THE BDTIMARK2000™: A SUMMARY MEASURE OF SIGNAL PROCESSING SPEED

A WHITE PAPER

BY

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The BDTImark2000™ provides a summary measure of processors' signal processing speed. The initial version of this metric (the BDTImark™) was introduced by BDTI in 1997; it was subsequently updated to better reflect current signal processing applications. A processor's BDTImark2000 score is based on its results on BDTI's suite of signal processing benchmarks, which are carefully optimized for the target processor. This paper explains the motivation for creating the BDTImark2000, the methodology used to develop the metric, and how the BDTImark2000 can be used to help select processors for signal-processing-intensive applications.

Introduction

Users of processors for digital signal processing applications need a simple, independently verified, single-number measure of processor speed on signal-processing-intensive applications. Traditional measures of speed such as MIPS and MFLOPS are not meaningful due to wide variations in processor instruction set efficiency.

In recognition of this need, in 1997 BDTI introduced the BDTImark™, a composite signal processing speed metric derived from a processor's performance on BDTI's suite of signal processing algorithm kernel benchmarks, the BDTI Benchmarks™. In 1999, BDTI updated the BDTI Benchmarks to better reflect current signal processing applications. As part of this update, BDTI also updated the BDTImark to create the BDTImark2000™. This paper explains the motivation for creating the BDTImark2000, the methodology used to develop the metric, and how the BDTImark2000 can be used to help select processors for signal-processing-intensive applications.

The Need for Signal Processing Benchmarks

Designers of signal-processing-based systems face many choices when selecting processors. Although just one of many factors to consider in making a selection, a processor's speed on signal processing applications is paramount and is one of the first attributes used to narrow the field of contenders. System designers thus require a single metric that characterizes processor signal processing execution speed. This allows them to quickly and efficiently identify which processors are likely to meet their speed requirements before they proceed with more detailed analysis.

Processor vendors often quote metrics such as millions of instructions per second (MIPS) and millions of floating-point operations per second (MFLOPS) as measures of processor speed. However, these metrics have lost relevance in the face of increased variability in processor architecture and instruction set efficiency.

Consider the inner loop of a finite impulse response (FIR) filter, represented mathematically as

$$y[n] = \sum_{j=0}^{Ntap - 1} x[n-j]h[j]$$

where x[n - j] is a sample value, h[j] is a coefficient, y[n] is the filter output, and Ntap is the number of coefficients.

The Texas Instruments TMS320C6202, a well-known DSP processor, has an instruction clock speed of 300 MHz and executes up to eight instructions per clock cycle. This gives the TMS320C6202 a MIPS rating of 2400—twenty times greater than Freescale's 120 MHz DSP56852, a conventional DSP processor that has a MIPS rating of 120. Despite this difference in MIPS ratings, the TMS320C6202B performs BDTI's Real Block FIR Filter Benchmark only about six times faster than the DSP56852. This discrepancy between MIPS rating and actual speed is a result of the dramatic difference in the amount of work that each processor performs per instruction.

A Freescale DSP5685x family processor would implement the inner loop of an FIR filter via a sequence of instructions such as:

```
MOVEU.W  X:DLYPTR,R0 ; load data address into r0 pointer
MOVEU.W  #COEFADDR,R3; load coefficient address into r3 pointer
REP      #NTAP       ; repeat the next instruction Ntap times
MAC      X0,Y1,B    X:(R0)+,Y1    X:(R3)+,X0
                     ; multiply and accumulate a sample and coef.
```

Because the DSP5685x features dedicated looping hardware, dual address generators, an enhanced Harvard memory architecture, and specialized signal processing instructions, the processor can carry out the inner loop by executing *Ntap* multiply-accumulate (MAC) instructions. During each instruction cycle the DSP5685x multiplies a sample by its corresponding coefficient, loads the next sample and coefficient, and updates the address pointers—all via a single instruction.

On the TMS320C62x family, the FIR filter's inner loop would be implemented via a sequence of instructions such as:

```
loop:
        ADD.L1      A0,A3,A0  ; A0=A0+A3
||      ADD.L2      B1,B7,B1  ; B1=B1+B7
||      MPYHL.M1X   A2,B2,A3  ; A3=A2(hi)*B2(lo)
||      MPYLH.M2X   A2,B2,B7  ; B7=A2(lo)*B2(hi)
||      LDW.D2      *B4++,B2  ; load into B2
||      LDW.D1      *A7--,A2  ; load into A2
||      ADD.S2      -1,B0,B0  ; decrement counter
||      [B0]        B.S1 loop ; branch if B0 nonzero
```

The TMS320C62x employs a very long instruction word (VLIW) architecture that allows it to execute the eight instructions in parallel. Its dual multipliers and dual adders allow the MAC operation to be performed for two taps at once, so the eight instructions above must be executed only *Ntap*/2 times each. Note, however, that the TMS320C62x requires separate instructions for loop control and memory loads, while the DSP5685x can perform these operations as part of its MAC instruction.

The TMS320C6202's 300 MHz clock speed and ability to perform two MAC operations in parallel give it a speed advantage of approximately 6.2:1 over the 120 MHz DSP56852 on BDTI's Real Block FIR Benchmark. The fact that each TMS320C62x instruction does a relatively small amount of work compared to DSP5685x instructions explains the disparity between the 20:1 MIPS ratio and the 6.2:1 performance ratio on this benchmark. This comparison illustrates the hazards of simplified metrics such as MIPS and shows why such metrics are not meaningful indicators of processor speed.

The BDTImark2000™

In 1997, BDTI addressed the need for a better signal processing speed metric by developing the BDTImark—a simplified representation of processor signal processing speed distilled from results on BDTI's popular signal processing benchmark suite, the BDTI Benchmarks. In 1999, in order to reflect the changing needs of signal processing applications, BDTI refined and updated the underlying benchmark suite. This led to the release of the BDTImark2000, successor to the original BDTImark. Since its release, the BDTImark2000 has become the de facto industry-standard measure of processor signal processing speed. As outlined below, the BDTImark2000 was designed to meet several key goals and as a result it is a superior alternative to simplified speed metrics such as MIPS.

Goals of the BDTImark2000

In order to be useful and effective, a signal processing performance metric must meet several objectives:

- **Relevance.** A signal processing speed metric must reflect a processor's performance on frequently used signal processing algorithms.
- **Fairness and accuracy.** The speed metric should be calculated from benchmark results obtained through a rigorous, repeatable benchmarking process—a process that treats all processors equally.
- **Single-number simplicity.** To allow quick and easy comparisons, the metric should be expressed as a single number.
- **Applicability.** The metric should be applicable to any type of programmable processor.
- **Independence.** Metric scores should be derived and verified by an independent party to ensure that they reflect true processor performance.
- **Availability.** The metric scores should be available to the public at no cost.

BDTImark2000 Characteristics

The BDTImark2000 accomplishes these goals, as described below.

- **Relevance.** A processor's BDTImark2000 score is derived from the processor's execution speed on the BDTI Benchmarks. The BDTI Benchmarks, listed in Table 1, are a suite of algorithm kernels found in popular signal processing applications. BDTI has implemented its benchmarks on dozens of processors and has documented the methodology in a white paper entitled *Evaluating DSP Processor Performance* (available on BDTI's Web site, www.BDTI.com). BDTImark2000 scores are issued only for processors that are widely available.
- **Fairness and accuracy**. BDTI issues BDTImark2000 scores only for processors whose BDTI Benchmark implementations have been rigorously reviewed by BDTI using a well-defined, repeatable process. BDTI verifies all benchmark results on hardware prior to issuing a BDTImark2000 score. BDTImark2000 scores are calculated at the fastest clock speed at which the processor is available to customers. Thus, users can be assured that they can obtain the performance shown by BDTImark2000 scores. (A related metric, the BDTIsimMark2000™, described later in this paper, is used for processors that are not yet available or whose performance has not been verified on hardware.)
- **Single-Number Simplicity.** The BDTImark2000 offers a single-number measure of a processor's signal processing speed that is calculated by combining the processor's score on all of the BDTI Benchmarks. BDTImark2000 scores are linearly scaled, with higher numbers representing faster execution speeds. Thus, a processor with a

BDTImark2000 score of 500 is twice as fast when executing typical signal processing algorithms as a processor with a BDTImark2000 score of 250.

- **Applicability.** The BDTImark2000 is applicable to any programmable processor. This universal applicability is possible because the BDTI Benchmarks can be implemented on any architecture. The BDTI Benchmark specifications rigorously define both benchmark functionality and allowable optimizations. These specifications afford programmers freedom to optimize the benchmark implementations for each processor.
- **Independence.** BDTI engineers independently verify every BDTImark2000 score and the underlying BDTI Benchmark implementations. Each benchmark implemen-

Function	Description	Example Application
Real Block FIR	Finite impulse response filter that operates on a block of real (not complex) data.	Speech processing, e.g., G.728 speech compression.
Single-Sample FIR	FIR filter that operates on a single sample of real data.	Speech processing, general filtering.
Complex Block FIR	FIR filter that operates on a block of complex data.	Modem channel equalization.
LMS Adaptive FIR	Least-mean-square adaptive filter; operates on a single sample of real data.	Channel equalization, servo control, linear predictive coding.
Two-Biquad IIR	Infinite impulse response filter that operates on a single sample of real data.	Audio processing, general filtering.
Vector Dot Product	Sum of the point-wise multiplication of two vectors.	Convolution, correlation, matrix multiplication, multi-dimensional signal processing.
Vector Add	Point-wise addition of two vectors, producing a third vector.	Graphics, combining audio signals or images, vector search.
Vector Maximum	Find the value and location of the maximum value in a vector.	Error control coding, algorithms using block floating-point.
Viterbi Decoder	Decodes a convolutionally encoded bit stream.	Wired and wireless communications, e.g., digital cellular phones.
Control	A contrived series of control (test, branch, push, pop) and bit manipulation operations.	Virtually all signal processing applications include some “control” code.
256-Point FFT	The Fast Fourier Transform converts a normal time-domain signal to the frequency domain.	Radar, sonar, MPEG audio compression, spectral analysis.
Bit Unpack	Unpacks words of varying length from a continuous bit stream.	Audio and speech decompression.

Table 1: The BDTI Benchmarks.

tation is carefully examined for functional correctness, specification compliance, and optimality. BDTI is independent of processor vendors, and subjects all benchmark implementations to the same review process.

- **Availability.** BDTI makes BDTImark2000 scores for commercially available processors (including licensable cores) available to the public without charge. Several example BDTImark2000 scores are included in Figure 1. The most current scores are available on BDTI's web site, www.BDTI.com.

Limitations of the BDTImark2000

Despite the many benefits of the BDTImark2000, users should be mindful of the limitations inherent in any simplified measure of processor speed. The key limitations of the BDTImark2000 are summarized below.

- The BDTImark2000 is a composite score encompassing a processor's performance on many different signal processing algorithms. Users should view BDTImark2000 scores as an estimate of processor execution speed for signal processing tasks in general, not for specific applications.
- A processor's aptitude for one specific application may not be reflected in its BDTImark2000 score. For example, a processor may contain special instructions or coprocessors that are specifically designed for one type of application, but that are not heavily weighted (or not used at all) when calculating BDTImark2000 scores.
- The BDTImark2000 reflects only signal processing speed. The BDTImark2000 does not consider other important performance factors, such as memory use, energy consumption, price, and on-chip integration.

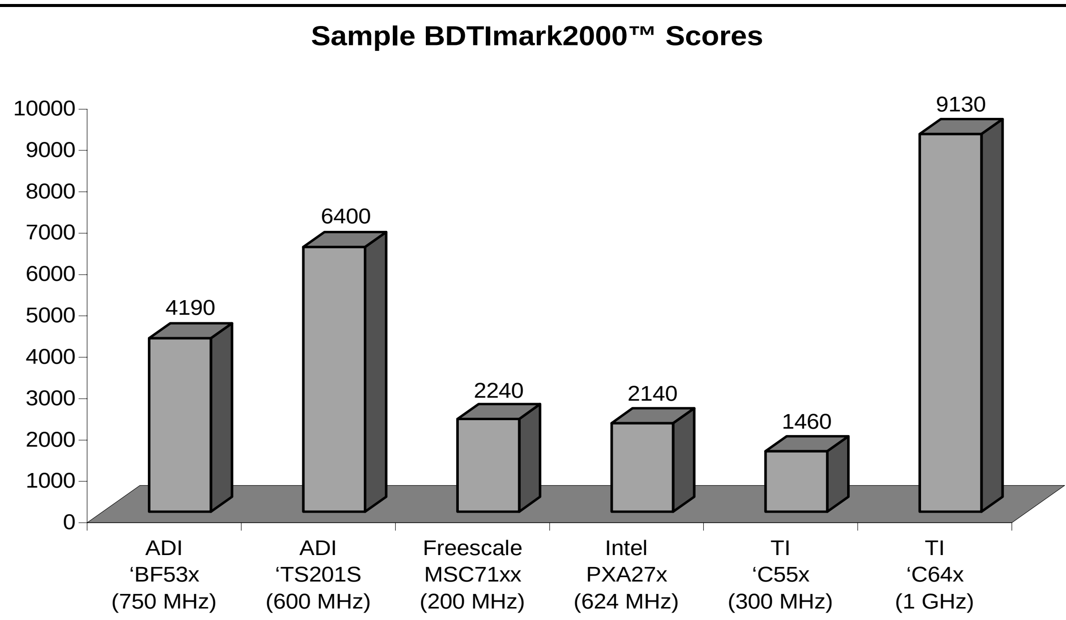

Figure 1: This chart illustrates the BDTImark2000™ scores for several popular fixed-point processors. Many additional BDTImark2000 and BDTIsimMark2000 scores are available at www.BDTI.com.

- The BDTImark2000 is based on BDTI Benchmark implementations that use a processor's native arithmetic format. Thus, users should be careful when comparing fixed- and floating-point processors, or processors with different data precision. For example, if a fixed-point and floating-point processor both have BDTImark2000 scores of 400, users should bear in mind that the floating-point processor is delivering more precise results and is consequently doing more work.

The BDTIsimMark2000™

As described earlier, BDTI's policy is to verify benchmark results on silicon before issuing a BDTImark2000 score. This policy helps to ensure that the score accurately reflects the performance that can be expected from actual silicon available today. However, it is not always practical to verify benchmarks on hardware. For example, a chip designer may need to evaluate a licensable core before the core has been fabricated. To meet such needs, BDTI publishes the BDTIsimMark2000. This metric is calculated in the same manner as the BDTImark2000, but is based on simulated results instead of hardware measurements. Like BDTImark2000 scores, BDTI publishes the BDTIsimMark2000 scores on its Web site at www.BDTI.com.

Although BDTIsimMark2000 and BDTImark2000 scores are calculated in the same manner, they should be compared with caution. In addition, caution should be used when comparing scores for chips to scores for cores. These considerations are explored in the following section.

Comparing Scores

Table 2 explains how BDTI determines whether a processor receives a BDTImark2000 or BDTIsimMark2000 score. Although BDTIsimMark2000 and BDTImark2000 scores are calculated in the same manner, they should be compared with caution. This is particularly true when comparing a processor that has not been fabricated to a processor that has been fabricated. First, the pre-silicon processor may not achieve the expected clock speed. Second, in the time it takes for the pre-silicon processor to reach production, competing vendors may achieve higher clock speeds or introduce new architectures.

It is also hazardous to compare scores for chips to scores for cores. For chips, vendors guarantee that the processor will achieve a certain clock speed. For cores, the clock speed depends on the fabrication process, synthesis targets, and other factors. Hence, the clock speed of a core may vary dramatically from one deign to the next.

For the sake of consistency, BDTI calculates scores for licensable cores using projected worst-case clock speeds in a 0.13 μm process. In this context, "worst-case clock speed" means the clock speed projected for a core assuming worst-case process, voltage, and temperature variations.

BDTI uses worst-case speeds for licensable cores because this is the speed with which chip designers typically are most concerned. Although BDTI relies upon processor vendors to supply the projected clock speed, BDTI evaluates the stated speed based on a variety of factors (such as the speed of similar processors) and adjusts the projection as necessary to obtain what it believes to be a realistic clock speed projection.

Detailed Processor Analyses

Although the BDTImark2000 and BDTIsimMark2000 are very useful tools, serious system designers will want to use more detailed processor analyses when making their processor choice. BDTI offers a wealth of detailed processor evaluations. These include detailed benchmark results for individual BDTI Benchmark algorithms and for metrics such as memory usage and energy consumption. BDTI also offers insightful analyses of factors that can't be captured in benchmark results, such as the sophistication of on-chip peripherals, ease of programming, and quality of development tools. These analyses are available in BDTI's *Buyer's Guide to DSP Processors*, processor-specific reports in the *Inside* series, and through BDTI's custom advisory services.

Conclusion

The BDTImark2000 and BDTIsimMark2000 provide accurate estimates of processor speed in typical signal processing applications and are vastly preferable to the simplified metrics often quoted by chip vendors. BDTI independently verifies and releases BDTImark2000 and BDTIsimMark2000 scores for processors commonly used in signal processing applications and makes these scores available to the public at no cost.

For the latest BDTImark2000 and BDTIsimMark2000 results, see www.BDTI.com.

For information on obtaining a BDTImark2000 or BDTIsimMark2000 score for your processor, please contact BDTI.

Processor Type	Fabrication Status	Measurement Methodology	Clock Speed Used	Score Type
Chip	Available in at least sample quantities	Hardware	Clock speed of fastest available chip	BDTImark2000
	Available in at least sample quantities	Simulator	Clock speed of fastest available chip	BDTIsimMark2000
	Not yet available	Simulator	Projected clock speed of fastest chip	BDTIsimMark2000
Core	Has been fabricated	Hardware	Projected worst-case clock speed in a 0.13µm process	BDTImark2000
	Has been fabricated	Simulator	Projected worst-case clock speed in a 0.13µm process	BDTIsimMark2000
	Has not been fabricated	Simulator	Projected worst-case clock speed in a 0.13µm process	BDTIsimMark2000

Table 2: Criteria for BDTImark2000 and BDTIsimMark2000 scores.

About Berkeley Design Technology, Inc.

BDTI provides analysis and advice that help companies develop, market, and use signal processing technology.

BDTI is a trusted industry resource for:

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