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OVERCOMING CHALLENGES IN HD AUDIO IC DESIGN

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Introduction

Advances in video streaming and image rendering technologies have created exceptional High Definition moving image quality. Together with the increasing popularity of home entertainment centers, these have been significant drivers in the pursuit of the "movie theater" experience at home, or on portable electronic devices. In addition to High Definition video, High Definition audio or "HD Audio" was also introduced to add a richer audio experience to the ever-expanding world of multimedia entertainment. Three broad sectors of the HD audio market will be addressed in this white paper. These are:

- Digital television - DTV
- Set-top boxes – STB
- Blu-ray DVDs

By 2011, according to a recent report[1], it is predicted that the sales of these items will be 187 million DTVs, 160 million set-top boxes and 116 million Blu-ray DVDs. In addition, there are other market segments such as A/V receivers, HD camcorders, IPTV and mobile phones.

However, significant differences exist between standard and HD audio specifications, in terms of processing requirements, audio channels, bit rates and precision requirements. These new demands from HD audio systems impact on every aspect of integrated circuit ("IC") design and create major challenges to delivering the audio quality promised by these new devices.

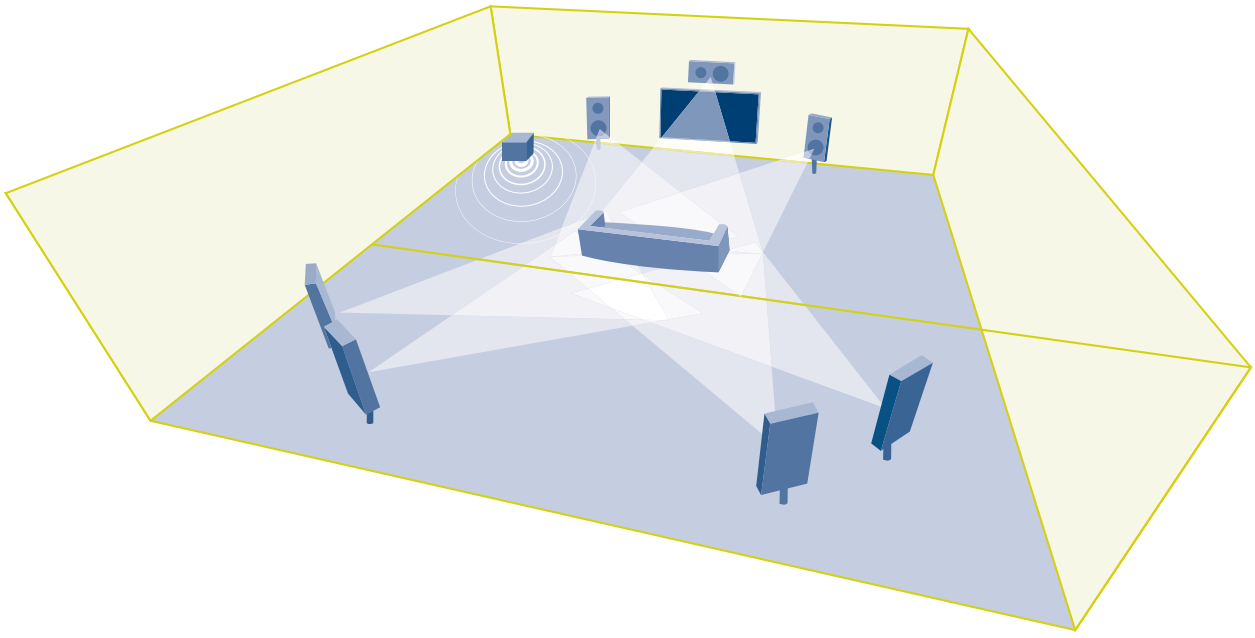
This white paper will review these different high definition delivery media, discuss the design challenges for IC designers and propose solutions and approaches for efficient HD audio implementation.

Opportunities for HD Audio

As outlined above, we will briefly review the three major application opportunities for HD Audio.

- **Digital TV ("DTV")**
  Digital television (DTV) involves using discrete (digital) signals to enable the sending and receiving of moving images and sound. The transition from analog TV to digital

[1] Oppenheimer & Co., January 2008



HD-Audio 7.1 typical speaker placement

TV began in the late 1990s, and was a particularly appealing technology for television broadcasting and consumer electronics industries because it provided a whole range of new commercial opportunities.
Early-adopter countries such as Holland and Finland completed their transition to digital TV in 2006 and 2007 respectively, and by February 17, 2009, all TV stations in the USA are expected to broadcast in digital mode only. By comparison, the UK has already started to transition to DTV, with a target date for full DTV broadcasting by 2012 and China is scheduled to complete the transition to DTV broadcasting by 2015.
A significant challenge in converting from analog to digital broadcast or playback is the data processing and data traffic required for HD audio applications. Any successful IC-based solution for HD audio needs to take this into account during development and implementation.
Another challenge for DTV is the requirement to keep the costs down for consumers, especially because of the mandate for the transition to DTV – consumers must replace their TVs due to regulatory decisions, and so they could be very price sensitive.

Set-top Boxes ("STB")

The set-top box ("STB") is a device for connecting a television to an external signal source, turning the signal into content which is subsequently displayed on the TV screen. Digital set-top boxes receive digital television broadcasts for TV sets that do not have a built in digital tuner. In the case of direct broadcast satellite systems, the set-top box is an integrated receiver/decoder (or IRD). For markets such as the USA, where analog broadcasting will cease in February 2009, audio quality is of immediate interest to set-top box manufacturers, who need to ensure that their audio signals will be of comparable quality to the video output.

Blu-ray Discs

Blu-ray Disc (also termed "Blu-ray" or "BD") is an optical disc storage medium. The key uses for Blu-ray are high-definition video and data storage. The name Blu-ray was derived from the blue-colored laser (actually, violet-colored) which is used to read from and write to this disc format. Due to the beam's much shorter wavelength (405 nanometers) than the beam used to encode standard DVDs (at 650 nm), Blu-ray Discs can store substantially more data. A standard, two-layer Blu-ray disc can store up to 50 gigabytes of data, which is almost six times more than a two-layer DVD, and over ten times that of a single-layer DVD.
In a significant announcement in February 2008, the battle between Toshiba's HD-DVD format and the Sony's Blu-ray Disc format was decided when Toshiba declared that it would no longer maintain its HD-DVD player and

	Current Home Audio	Next Generation Home Audio
Number of channels per stream	5.1 channels	7.1 channels
Number of simultaneous streams	1 to 2	2 to 3
Audio Codecs	AC-3, MLP, DTS, HE-AAC, etc.	Dolby Digital Plus, TrueHD, DTS-HD, lossless codecs Transcoding also required
Bit Rates	Up to 640Kbps	Up to 24Mbps Transcoding also required for backward compatability
Post processing	Up/down sampling, equalizer, spatial effects	Room correction, SRS WOW HD, Dolby Pro Logic II / IIx, Virtual Speaker, THX...
Data Precision	16-bit or 24-bit precision sufficient	32-bit data precision required for some HD Audio standards

Evolution of Home Audio - Increased Challenges

recorder business. This set Blu-ray as the leading HD recording medium for multimedia. There are now around 1,000 movies available on Blu-ray Discs in various languages, which is set to increase significantly, following the end of the format war between HD-DVD and the Blu-ray groups.

- Mandatory Audio Codecs for Blu-ray

  Specifications for the Blu-ray format define two sets of codecs that can be implemented in Blu-ray players. The first set of codecs is obligatory and must be used as the primary audio soundtrack source for Blu-ray discs. The codecs are:

  › **DTS** – a multi-channel, digital surround sound format used for commercial/ theatrical as well as consumer applications such as video games.

  › **Dolby Digital**, or **AC-3** – a codec that allows up to six discrete channels of audio, with a maximum coded bit rate of 640 kbit/s, although 35mm movie film use a fixed rate of 320 kbit/s and DVD-Video discs are limited to 448 kbit/s.

  › **Linear PCM** – an uncompressed audio format with up to 8 channels of audio at 48khz or 96khz sampling frequency and 16, 20 or 24 bits per sample. It has a maximum bitrate of 6.144 MB/s.

- Optional Audio Codecs for Blu-ray

  The optional audio codecs for Blu-ray include lossy and lossless codecs:

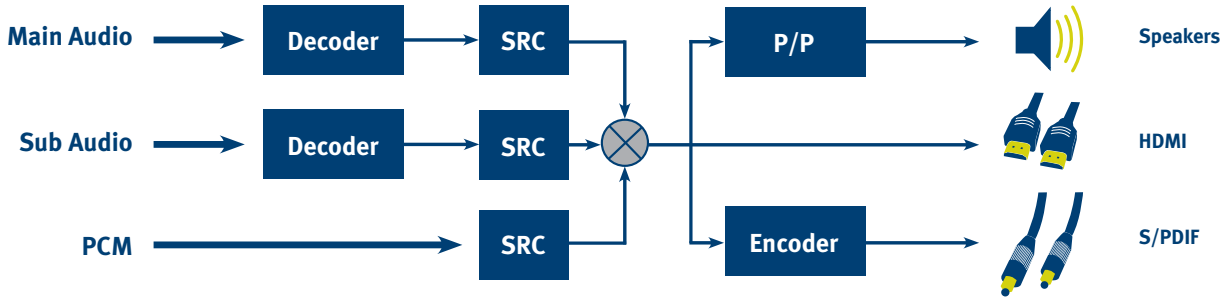
  › **Dolby Digital Plus** – an enhanced lossy codec based on AC-3, offering increased bitrates up to 6.144 Mbit/s and up to 7.1 audio channel support. It also provides improved coding techniques which reduce compression artifacts, and is backwards compatible with existing AC-3 hardware.

  › **DTS-HD High Resolution Audio** – a lossy codec which extends the original DTS format, delivering up to 7.1 channels of sound at 96 kHz and 24-bit depth resolution. DTS-HD High Resolution Audio offers a constant bit rate of up to 6.0 Mbit/s.

  The lossless codecs are:

  › **Dolby Digital TrueHD** – an HD multi-channel audio codec mainly for use in HD home entertainment equipment (such as Blu-ray Disc). The maximum encoded bitrate is 18 Mbit/s, which is the uncompressed rate. This already indicates the high data traffic requirement for HD audio.

  › **DTS-HD Master Audio** – an extension of the original DTS codec previously known as DTS++ or DTS-HD. It is a lossless Audio with variable data rates up to 24.5 Mbps, up to 7.1 discrete channels with a sampling frequency of up to 192kHz and 24 bits of signal resolution



- A Blu-ray HD-Audio Use-Case

  A computationally-intensive Blu-ray use case for HD Audio consists of main audio and sub audio streams and an effects stream. The main audio stream can incorporate DTS-HD Master Audio (see Blu-ray Discs section above) or Dolby TrueHD 7.1 channel, which is used for the disk playback. The sub audio stream can use DTS-HD Express or Dolby Digital Plus and is used for obtaining additional data such as director's commentary from the internet. The effects stream is a simple PCM audio stream used to add sound effects to on-screen menu selections.

  The encode stream can use DTS 5.1 Encoder or Dolby Digital 5.1 Encoder and the encoding is needed to transmit the data to a compatible Audio/Video receiver in a compressed format (e.g. via an S/PDIF cable). Post-processing functions could be required for the mixed signal, before it is sent to the speakers, in order to compensate for acoustically mismatched playback environments or various audio imperfections.

Design Challenges for HD Audio ICs

There are several factors to consider when designing ICs for HD Audio. The overriding nature of HD audio is the volume of data traffic, which increases dramatically when compared to conventional audio applications. Just for I/O, this traffic for certain codecs can reach 24.5Mbps for input and 96KHz x 8 x 24bit, giving 27.6Mbps, for output per second. This requires a new approach to IC design to ensure that these challenges are met, while maintaining audio quality.

Furthermore, the computational requirements of lossless audio codecs such as DTS-HD Master Audio or Dolby TrueHD at 192KHz sampling rates with 6 or 8 channels at high arithmetic precision are huge. Each of these codecs alone can easily consume the full MHz budget of a traditional DSP, if not surpass it.

Performance Requirements

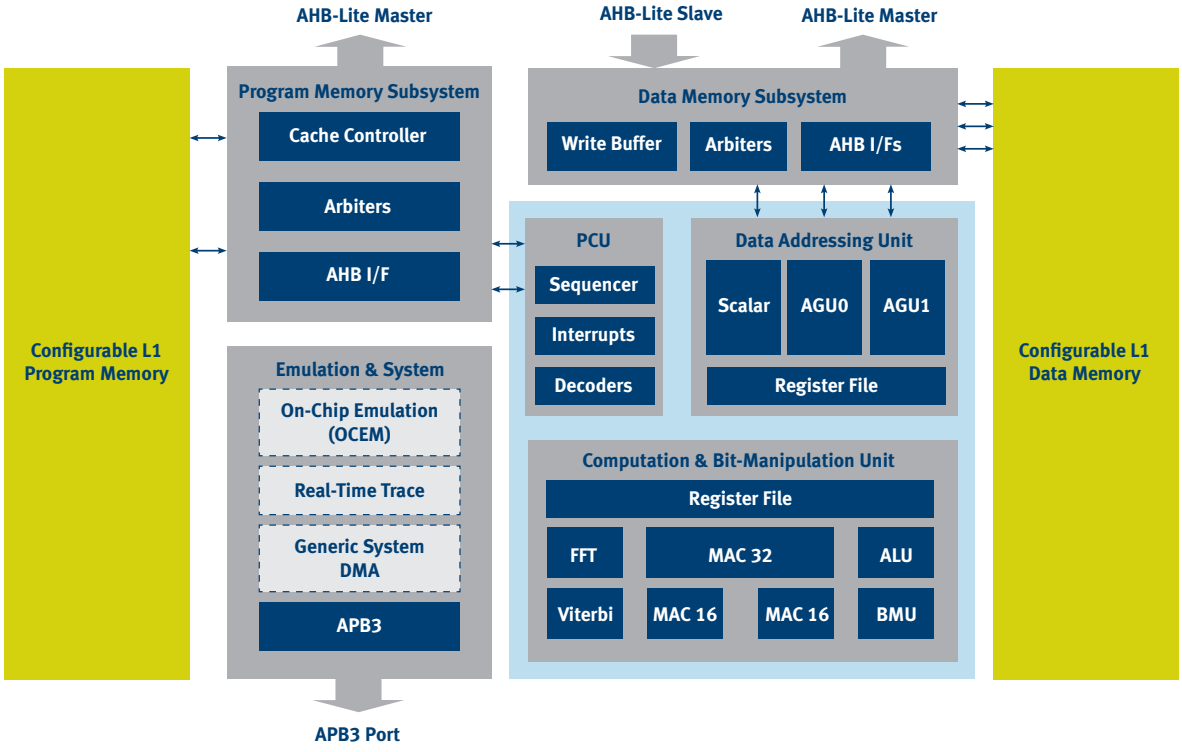
Data processing requirements for implementation of HD audio, such as for Blu-ray disc applications are very high, as we have described above. Data rates are so high that many existing single-core DSP solutions are not able to maintain high quality data processing and many industry solutions are tending towards dual-core approaches that can accommodate the processing overhead for combined video and audio.

In addition, there are many post-processing functions that are required on top of the mandatory and optional audio codecs that are implemented in the DSP solutions. These post-processing functions are the differentiating factors for many implementations. With many single-core DSPs becoming overloaded while processing the minimal HD audio codecs, there is very little horsepower left over, if any, for this almost mandatory post-processing.

Die Size/Power Consumption Considerations

Existing die sizes are also under tremendous strain as manufacturers and designers grapple with the challenges associated with crowding all of the required processing capabilities into ever smaller die size limitations. Moving up to multi-core solutions may provide the processing capabilities, but the trade-off in terms of die size, corresponding price increases and electrical power required to drive the subsystems can often be prohibitive. This is even more critical when addressing the extraordinary power and form factor constraints for HD devices such as portable gaming consoles.

Power consumption is an important factor even for non-mobile devices as it affects the heat dissipation of the device. Higher power consumption may require certain cooling requirements that may affect the overall design of the product.



CEVA-TeakLite-III Block Diagram

Memory Swaps for Task Switching

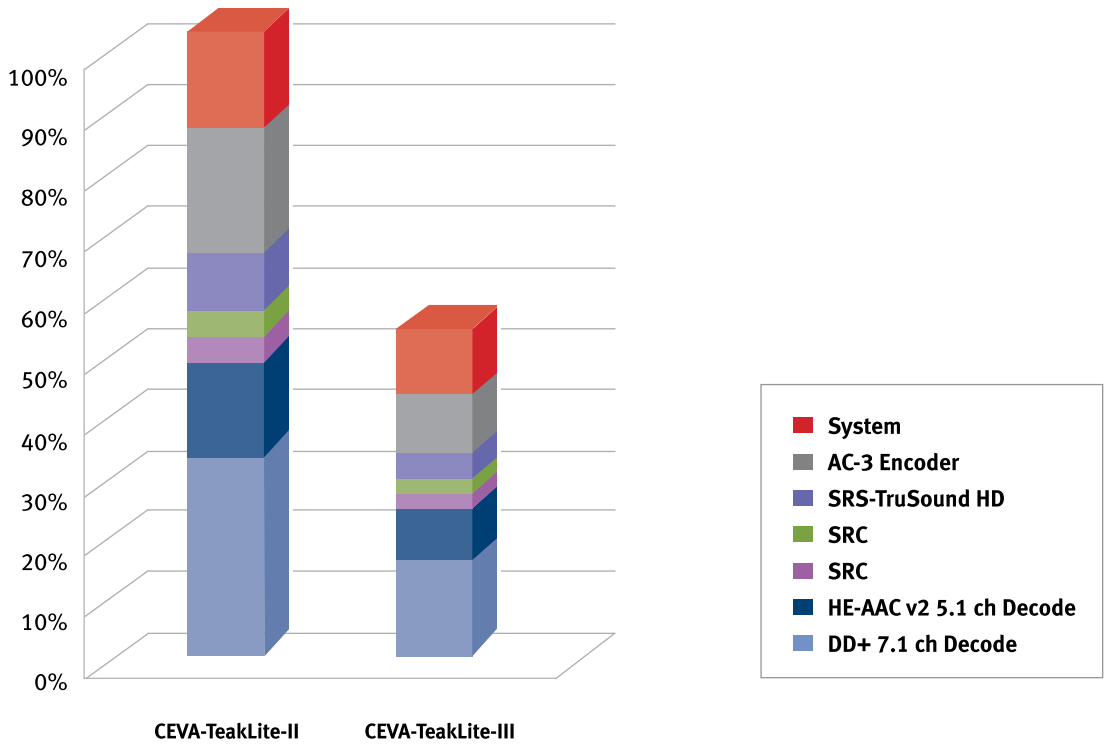
The amount of parallel tasks that need to be performed in HD audio systems require very frequent memory swaps. These swaps invariably lead to memory bandwidth becoming overloaded. This can rapidly degrade the sound quality as the system fails to cope with the increased bus traffic. Instruction sets are often written in 32-bit formats, which generate larger instructions and longer intervals between transactions. This further aggravates the problem of data overload, where 16-bit instruction sets may ease the load. On the data side, certain HD-Audio codecs require over 100KW of data RAM plus rather large tables which mandate memory swapping for efficient RAM memory utilization.

Slow External Memory Access

Many audio algorithms operating on DSPs traditionally access large buffers in a non-sequential fashion. Generally, these buffers are too large to reside in the on-chip memory of the processor, so they must be placed in external, slow memories such as DDR SDRAM. Furthermore, the non-sequential accesses can also present a challenge in maintaining high performance. The audio decoder often competes with the video decoder on the data bus throughput. Thus efficiency of memory accesses is very important.
This obstacle to consistent performance must be addressed in order to deliver a high quality audio experience.

Resolving the Challenges

Addressing the multiple issues dominating the HD audio DSP field, CEVA has developed CEVA-HD-Audio; a comprehensive, single-core DSP-based solution for tackling even the most demanding HD audio use cases.
CEVA-HD-Audio is based on the CEVA-TeakLite-III DSP core. The CEVA-TeakLite-III delivers native 32-bit processing and a dual Multiply-Accumulate (MAC) architecture, making the DSP ideal for deployment in HD audio applications requiring advanced audio standards.
In addition to its 32-bit processing power and dual-MAC architecture, CEVA-TeakLite-III features a well-balanced 10-stage pipeline which enables the core to reach operating speeds of more than 550 MHz in a 65nm process (worst-case conditions and process). Compared to CEVA-TeakLite, initial performance show it to be up to 4 times faster on basic operations and twice as efficient on most popular



audio codecs. CEVA-HD-Audio incorporates a native 32-bit SIMD DSP processor with a 32-bit register file, 64-bit data memory bandwidth, 32x32 bit multiplier and an automatic 32-bit saturation. The CEVA-TeakLite-III also has a dual 16x16 MAC with a comprehensive MAC instruction set for Speech/VoIP and comprehensive bit-manipulation capabilities, which are useful for stream processing.

In addition to its inherent 32-bit data processing functions with multiple precision points, the single cycle 32 bit MAC unit includes 72-bit MAC accumulation for lossless codecs and unique single-precision and double-precision FFT butterfly instructions, with a 2/4 cycle kernel.

The CEVA-TeakLite-III also incorporates CEVA-Quark™; a stand-alone comprehensive and embedded compact Instruction Set Architecture (ISA). This unique ISA is targeted at reducing die size and die cost, by utilizing only 16-bit instructions. This also reduces power consumption, having fewer memory accesses. CEVA-Quark ISA represents a complete set of instructions, including memory accesses, arithmetic and multiplication operations, logical, shift and bit manipulation instructions and control operations.

Application developers can also mix CEVA-Quark instructions with other, more advanced CEVA-TeakLite-III instructions, without a need to switch to different modes of operation. This combination of features offers a fourfold decrease in code size and almost nine-fold reduction in cycle count.

High Performance HD Audio from a Single Core

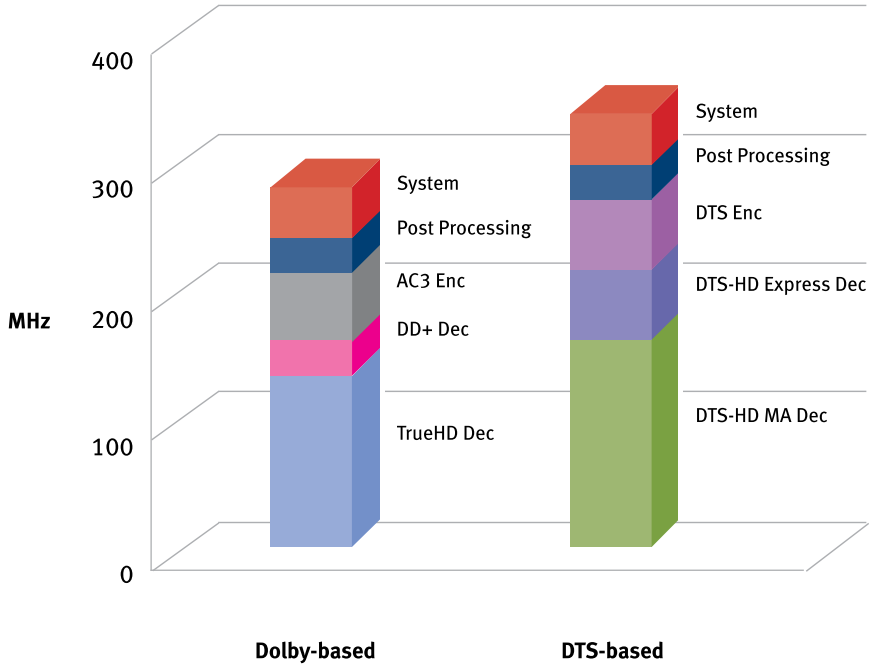
The processing efficiency described above means that CEVA-TeakLite-III can comfortably provide complete HD audio support using a single DSP core. Coupled with smaller memories, this has major implications in terms of smaller die size and higher performance than other competitive solutions in the marketplace. A single core implementation also translates into easier application development and integration, both from a hardware and software perspective.

CEVA is already working with a consumer IC supplier that has successfully integrated the most demanding audio use-case for Blu-ray discs using CEVA's single core solutions for HD audio.

Native Audio Processing

Incorporating the CEVA-TeakLite-III means that CEVA-HD-Audio offers 32-bit native audio processing, providing high precision for high performance. In addition, a 64-bit data memory bandwidth ensures the DSP can be constantly fed with data samples and coefficients for continuous processing.

The CEVA-HD-Audio solution also comes with a complete set of audio codecs that were implemented while taking these challenges into account. A generic DMA engine is used for the audio codecs algorithms design,



which has a positive impact on the performance of the audio algorithms and codec flow, as data transfers and algorithm execution are done in parallel. Furthermore, CEVA-HD-Audio includes a memory subsystem with instruction cache, tightly coupled memory for data and AHB/APB system interfaces – master and slave. These enable CEVA's licensees to meet the stringent requirements of sophisticated audio use cases, high latencies in external memory accesses and limited system speeds. They also ease integration into CPU-based SoCs and allow quick ramp-up of the complete audio system. For example, looking at the comparative diagram above, the left column shows the performance of CEVA-TeakLite-II with regards to the computational load for a standard HD audio use case. The right column shows the same load on CEVA-TeakLite-III (at the maximal achievable frequency for the same process, 90nm G). This allows the CEVA-TeakLite-III core to decode the toughest Blu-ray HD audio use case, with plenty of headroom for additional processing functionality. The above use case illustrates the dual advantage of the CEVA-TeakLite-III, offering a deep 10-stage pipeline which allows it to reach higher frequencies compared to older cores, as well as demonstrating architectural efficiency which allows it to accomplish more with each instruction.

Blu-ray DVD Audio Use Cases

CEVA-HD-Audio has been developed to handle the most demanding audio use cases. Currently, the Blu-ray DVD format provides the richest audio experience, but requires processing power to match.
In worst-case scenarios, CEVA-HD-Audio requires 253 MHz to support Dolby-based Blu-ray audio processing and just 304 MHz to support the most complex DTS-based Blu-ray audio processing, including system functions. With more than 550MHz available on a single-core implementation, this leaves ample room for additional processing, reduces power consumption and enables licensees to integrate CEVA solutions into their devices quickly, with more confidence in the quality of the audio output.

Software Development for HD Audio

CEVA-HD-Audio comes complete with a full software development tools kit. These allow customers quick and easy system development and integration.
The GUI-based development environment allows the programmer to comfortably follow the various processes, allowing greater efficiency within programming, compiling and debugging processes.

The software development tools include:

- Advanced user friendly IDE
- Optimizing C Compiler
- Assembler, linker & utilities
- Advanced GUI debugger
  - › Scripting support (CLI/TCL)
  - › Multi core Support
  - › Interface to Verilog simulators (DBGVerifier)
  - › Built in extendible simulator
  - › Emulator I/F (PP/USB/JTAG)
  - › MATLAB connection
- Application Profiler
  - › Performance measurement
- Mature and long-time field proven tools are available for PC/Windows, UNIX/Solaris and Linux operating systems

Development hardware boards include:

- Support for audio-in, audio-out, SD/MMC card
- Easy integration with ARM development board

Other SDK components include:

- Generic DMA description
- System software drivers – Generic DMA
- RTOS for easy software integration into complete application

› Industry-renowned Heritage

The CEVA-TeakLite family of DSP cores – CEVA-TeakLite, CEVA-TeakLite-II and now CEVA-TeakLite-III – has shipped in over one billion devices during the last decade with many generations of improvements and refinements to extract maximum power and performance out of more efficient cores.

CEVA-TeakLite cores had their origins in addressing the earliest DSP applications for mobile audio and voice products, where power consumption, die size and overall efficiency are of extreme importance. The heritage and discipline in designing the CEVA-TeakLite-III has contributed to significantly lower power consumption, smaller die size and modest memory consumption.

CEVA is also experienced in providing highly optimized software library implementations often using short instruction sets, eventually enabling significantly lower overhead, lower power requirements and higher performance of CEVA DSP cores for a broad range of audio scenarios.

This is now becoming a significant factor, as we have described above, with the tremendous data processing requirements of HD audio applications.

Summary

HD audio is the most challenging audio compression scheme in terms of sheer processing requirements that the multimedia market has encountered to date. Solutions need to be robust enough to handle a broad range of audio codecs, coupled with many more audio channels and higher bit rates and sampling rates.

Complex use-cases, such as Blu-ray DVD, offer exciting possibilities in terms of audio user experience, but require tremendous processing power that usually cannot be delivered comfortably with single-core DSP solution. This has a significant impact on price.

CEVA-HD-Audio is a powerful, yet power-light single-core solution to the rapidly evolving world of HD audio, well suited to high-end home entertainment audio market. The CEVA-TeakLite-III DSP core, at the center of this HD audio solution, addresses all of the major challenges involved in providing reliable HD audio quality with a single-core implementation. With a heritage of one billion audio ICs shipped and a legacy of audio-focused development, CEVA has provided the market with one of the most high-performance, cost-efficient DSPs that is capable of delivering a high quality user experience for the HD audio era.

› www.ceva-dsp.com

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