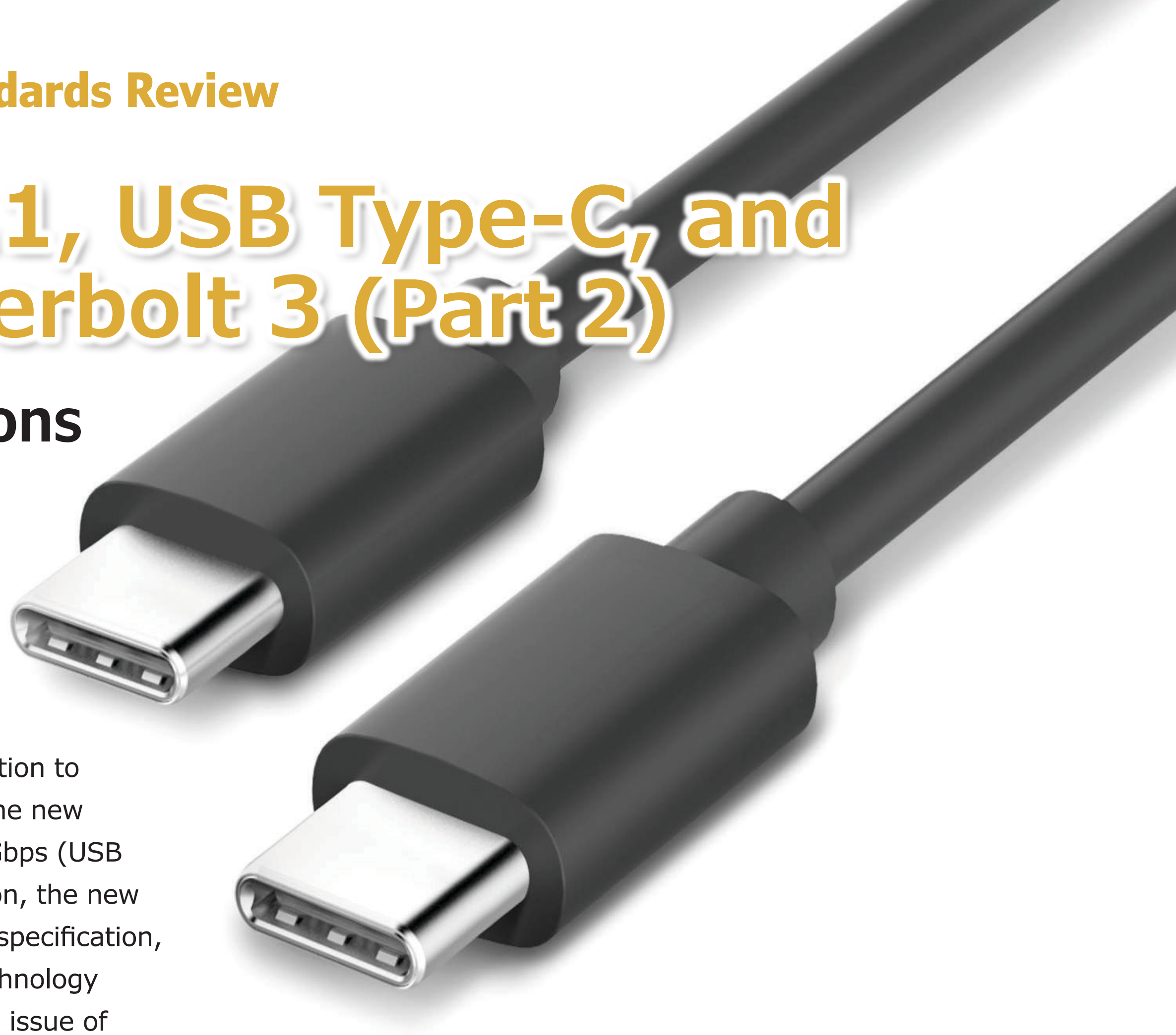
USB 3.1, USB Type-C, and Thunderbolt 3 (Part 2)

Implications on Audio



Following our introduction to the fundamentals of the new SuperSpeed USB 10 Gbps (USB 3.1 Gen 2) specification, the new USB Type-C interface specification, and Thunderbolt 3 technology in the December 2016 issue of *audioXpress*, we will now examine how these technologies have evolved and how they work together. We also look at the USB Audio Device Class 3.0 specification, which standardizes audio over USB Type-C.

By
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(Editor-in-Chief)

Due to the combination of the discussed specifications, and the fact that soon most computers (and all sorts of devices) will eventually combine USB-C ports—which in most cases will be Thunderbolt 3 ports, with some ports limited to USB 3.1 Gen2, mainly because of cost considerations or CPU limitations—this means the audio industry will have multiple options available to design new audio systems, all benefiting from simplified connectivity, extended bandwidth, and faster data rates.

Considering that Thunderbolt is basically a PCI Express slot (four lanes of PCI Express Gen 3) exposed on a physical connector—now a USB Type-C connector—this means that we will see an increase of audio peripherals in detriment to the typical PCIe internal cards. It also means that Thunderbolt 3 will be the ideal interface for professional audio applications. Thunderbolt 3 supports low-latency multi-track applications in high-resolution/high-sampling frequency, with the low track count production stabilizing on 24-bit/96 kHz, which is now the standard for low-channel count, consumer and high-end applications, enabling studios to work with 24-bit/192 kHz workflows without any worries.

For those who are not familiar with professional production standards, remember that even home studios have standardized on 24-bit/96 kHz production—with all the benefits for dynamic processing and track bouncing. Since that was the Firewire (1394) interface threshold, it is also now part of the Thunderbolt specification since version 1. And with consumer distribution evolving to higher resolution as well, the audio industry certainly needs to eliminate existing bottlenecks.

The same USB-C port will also enable support for all the audio-over-IP (AoIP) protocols that are currently emerging (e.g., Dante, Ravenna, Livewire, etc.), given that Thunderbolt 3 supports standard 10

Gigabit Ethernet. And of course, the same port will also support the legacy USB 2.0, USB 3.0 interfaces, and support existing applications.

Additional Information

Since we published the first part of this article (*audioXpress*, December 2016), we witnessed the expected revelation from Apple about its latest generation MacBook Pro laptops. While we are still waiting for the workstation class Mac Pro and iMac updates (and eventually the Mac Mini as well), we now know that Apple is moving forward with Thunderbolt 3.

Its new 13” and 15” MacBook Pro benefit immensely from the technology, with the only limitation being the availability of Intel processors, which still do not provide the required number of PCIe lanes. That will change in 2017, with the general availability of new Intel processors expected to power new iMacs and Mac Pros and certainly first-generation Thunderbolt 3-oriented PCs.

The new Thunderbolt 3 machines enable transferring data at speeds of up to 40 Gbps, which is two times faster than Thunderbolt 2, four times faster than standard USB 3.1 Gen2 ports (current standard), and eight times faster than the original USB 3 standard—which amazingly we still see being announced for machines to be released in 2017.

Also important to remember that apart from the graphics capabilities to support multiple displays (e.g., DisplayPort, HDMI, etc.) and extended resolutions (4K/5K), external Thunderbolt 3 SSD drives allow for extreme throughput. It is already better than internal SATA drives and it will keep improving.

An example, the new LaCie Bolt3 external drive (2× M.2 PCIe SSDs) uses Dual Thunderbolt 3 to achieve 2,800 MB/second read and 2,200 MB/second write speeds while the latest generation SSD SATA 3 drives (6 Gbps) are able to achieve 550 MB/second read and 520 MB/second write speeds.

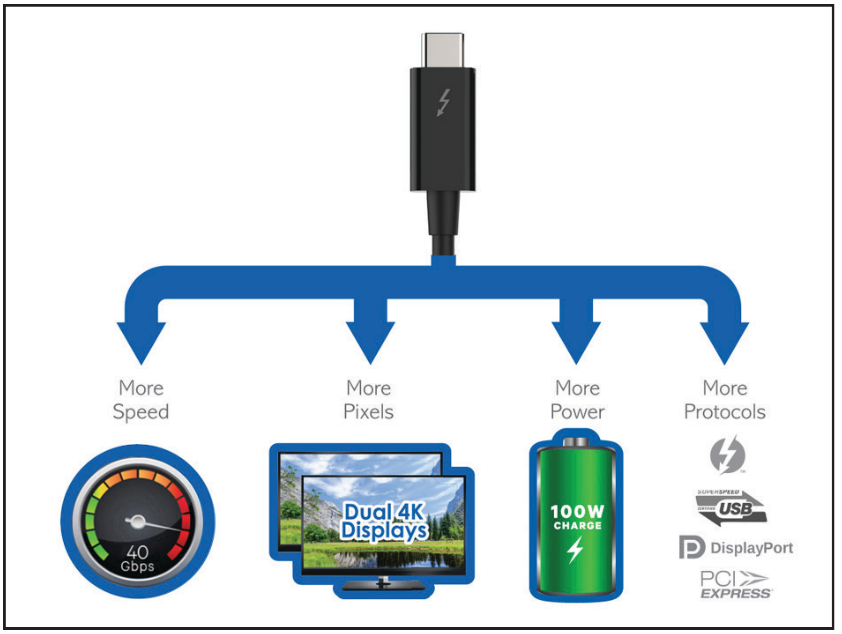
For those who don’t yet understand how the new USB Type-C connectors work, the idea is not to “limit” the user on the type of the devices to which they can connect or force people to use “dongles” as is the distorted perception generated following Apple’s announcement.

A single Thunderbolt 3 port enables users to daisy-chain up to six Thunderbolt devices through a single port without needing a hub or a switch. The new MacBook Pro provides four ports! And for those legacy devices we still need to connect, (e.g., existing Firewire external drives, audio interfaces, and memory card readers), there are already Thunderbolt 3 docks that will provide all those options, including S/PDIF digital audio. Gradually, all users will stop carrying converters and dongles as the industry transitions to the “universal” USB Type-C connector, which was planned by the industry in general and not just an Apple decision! Of course, it will be complicated at first and some dongles will remain for more time than others (e.g., the Ethernet RJ45 to USB-C converters).

Now that this has been clarified, let’s look at how USB has improved and how we can benefit from the updates, be that over USB 3.1 Gen2 or Thunderbolt 3 ports.

Putting the Puzzle Together

For this article, we have researched many



Thunderbolt 3 carries the latest generation USB SuperSpeed 10 Gbps but offers significant advantages.

Apple recently revealed its new MacBook Pro 2016 models and, as expected, adopted Thunderbolt 3, providing two or four ports.

Windows PCs will also support USB-C and Thunderbolt 3 and that will be essential to support external graphics accelerators, 4K displays, and the latest generation fast storage.

different sources and, in general, we found Intel and Apple to be the main organizations truly committed to advancing the technology and actively promoting it. In fact, we've learned that Apple was the main force behind these advancements and the company that assigned the largest number of engineers to the consortium workgroups and to work on the specifications. After all, Apple had already greatly contributed to the Thunderbolt specification, which had remained largely an inside effort from Intel.

The technology was introduced as Light Peak at the 2009 Intel Developer Forum (IDF) and it was originally an optical interface with the potential to provide 10 Gb/s minimum speeds over optical cables. In 2010, Intel, working with "other industry partners," switched the development to electrical connections in order to supply power to connected devices and also because of cost considerations of optical cables and adapters. When the technology was introduced in 2011, Light Peak was renamed Thunderbolt and Apple brought the first MacBook Pro computers to market using a Mini DisplayPort connector, allowing multiplexing data onto a single Thunderbolt cable and to daisy-chain up to six devices, including displays.

In 2013, Intel updated the spec to Thunderbolt 2, enabling channel aggregation of the two previously separate 10 Gb/s channels and combining it into a single 20 Gb/s channel. This would also allow the support for 4K video and connecting 4K displays with support for DisplayPort 1.2. Again, Apple was the first company to immediately bring products to market with Thunderbolt 2, removing existing separate Ethernet and FireWire interfaces from its machines. Other than a dedicated power connector, the only other remaining interfaces on Mac computers were USB and HDMI.

And the cooperation between Intel and Apple continued. While Apple internally developed its own Lightning interface for mobile devices, replacing its own iPod 30-pin connector (which carried both USB and FireWire, together with audio, video and controls), it was clear that an effort was being made to also reach a convergence with the USB Implementers Forum (USB-IF) and eventually allow for some form of USB compatibility with Thunderbolt.

Unfortunately, getting any information from Apple directly regarding its participation in the process proved impossible and we had to resort to the few facts from published sources and the previously mentioned technology consortia such as Mobile High-Definition Link (MHL) and High-Definition Multimedia Interface (HDMI).

We also approached several silicon companies as well as manufacturers that were actively trying to stay ahead of the curve by closely monitoring the latest specifications, engaging with the consortiums and standard bodies and experimenting with early implementations.

I think it is still important to share our conversation at CES 2016 with USB-IF executives, Brad Saunders (Architect Strategist at Intel Corporation and USB-IF chairman) and Rahman Ismail (USB-IF CTO) also from Intel, leading the audio aspects of the USB Device Working Group

The new LaCie Bolt3 external drive (2× M.2 PCIe SSDs) uses dual Thunderbolt 3 to achieve 2,800 MB/second read and 2,200 MB/second write speeds.

While the market fully transitions to USB Type-C, we will depend upon adapters to provide connectivity with legacy equipment. Things such as USB 2.0 to USB-C, AV adapters to HDMI and DisplayPort, and even Lightning to USB-C for Apple's own iOS devices.

and the USB Compliance Committee. As it was publicly stated at CES 2016, the entire focus for the introduction of the USB Type-C connector resulted from pressures from the mobile industry. Apple generously contributed to the USB-IF efforts, while simultaneously pursuing the evolution of Thunderbolt to converge with USB.

Apple's efforts resulted in the new Thunderbolt 3 specification and adopting the USB Type-C connector. For the mobile industry, this would mean one single universal connector for charging, synchronization, connecting external displays and peripherals and for audio, replacing the 3.5 mm analog jack.

As Brad Saunders explained to *audioXpress*, the USB-IF actively engaged with all companies working on the USB Type-C spec team, from Apple, Google, Microsoft, Qualcomm, and others, and looked at all solutions to improve the specification for audio—making it possible to replace the venerable analog connector, which lead to the recently published USB Audio Device Class 3.0.

The following is an excerpt from our interview with Brad Saunders and Rahman Ismall:

audioXpress: Intel unveiled Thunderbolt 3, introducing support for USB devices and replacing the original mini-DisplayPort connector for the USB Type-C connector. How coordinated are the USB-IF workgroups with the Thunderbolt initiatives promoted by Intel and Apple?

Brad Saunders: There are connections at different levels. Obviously Thunderbolt 3 is based on using this connector (Type-C). Intel internally designed Thunderbolt 3 to run over this cable and they do it as a legitimate alternate mode. Intel to Intel or Dell to Dell as we have an example here on demonstration. So, clearly that's been done. Intel has a lot of experience at running at 10 and 20 Gbps in Thunderbolt and USB has now moved into the 10 Gbps space.

Some of the engineers who worked on USB 3.1 and USB Type-C are people that we've got from the Thunderbolt team. So, we've gained from their experience, and one of our favorite engineers happens to be a Thunderbolt person—Christine Krause—and we love what she's done for us, she's brought tremendous experience in this space. There's a lot of technology sharing going on, obviously at a level were IP is freely able to be passed, because Intel contributes the IP.

But from a planning or business perspective, they're completely independent. Thunderbolt is an Intel product and USB-C is an open-standard ecosystem.

audioXpress: So, what are the implications for USB audio?

Saunders: Well, Thunderbolt 3 carries USB.

audioXpress: So, whatever the USB-IF does on the USB side…?

Saunders: They get. Yes. If they carry USB, yes.

During CES 2016, audioXpress interviewed USB-IF executive Brad Saunders, who is the Architect Strategist at Intel Corp. and USB-IF chairman.

audioXpress: Thunderbolt has a lot of momentum on the pro audio, video post-production and broadcast industry. The gaming industry is also pushing Thunderbolt 3 to support external graphics systems, which makes sense. The consumer audio industry will not move to Thunderbolt unless they have a clear advantage, and it seems USB offers more than enough... But eventually, since they now share the same connector, people will connect one type of equipment to the other. Is there a transparency on carrying USB over Thunderbolt for audio applications?

Rahman Ismail: Yes. Thunderbolt will always carry USB now. Every solution has to be implemented so that they carry USB and so on. They can use it.

Saunders: It really depends on what's connected at the far-end. If the thing connected at the far-end is USB, and Thunderbolt is used just as an intermediate transport, you are good, because the USB functionality is carried out to the end-point, and Thunderbolt is effectively transparent.

We also interviewed Rahman Ismail (CTO) also from Intel, and currently leading the audio aspects of the USB Device Working Group.

Now, if the end-product that's connected is some sort of Thunderbolt native or PCI native then they benefit from everything that PCI does, like precision time management and mechanisms for doing that kind of stamping, which by the way are basic mechanisms at the software level, and they

USB audio will be carried over Thunderbolt 3 cables in a fully transparent way. The only difference...we will be able to use longer cables with Thunderbolt 3.

are based on a IEEE time management scheme that everybody has built-on. But you will benefit from this, even if using a Thunderbolt environment.

USB Audio Device Class 3.0 Specification for Digital Audio Applications

Now that we've explored the origins of USB 3.1 Gen2, USB Type-C, and Thunderbolt 3, it's important to examine the USB Audio Device Class 3.0 specification, announced in September 2016 and finally shine some light over how this all should work for audio.

The USB-IF, the support organization for the advancement and adoption of USB technology, completed and published the USB Audio Device Class (ADC) 3.0 specification. The specification establishes USB Audio over USB Type-C as the primary solution for all digital audio applications, including headsets, mobile devices, docking stations, gaming setups, and virtual reality (VR) solutions. The updated ADC 3.0 specification is defined by a set of four separate documents.

The first document defines in detail all the Terminal Types that are supported. The second document describes and defines all the Audio Data Formats that are supported. The third document provides the definitions for Basic Audio Functions that create a higher level of interoperability among Hosts and Audio Devices. The fourth document is the most extensive, with 152 pages, and is the ADC 3.0 specification itself, describing the minimum capabilities and characteristics of an USB audio device and providing recommendations for optional features. The specification provides a complete description of the devices or functions used to manipulate audio, voice, and sound-related functionality, including both audio data (analog and digital) and the functionality that is used to directly control the audio environment, such as Volume and Tone Control.

As detailed in the specification introduction, USB has become a ubiquitous connector on modern PCs and is well-understood by most consumers today, being used for audio transport from low-fidelity voice connections to high-quality multi-channel audio streams. But many applications that currently depend upon USB audio features were far from ideally implemented. As Saunders stated in our interview, "the latest and greatest version of USB audio is a 10-year-old definition! And the major OS in the world doesn't even support that one!"

So, to improve the situation, the USB-IF examined all areas that could be updated and improved without compromising interoperability. As it states, "In principle, a versatile bus specification like the USB provides many ways to propagate and/or control digital audio. For the industry, however, it is very important that audio transport mechanisms be well defined and standardized on the USB. Only in this way can interoperability be guaranteed among the many possible audio devices." "Standardized audio transport mechanisms also help to keep software drivers as generic as possible."

The new Audio Device Class 3.0 specification tries to satisfy those requirements and the USB-IF recommends that all device classes that address audio in some way refer to the latest documents for their audio interface specification.

Areas considered vital in the audio update include synchronization of the data streams, since "the

A Sampling of the Many Silicon Manufacturers and Development Platforms Consulted for This Article

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Lattice Semiconductor | www.latticesemi.com
Microchip | www.microchip.com
NXP | www.nxp.com
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Qualtek Electronics | www.qualtekusa.com
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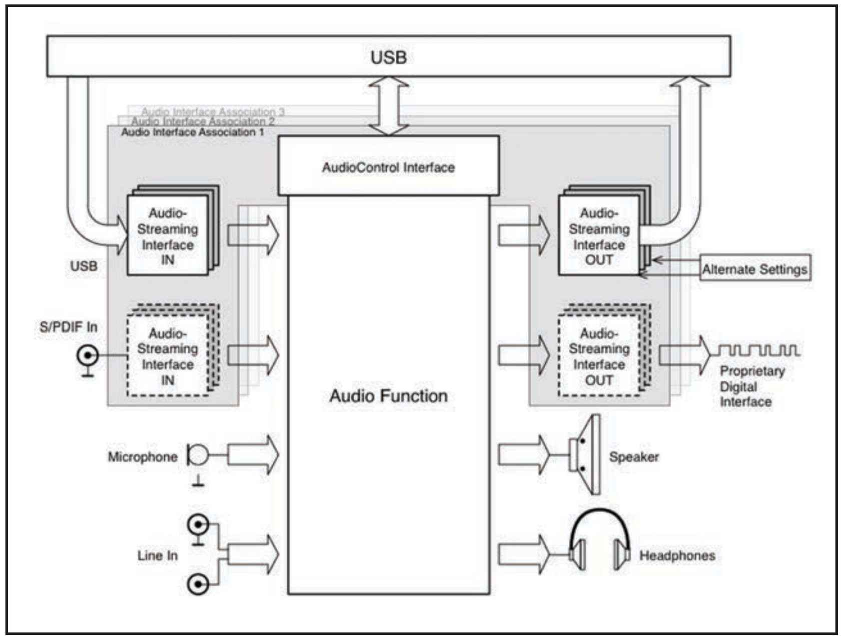
STMicroelectronics | www.st.com
StreamUnlimited | streamunlimited.com
Synopsys | www.synopsys.com/home.aspx
Texas Instruments | www.ti.com
XMOX | www.xmos.com

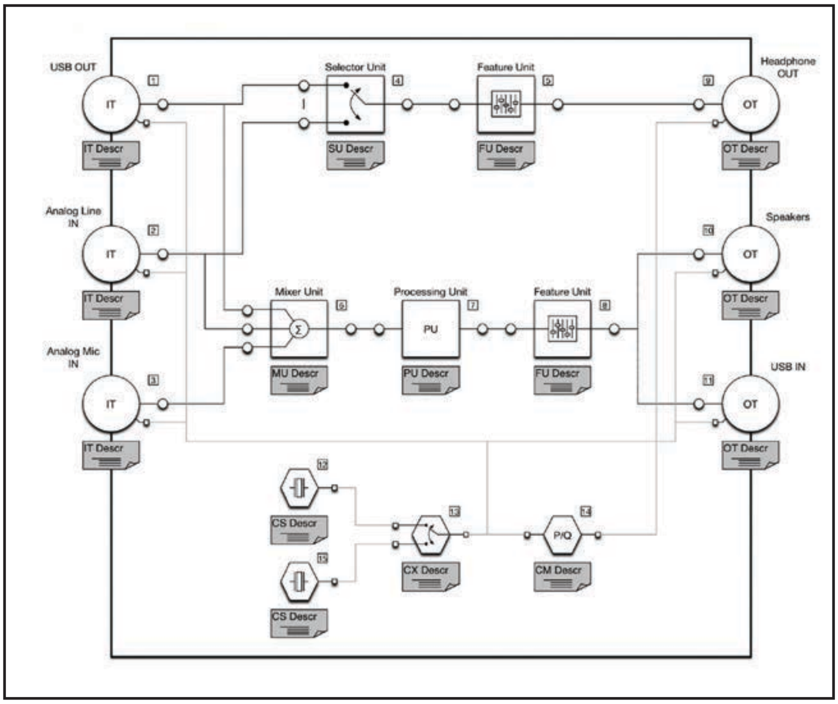
smallest artifacts are easily detected by the human ear." Therefore, a robust synchronization scheme on isochronous transfers has been developed and incorporated in the USB Specification and the USB 3.1 Specification. The Audio Device Class definition adheres to these synchronization schemes to transport audio data reliably over the bus.

The new specification also contains all necessary information for a designer to build a USB-compliant device that incorporates audio functionalities. It specifies the standard and class-specific descriptors that should be present in each USB Audio Function. It further explains the use of class-specific requests that allow for full Audio Function control, and a number of predefined data formats are listed and fully documented. Each format defines a standard way of transporting audio over the USB, and provisions have been made so that vendor-specific audio formats and compression schemes can be handled as well.

In the document, the USB-IF also states that, "many of the changes introduced in this version of the USB Specification for Audio Devices are inspired by the desire to use USB Audio in modern portable



Inside the Audio Function. The figure describes a hypothetical USB ADC 3.0 Audio Function that incorporates 15 Entities: three Input Terminals, five Units, three Output Terminals, two Clock Sources, a Clock Selector, and one Clock Multiplier. Each Entity has its unique ID (from 1 to 15) and a descriptor that fully describes the functionality of the Entity and also how that particular Entity is connected into the overall topology of the Audio Function.



USB ADC 3.0 Audio Function global view and its associated interfaces. All functionality pertaining to controlling parameters that directly influence audio perception (like volume) are located inside the central rectangle and are exclusively controlled through the AudioControl interface. Streaming aspects of the communication to or from the Audio Function are handled through separate AudioStreaming interfaces, as necessary.

devices." The specification pays special attention to how to make the Audio Device Class more power-friendly by providing new tools to selectively enable and disable parts of the Audio Function and also by supporting burst mode data transfers for longer sleep times in between data transfers.

In addition, the specification supports new codec types and data formats for consumer audio applications, provides numerous clarifications of the original specification and extensions to support various changes in the core specification.

In the provided reference list of "Key Differences Between ADC V2.0 and V3.0," the things that have been removed were mostly because they were either obsolete or no longer used. That's the case with the copy protection (S/PDIF-style) function, which was removed as well as some specific descriptors and some Type II and Extended Type II Audio Data Formats—in particular the formats that do not preserve the notion of physical channels during the transmission (typically, all non-PCM encoded audio data streams). And new Type III and IV formats were introduced—essentially new surround formats of the MPEG-4 AAC family, support for 3D audio and Ambisonic formats, and new compressed formats. In case you are wondering, the Direct-Stream Digital (DSD) format is included in the Type I list of supported data formats. Adding new Audio Data Formats to the specification is also possible by proposing it to the Audio Device Class Working Group.

One of the key aspects of the new specification has to do with synchronization parameters and specifically inter channel synchronization to respect phase differences that are applied to the different physical audio channels used to reproduce the audio source. The documents state that when dealing with audio, and 3-D audio in particular, "it is imperative that USB Audio Functions respect the phase relationship among all related audio channels. However, the responsibility for maintaining the phase relation is shared among the USB host software, hardware, and all of the audio peripheral devices or functions."

Another very important new consideration has to do with bus power. The ADC 3.0 specification now defines that a bus-powered Device that contains an Audio Function shall support the Link Power Management LPM/L1 power state. This was introduced with the USB 3.0 specification and defines a fast host transition from an enabled sleep state, allowing considerable power savings. The Power Domain allows a host to selectively reduce power consumption when parts of the Basic Audio Function are currently not being used.

There are also many new function units and descriptors detailed in the specification. To overcome the limitations of the standard Get Descriptor request (limited to maximum 256 bytes long), the new specification provides a class-specific method to retrieve larger descriptors from Audio Functions. Also, since High Capability descriptors have the ability to report changes dynamically, they can be used whenever there is a need for the descriptor to indicate that some of its values have changed (even when its length is less than 256 bytes).

It is also important to note that all MIDI-related information is now grouped in a separate document—Universal Serial Bus Device Class Definition for MIDI Devices that is considered part of the specification.

Audio Functions

Essential to the understanding of the new ADC 3.0 specification are a few concepts such as Audio Functions. To be able to manipulate the physical properties of an Audio Function, its functionality is divided into addressable Entities. Two types of such generic Entities are identified and are called Units and Terminals. In addition, a special type of Entity is defined. These Entities are called Clock Entities and they are used to describe and manipulate the clock signals inside the Audio Function.

Units provide the basic building blocks to fully describe most Audio Functions. Audio Functions are built by connecting together several of these Units. Every Unit in the Audio Function is fully described by its associated Unit descriptor (UD). Likewise, there is a Terminal descriptor (TD) for every Terminal in the Audio Function. In addition, these descriptors provide all necessary information about the topology of the Audio Function. They fully describe how Terminals and Units are interconnected.

Listed types of standard Units and Terminals that are considered adequate to represent most Audio Functions include:

- Input Terminal (IT)
- Output Terminal (OT)
- Mixer Unit (MU)
- Selector Unit (SU)
- Feature Unit (FU)
- Sampling Rate Converter Unit (RU)
- Effect Unit (EU)
- Processing Unit (PU)
- Extension Unit (XU)

Besides Units and Terminals, the concept of a Clock Entity is introduced. Three types of Clock Entities are defined by this specification:

- Clock Source (CS)
- Clock Selector (CX)
- Clock Multiplier (CM)

A Clock Source provides a certain sampling clock frequency to all or part of the Audio Function. A Clock Source can represent an internal sampling frequency generator, but it can also represent an external sampling clock signal input to the Audio Function.

By using a combination of Clock Source, Clock Selector, and Clock Multiplier Entities, the most complex clock systems can be represented and exposed to Host software.

The ensemble of Unit descriptors, Terminal descriptors, and Clock Entity descriptors provide a full description of the Audio Function to the Host. This information is typically retrieved from the device at enumeration time. By parsing the descriptors, a generic audio driver should be able to fully control the Audio Function, except for the functionality represented by Extension Units. Those require vendor-specific extensions to the audio class driver.

For the USB specification, an Audio Function is completely defined by its interfaces and an Audio Function has one or more Audio Interface Associations (AIA)—the part that provides access to it at different compliance levels. Only one AIA can be active at one time and each AIA can only have one AudioControl interface and can have zero or more AudioStreaming interfaces.

The specification describes Function Categories for a Desktop Speaker and Home Theater systems, Microphone, Headset, Telephone, Converter, Voice/Sound recorder, IO Box,

The new Audio Device Class 3.0 specification was designed to make audio functionalities as simple as analog connections on any device, and make the entire system more power-friendly.

Musical Instrument, Pro-Audio devices (e.g. editing equipment, multi-track recording equipment, etc.), Audio/Video systems, Control Panel (e.g., a mixer panel), and Other (any device whose primary purpose is sufficiently different from the above descriptions).

Basic Audio Device Definition (BADD)

One of the most important aspects in the new ADC 3.0 specification is the mandated support for BADD (Basic Audio Device Definition, providing only supports for 48 kHz at 16 bits and 24 bits sample sizes) on each ADC 3.0 compliant device.

The purpose of the new BADD definition was to create a higher level of interoperability among Hosts and Audio Devices, by establishing a set of essential audio features and allowing the simplification of Host USB drivers. Also, this is what ensures some degree of backward compatibility with any of the previous versions of the same specification (ADC 1.0 or ADC 2.0.) and simplifies discovery and management of the different BADD profiles.

As stated in the specification documents, "The purpose of this specification is to create a higher level of interoperability among Hosts and Audio Devices. By establishing a set of essential audio features, users can expect a consistent experience, Device manufacturers have a solid template to follow, and Host drivers may be simplified."

The Basic Audio Device Definition (BADD) exists as a separate document and defines a subset of functionality commonly found in headphones, microphones, and headsets using the features and tools provided by the ADC but it removes all of the optionality allowed by the previous specifications and prescribes rigorously how certain features shall be implemented.

Conclusion

The USB Audio Device Class 3.0 specification makes it easier to support digital audio over USB, adds capabilities to reduce power consumption, and adds support for new features. It defines minimum interoperability requirements across analog and digital solutions to minimize user confusion when not all hosts or devices support audio consistently.

And with this new ADC 3.0 specification, device manufacturers will finally be able to eliminate the need for multiple ports and efficiently deliver data, power and video over a single connector with USB Type-C and USB Power Delivery.

"USB is the simplest and most pervasive connector available today, making USB Type-C the logical choice for the future of digital audio. We encourage companies interested in adopting USB specifications to take advantage of USB-IF resources to reduce time-to-market and deliver reliable USB products," stated Jeff Ravencraft, USB-IF President and COO, when the ADC 3.0 specification was published.

It is important to remember the new USB ADC 3.0 specification supports both analog and digital audio over USB-C cables and it is not so difficult to implement. So, please stop the alleged "analog jack conspiracy plot" debate.

As Saunders also told us "You can do a lot of cool stuff with USB audio...and it works as simple as an audio jack!"

Resources

M. Christiansen, "Implementing USB Type-C in High-Speed USB Products" Application Note: USB IP, Synopsys, www.synopsys.com/Company/Publications/DWTB/Pages/dwtb-usb-type-c-2015q3.aspx.

———, "Converting Existing USB Designs to Support USB Type-C Connections Application Note: USB 2.0 PHY and Type-C connectors (available through Solvnet), www.synopsys.com/Company/Publications/DWTB/Pages/dwtb-convert-usb-designtype-c-2015q1.aspx.

S. Haskell, T. Nguyen, and A. Salazar, "Challenges of USB 3.1 IP Certification" www.synopsys.com/Company/Publications/DWTB/Pages/dwtb-challenges-usb-certification-2016q2.aspx#sthash.BUv8spMJ.dpuf.

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Mobile High-Definition Link (MHL) | www.mhltech.org

Sonnet Technologies | www.sonnettech.com

Thunderbolt Technology Community | thunderbolttechnology.net

USB Implementers Forum (USB-IF) | www.usb.org.

"Universal Serial Bus Device Class Definition For Audio Devices Release 3.0," USB Implementers Forum Inc., September 2016, www.usb.org