced with real-time applications, merely embedded applications.

MCU was judged excellent in the matter of feature flexibility. MCU is a programmable processor and thus can utilize software programmability to achieve different functions and features, saving time versus similar hard coded logic implementations.

2.1.1.6 RISC/GPP (Reduced Instruction Set Computer/ General Purpose Processor)

RISC/GPP was judged good in the matter of time to market. DSP, RISC processors and MCUs are all programmable processors and thus can utilize software programmability to achieve different functions and features, saving time to market versus similar hard coded logic implementations. For real-time signal processing, RISC/GPP is rated good and third best to MCU's second best, since it also has a broad product, toolset and value web. However, it is not a strong match to real-time applications and not as oriented towards embedded applications, focusing instead on desktop computer purposes.

RISC was judged good in the matter of performance. RISC's typical high Megahertz levels will yield decent signal processing, but typical lack of mathematical specific single cycle instructions and multiplier units limit their real-time performance.

RISC was judged fair in the matter of price. RISC processors have significant general purpose functions on board that tend to make them good for desktop applications, but only fair on price effectiveness for real-time signal processing.

RISC was judged fair in the matter of power. Typically, RISCs are general in nature, making them less power efficient than DSPs, ASSPs or what configurable should be able to achieve.

RISC was judged good in the matter of development ease. RISC programmability of existing chips allows for faster development cycles for the desired function versus typically developing application-specific chips or ASICS. With proper use of high-level programming and/or use of standard code modules, one can cut development time significantly, and thus save development cost. In terms of development help, RISC designers receive general support, but don't get any application-specific or real-time help due to general lack of application-specific and real-time content knowledge at RISC suppliers.

RISC was judged excellent in the matter of feature flexibility. RISCs are programmable processors and thus can utilize software programmability to achieve different functions and features, saving time versus similar hard coded logic implementations.

3 Conclusion

Real-time signal processing is taking the digital revolution to the next step, making equipment that is more personal, more powerful and more interconnected than most people ever imagined possible. Over the years, different technologies have powered the most innovative creations — from the mainframe and minicomputer eras to the PC and today's Internet era. And, consumers are driving real-time functionality, demanding end equipments that are extremely fast, portable and flexible. To meet those needs, designers are facing more pressures than ever, but also have more options than ever to address them.

After a careful evaluation of each option, there are clearly several viable alternatives for embedded applications. However, for implementing today's real-time signal processing applications, the DSP is the best choice. No digital technology has more strengths than DSP nor better meets the stringent criteria of today's developer. Certainly, other digital options can address any one of these relevant problems well, but only with significant trade-offs.

DSP gives designers the best combination of power, performance, price and flexibility and allows them to quickly deliver their real-time applications to the market.

Appendix A A Closer Look at the Criteria Used in This Decision-Making Process

A.1 Time to Market (Overall Importance: High)

Time to market is fast becoming the most critical criteria in a product development cycle. With product life cycles shrinking from years to months in the Internet and consumer- appliance age, it becomes ever more critical. In fact, Cahners' 2002 "Mind of the Engineer" survey noted that "time to market is still driving the industry." Therefore, time to market rates at or near the top priority of criteria in most cases.

A.2 Performance (Overall Importance: High)

Performance is very important because it often determines the capability of a product. Increased performance often differentiates products by enabling new functions to be achieved, more channels per cost or area and higher speed data rates, as well as denser and higher-quality compressions.

Performance may be measured in many ways, but generically we look at millions of operations per second (MIPS), millions of multiply accumulates per second (MMACS), or, sometimes, the more simple millions of cycles per second (MHz) clock rate. Relevant benchmarks become a useful metric when trying to assess relative performance amongst different alternatives. Performance is lower on a priority basis only when other key requirements such as low power or low cost increase in priority.

A.3 Price (Overall Importance: High)

Price is often the most obvious priority criteria, but it comes slightly behind time-to- market and performance in most cases. Price impacts the bill of materials (BOM) and recurring production cost of the product. As such, the higher volume and the more consumer- or retail-oriented the product is, the higher the likely priority on low price. In contrast, the more infrastructure and business/commercial the end product is, the less sensitivity to price as cost of ownership and efficiency tends to command more attention.

A.4 Development Ease (Overall Importance: High)

Development ease brings together development support, development tools,and development costs, and is clearly a criterion of increasing importance. Development ease is multi-faceted, and in a more detailed analysis, would be broken down into separate components, such as technical support, technical training, third party value web, software tools, documentation, engineering time and overhead and NRE development expenses.

Clearly, the more technical support a designer can get from a vendor or from the partners of that vendor the easier it will be for a designer to focus on his or her own innovation and achieve faster time-to-market. Each should offer consulting, PC boards, EVMs, software tools and component software and algorithms. Designers having the option to buy versus make, or purchase consultant-expertise versus having to own or do it all themselves, can also save significant development effort and dollars. Therefore, development ease can lead to higher quality end products because valuable time and money are spent on differentiation rather than foundation.

Development cost is the composite cost of all the non-recurring engineering R&D costs required to develop, test and take a product into production. These costs impact the return on investment financial decisions associated with new product planning. If development costs grow too high, achieving return becomes difficult or risky.

Development tools are also a key to design. Robust development tools such as DSP Starter Kits, Integrated Development Environments and compilers give designers more visibility into their design and allow them to reduce their time to market. Also, tools for the target hardware are seeing an increasing importance as developers are looking for ways to reduce costs. Silicon vendors who can offer royalty-free operating systems, off-the-shelf code from third parties and frameworks that allow designers to get going quickly on their design all contribute to significant overall development cost reduction.

A.5 Power (Overall Importance: Medium)

Low power is becoming increasingly important in two primary domains. In portable products, such as digital cell phones and Internet audio players, low power translates to longer battery life - a significant end user care-about. In infrastructure applications, lower power translates to less heat dissipation. Often, heat dissipation ”envelopes” can be the limiting factor for channel density or feature additions in non air-flow-conditioned ”boxes.” Thus, less heat means more channels or more features within the same physical box.

A.6 Feature Flexibility (Overall Importance: Low)

Feature flexibility is the capability to modify or add features to meet changing requirements. Requirement changes occur more and more rapidly in today’s markets. For example, early entry into standards-based products (such as communications or compression standards) before the standards are solidified is critical if manufacturers are to lead in the market. However, designers must build ”future proof” products that can be upgraded to reflect the final standard after all nuances have been worked out. Thus you must have the feature flexibility required to update your product easily and quickly after market.

Another example of feature flexibility has to do with Internet audio players and answers the question: what audio codec do I support at any given time? The answer is always the one in which the downloaded music is encoded. Given this feature-flexibility requirement but lack of coexisting function need, a designer can re-deploy the same resource to the selected function on demand as opposed to allocating dedicated resource for each and every potential function. Flexibility also gives designers an important edge by readying them for convergence between consumer, communications and computer functionality as the markets dictate.

A.7 Other Considerations For Future Comparisons

Two other criteria that would be salient to this discussion but fall outside of the scope of this paper are peripherals and production ramp. Peripherals are critical elements in today’s designs and are relevant to any application. As more products and standards evolve, the types and capabilities of peripherals are growing exponentially. Therefore peripheral availability, or the lack thereof, can become a key issue.

Production ramp is often overlooked. It may be assumed, but often is not as problem-free as one assumes. Consequently, paying more attention sooner rather than fixing problems caused by lack of supply later is becoming more important as product life cycles are shorter, product ramps are faster and market windows come and go a more rapid pace.

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