

# Thunderbolt™ Technology

## The Transformational PC I/O



Thunderbolt™ technology is a transformational I/O innovation that provides a leap in performance over current I/O technologies with 10 Gbps of full-duplex bandwidth per channel. It significantly simplifies the end-user experience by concurrently supporting data (PCI Express\*) and display (DisplayPort) connections over a single cable. Thunderbolt products may be connected using electrical or optical cables. Thunderbolt technology enables flexible and innovative system designs by allowing multiple, high-performance, PCI Express and DisplayPort devices to attach to a computer through a single physical connector.

### Why Thunderbolt Technology Matters

Data transfers for backup, sharing, and editing are faster with Thunderbolt technology, significantly reducing times to complete these tasks.

For time-sensitive data, such as video and audio during creation and playback, data transfers can be critical to the success of the work. Thunderbolt technology was specifically designed with video and audio applications in mind with inherently low latency and highly accurate time synchronization capabilities.



**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

- Dual-channel 10Gbps per port
- Bi-directional
- Dual-protocol (PCI Express and DisplayPort)
- Compatible with existing DisplayPort devices
- Daisy-chained devices
- Electrical or optical cables
- Low latency with highly accurate time synchronization
- Uses native protocol software drivers
- Power over cable for bus-powered devices

For some power users, optimal workflows can be had with workstation performance and expandability while using a thin and light laptop. Thunderbolt technology enables using the thinnest and lightest laptops, connected, with “in the box” performance over a single external cable, to high-performance external media drives, HD displays, HD media capture and editing systems, as well as legacy I/O hubs and devices, for the utmost in performance, simplicity and flexibility.

### 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 greater-than-high-definition display resolutions, 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 bandwidth between ports or between upstream and downstream directions. The Thunderbolt protocol architecture can be abstracted into four layers as shown in Figure 2.

A Thunderbolt connector is capable of providing two full-duplex channels. Each channel provides bi-directional 10 Gbps of bandwidth. A Thunderbolt connector on a computer is capable of connecting with a cable to Thunderbolt products or to DisplayPort devices. The Thunderbolt connector is extremely small, making it ideal for thin systems and compact cables. Compatibility with 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.

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; tens of meters.

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.

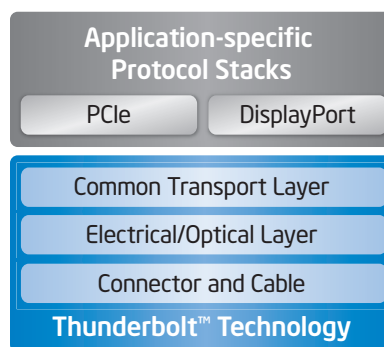


Figure 2. Thunderbolt™ Technology Architecture.

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 symmetric architecture that supports flexible topologies (star, tree, daisy chaining, etc.) and enables peer-to-peer communication (via software) between devices.
- A novel 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 destination 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.

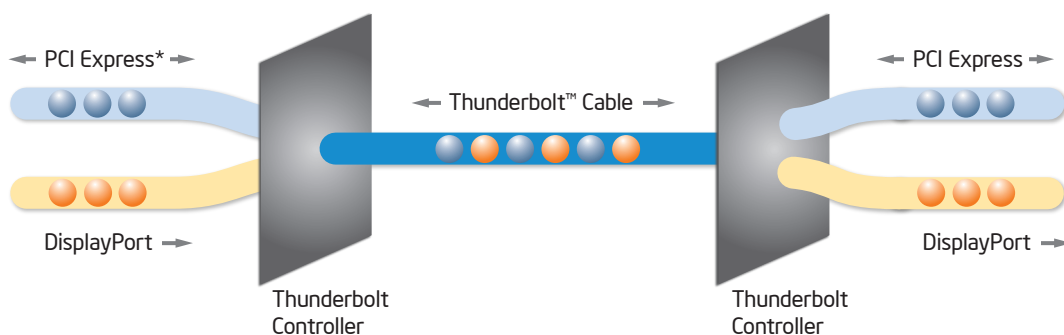


Figure 3. PCI Express\* and DisplayPort transported between Thunderbolt™ controllers over a Thunderbolt™ cable.

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.

## 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
- A PCI Express switch with one or more PCI Express protocol adapter ports

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.

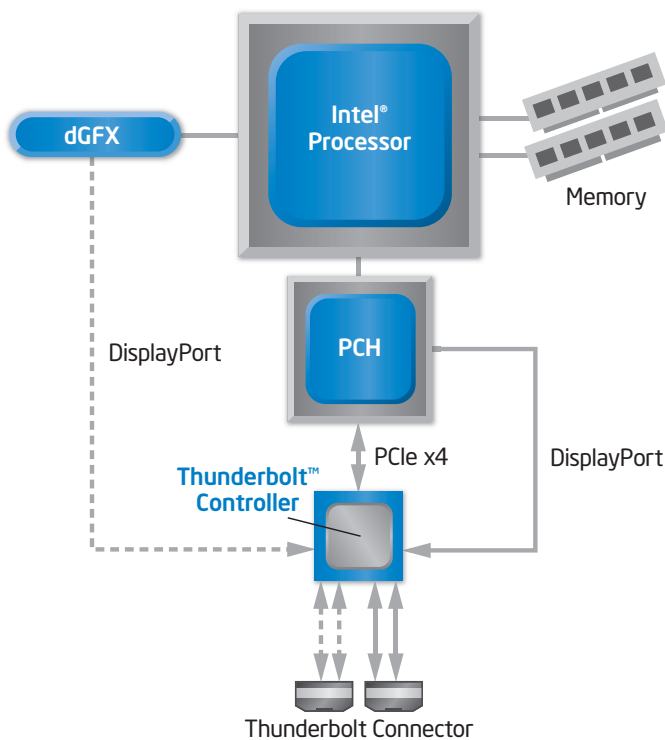
Thunderbolt technology leverages the native PCI Express and DisplayPort device drivers available in many operating systems today. This native software support means no extra software development is required to use a Thunderbolt technology-enabled product.

## 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 7 devices, 1 or 2 of which can be high-resolution DisplayPort v1.1a displays (depending on the controller configuration in the host PC). 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 always connect to their other non-Thunderbolt products at the end of a daisy chain 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.

## Example PC System Diagram Other system configurations possible



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

System designers taking advantage of Thunderbolt technology can pursue ever thinner and lighter system designs, using fewer connectors while still achieving high performance between their products and external devices. With Thunderbolt technology, workstation-level performance feature expansion can be packaged as standalone accessories, and is only a cable away. And 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,<sup>1</sup> 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.intel.com/technology/io/thunderbolt/index.htm](http://www.intel.com/technology/io/thunderbolt/index.htm)

<sup>1</sup>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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