Technology Brief
Interconnect Technology

Thunderbolt™ Technology

The Fastest Connection to your PC[1]

Thunderbolt™ technology is a transformational high-speed, dual protocol I/O that provides unmatched performance over current I/O technologies with 10Gbps bi-directional transfer speeds. It provides flexibility and simplicity by supporting both data (PCIe) and video (DisplayPort) on a single cable connection that can daisy-chain up to six devices. Thunderbolt technology enables flexible and innovative system designs and is ideal for thin profile systems and devices such as Ultrabooks™.

Key Thunderbolt Technology Benefits

Thunderbolt technology dramatically increases the data transfer rate enabling faster backup, editing and file sharing, significantly reducing the time to complete key tasks.

Thunderbolt technology was specifically designed with inherently low latency and highly accurate time synchronization capabilities. These features enable extremely accurate audio and video creation, playback and editing that no other standard interconnect technology can match.

Figure 1. Thunderbolt™ cables expand a thin and light laptop to a high-resolution display and high-performance storage in a simple daisy chain.

Key Features

- 10Gbps bi-directional, dual channel data transfer
- Data & Video on single cable with Dual-protocol (PCI Express and DisplayPort)
- Daisy chain up to six devices
- Compatible with existing DisplayPort devices
- Low latency with highly accurate time synchronization
- Uses native PCIe and DisplayPort protocol software drivers
- Power over cable for bus-powered devices (electrical cables only)

Some users need workstation performance but demand an Ultrabook form factor. With Thunderbolt technology it is now possible to enable the thinnest and lightest laptops connected over a single cable to high performance storage, external media drives, multiple HD displays, HD media and editing systems as well as legacy I/O hubs and devices. Giving users the ability to have thin and light ultrabook systems but also the power, capability and expandability of a traditional workstation.

Rethinking I/O

As every generation of information technology progresses, I/O technologies evolve to provide higher bandwidth for getting data into and out of computers. At its simplest, two discrete types of I/O have resulted – display (with formatted video and audio components), and data. Traditional approaches to this evolution have been to make an existing technology faster. Thunderbolt technology combines the next step in higher performance with the innovation of mapping two of the most fundamental I/O protocols at the heart of computing (PCI Express and DisplayPort), onto a single highly efficient meta-protocol, transmitting them over a single cable, and managing the traffic routing (supporting daisy chaining and hot-plugging devices) with intelligent hardware controllers. The choice of PCI Express was clear, providing for off-the-shelf controller use to attach to nearly any technology imaginable, and the choice of DisplayPort was equally clear for meeting the needs of the PC industry with capabilities like support for multiple HD displays, and support for up to 8 channels of high-definition audio.

Protocol Architecture

Thunderbolt technology is based on a switched fabric architecture with full-duplex links. Unlike bus-based I/O architectures, each Thunderbolt port on a computer is capable of providing the full bandwidth of the link in both directions with no sharing of band- width between ports or between upstream and downstream directions. The Thunderbolt protocol architecture can be abstracted into four layers as shown in Figure 2.

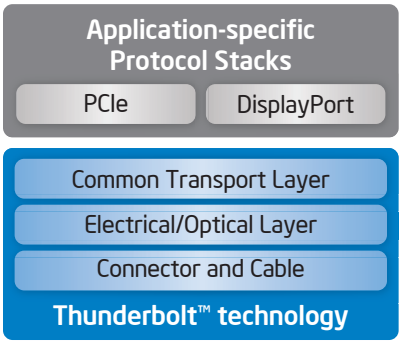

Figure 2. Thunderbolt™ Technology Architecture.

A Thunderbolt connector is capable of providing two full-duplex channels. Each channel provides bi-directional 10Gbps of band-width, as shown in Figure A. A The Thunderbolt connector is extremely small, making it ideal for Ultrabooks, plus it is enables connection to Thunderbolt products or to DisplayPort devices. Compatibility to DisplayPort devices is provided by an interoperability mode between host devices and DisplayPort products; if a DisplayPort device is detected, a Thunderbolt controller will drive compatibility mode DisplayPort signals to that device. Support for DisplayPort also enables easy connectivity to other display types, such as HDMI, with an adapter.

Thunderbolt cables may be electrical or optical; both use the same Thunderbolt connector. An active electrical-only cable provides for connections of up to 3 meters in length, and provides for up to 10W of power deliverable to a bus-powered device. And an active optical cable provides for much greater lengths of up to 50m but does not provide power for bus-powered devices.

The Thunderbolt protocol physical layer is responsible for link maintenance including hot-plug detection, and data encoding to provide highly efficient data transfer. The physical layer has been designed to introduce very minimal overhead and provides full 10Gbps of usable bandwidth to the upper layers.
The heart of the Thunderbolt protocol architecture is the transport layer. Some of the key innovations introduced by the transport layer include:

- A high-performance, low-power, switching architecture.
- A highly efficient, low-overhead packet format with flexible QoS support that allows multiplexing of bursty PCI Express transactions with isochronous DisplayPort communication on the same link.
- A time synchronization protocol that allows all the Thunderbolt products connected in a domain to synchronize their time within 8ns of each other.

DisplayPort and PCI Express protocols are mapped onto the transport layer. The mapping function is provided by a protocol adapter which is responsible for efficient encapsulation of the mapped protocol information into transport layer packets. Mapped protocol packets between a source device and a desti- nation device may be routed over a path that may cross multiple Thunderbolt controllers. At the destination device, a protocol adapter recreates the mapped protocol in a way that is indistinguishable from what was received by the source device.

The advantage of doing protocol mapping in this way is that Thunderbolt technology-enabled product devices appear as PCI Express or DisplayPort devices to the operating system of the host PC, thereby enabling the use of standard drivers that are available in many operating systems today.

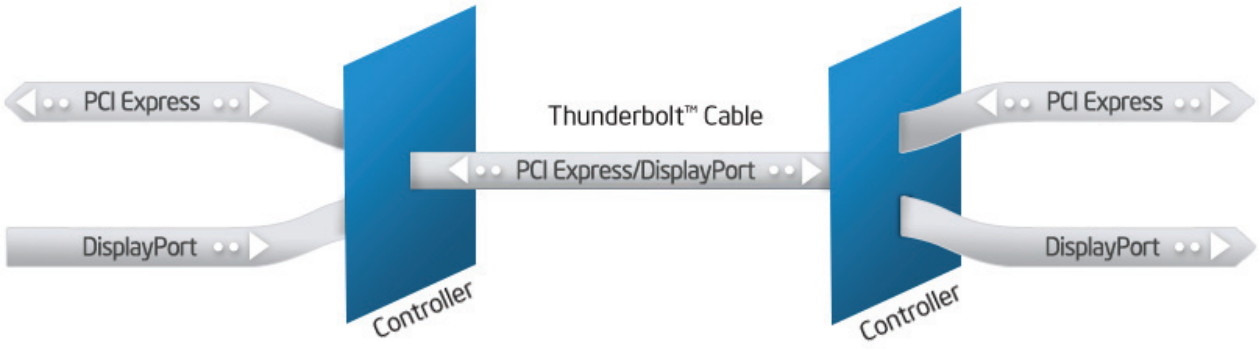

Figure 3. PCI Express* and DisplayPort transported between Thunderbolt™ controllers over a Thunderbolt cable.

Controller Architecture

A Thunderbolt controller is the building block used to create Thunderbolt products. A Thunderbolt controller contains:

- A high-performance, cross-bar Thunderbolt protocol switch
- One or more Thunderbolt ports
- One or more DisplayPort protocol adapter ports
- One or more Thunderbolt ports
- A PCI Express switch with one or more PCI Express protocol adapter port

The external interfaces of a Thunderbolt controller that are connected in a system depend on the application for which the system is designed. An example implementation of a host-side Thunderbolt controller is shown in Figure 4. Host side Thunderbolt controllers have one or more DisplayPort input interfaces, a PCI Express interface along with one or more Thunderbolt technology interface. By integrating all the features necessary to implement Thunderbolt into a single chip, the host-side controller enables system vendors to easily incorporate Thunderbolt technology into their designs.

Thunderbolt technology leverages the native PCI Express and DisplayPort device drivers available in most operating systems today. Native software support means no additional software development is required to use a Thunderbolt technology enabled product.

Thunderbolt Technology Possibilities

With Thunderbolt products, performance, simplicity and flexibility all come together. Users can add high-performance features to their PC over a cable, daisy chaining one after another, up to a total of 6 devices, including up to 2 high-resolution DisplayPort v1.1a displays. Because Thunderbolt technology delivers two full-bandwidth channels, the user can realize high bandwidth on not only the first device attached, but on downstream devices as well.

Users can connect to their other non-Thunderbolt products as well by using Thunderbolt technology adapters (e.g., to connect to native PCI Express devices like eSata, Firewire). These adapters can be easily built using a Thunderbolt controller with off-the-shelf PCI Express-to-"other technology" controllers.

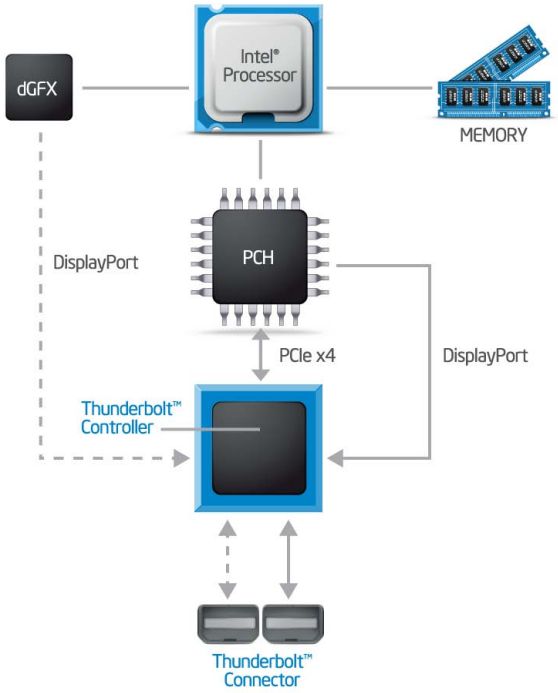

Figure 4. Block diagram of example PC system showing Thunderbolt™ controller connections.

System designers taking advantage of Thunderbolt technology can pursue leading edge Ultrabook designs that use fewer connectors while still achieving high performance between their computers and external devices. With Thunderbolt technology, workstation-level performance and feature expansion can supported with various Thunderbolt devices that are in the market. By leveraging the inherently tight timing synchronization (within 8ns across 7 hops downstream from a host) and low latencies of Thunderbolt technology, broadcast-quality media can be produced using Thunderbolt products.

Conclusion

Thunderbolt technology brings a new balance of performance, simplicity and flexibility to end users and product designers alike. As the fastest PC I/O technology,[1] leveraging two key technologies (PCI Express and DisplayPort) on one shared high-performance transport, Thunderbolt technology opens doors to entirely new system and product designs.

To learn more about Thunderbolt technology, visit
www.thunderbolttechnology.net

[1] As compared to other PC I/O connection technologies including eSATA, USB, and IEEE 1394 Firewire.* Performance will vary depending on the specific hardware and software used. For more information go to http://www.intel.com/technology/io/thunderbolt/index.htm.

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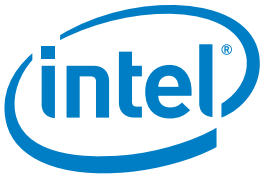

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