PCIe® 6.0 SSDs: Powering the Future of Compute and Storage SSD Technology

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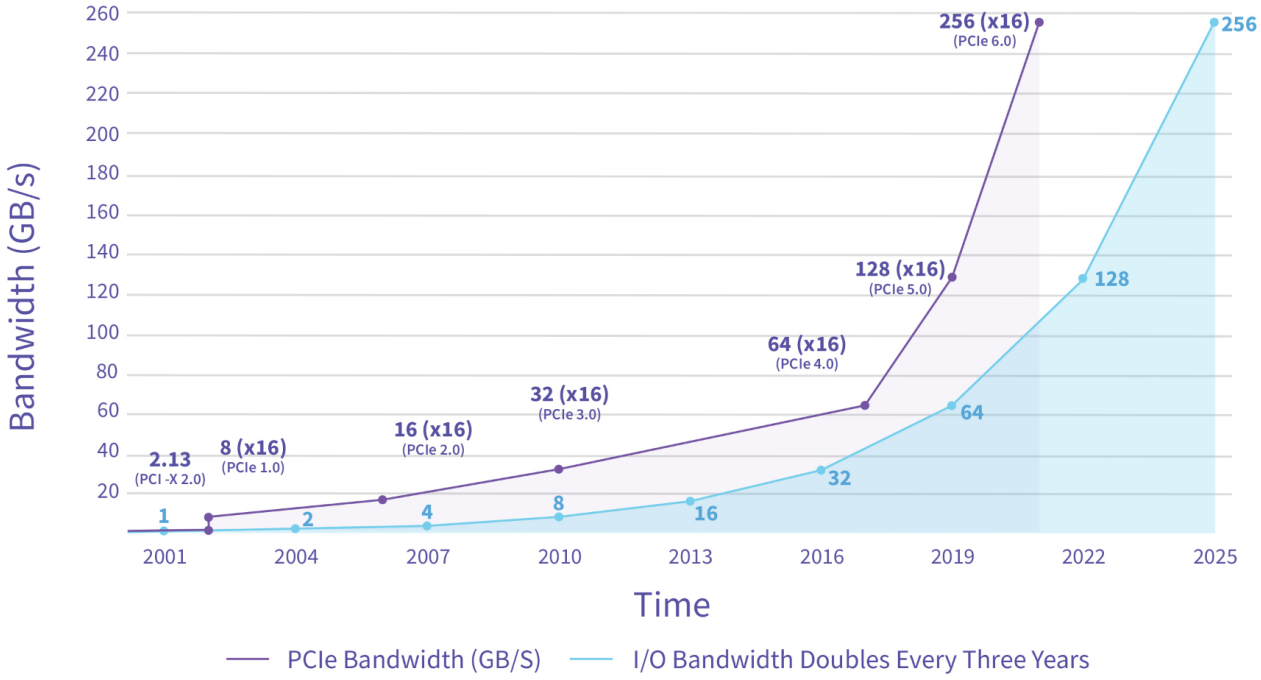
PCIe is a registered trademark of PCI-SIG.

Quick PCIe® Technology Background

- PCI Express®, born out of the need to move beyond parallel bus limitations, introduced in 2003
- PCIe bandwidth has grown significantly to meet the needs of modern compute hardware and applications
- NVMe® specification first ratified in 2011
- Major drive form factors: AIC, 2.5”[1], M.2
- First KIOXIA NVMe SSDs on major PCIe versions
  - PCIe 3.0: CM5 Series announced in 2017
  - PCIe 4.0: CM6 Series announced in 2020
  - PCIe 5.0: CM7 Series announced in 2022
  - PCIe 6.0: Stay tuned!

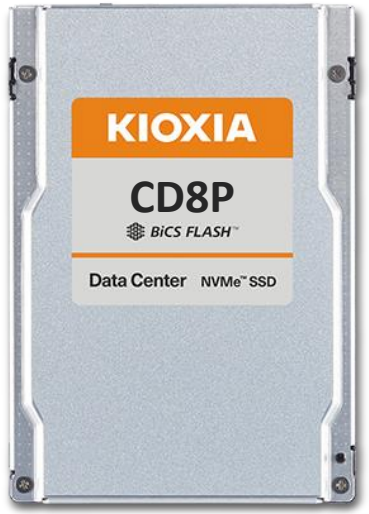


Source: PCI-SIG Press Release, Jan 11, 2022

[1] "2.5-inch indicates the form factor of the SSD and not its physical size. PCIe and PCI Express are registered trademarks of PCI-SIG. NVMe is a registered or unregistered mark of NVM Express, Inc. in the United States and other countries.

PCIe® Generational Improvements

PCIe Generation	Benefits and Changes	NVMe® Version	Predominate Drive Form Factors
PCIe 3.0	-Link Equalization -128b/130b Encoding for 20% Overhead Improvement	1.0 1.2	Add-in Card 2.5”[1] M.2
PCIe 4.0	-Reduced Latency -Lane Margining -Specs for Retimers and Redrivers	1.3 1.4	2.5” M.2 E1.L E1.S
PCIe 5.0	-CXL® Support -Various Physical Layer Improvements	1.4 2.0	E3.S/E3.L 2.5” E1.S/E1.L



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[1] "2.5-inch indicates the form factor of the SSD and not its physical size. The product images shown are a representation of the design models and not an accurate product depiction. PCIe is a registered trademark of PCI-SIG. NVMe is a registered or unregistered mark of NVM Express, Inc. in the United States and other countries. CXL and Compute Express Link are registered trademarks of the Compute Express Link Consortium, Inc.

PCIe® 6.0 Technical Improvements and Device Enablement

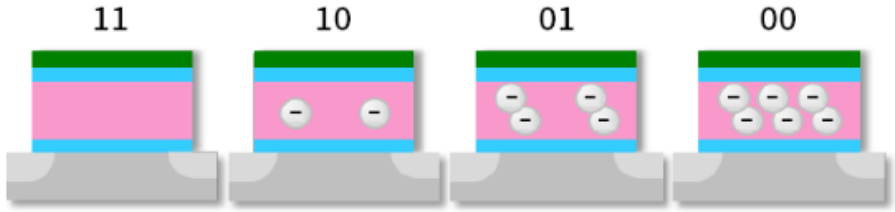
Improvements:

- Overall Bandwidth Doubles from 32GT/s to 64GT/s
- Pulse Amplitude Modulation 4 (PAM4)
- Forward Error Correction and Cyclic Redundancy Check (CRC)
- Flow Control Unit (FLIT): Fixed Flow Control Unit Size
- L0p and Dynamic Lane Width Changes for Improved Power Efficiency

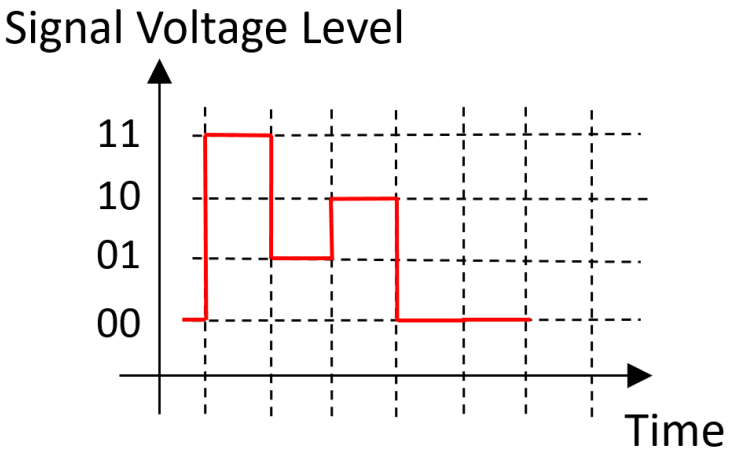
Enables:

- Higher Performance NVMe™ SSDs
- CXL® 3.0
- 800 Gigabit Ethernet Networking
- Faster Artificial Intelligence and High Performance Computing Processing

MLC NAND: Two bits of data are stored per memory cell



PAM4: Two bits of data are stored per clock



PCIe® 6.0 SSD Considerations

- Enterprise and Datacenter Standard Form Factor (EDSFF) E3.S or E3.L will be required for signal integrity and performance
- Increased power means increased heat dissipation requirements
  - Enhanced chassis cooling
  - Alternative drive heat sink strategies
- Potential for lane count reduction
  - L0p dynamic lane reduction
  - Gen6 x2 Link = Gen5 x4 Link
- Full Gen6 speeds realized with new system on chips (SoCs), DDR5 support, and higher NAND interface speeds
- Queue depth >512 needed for maximum performance

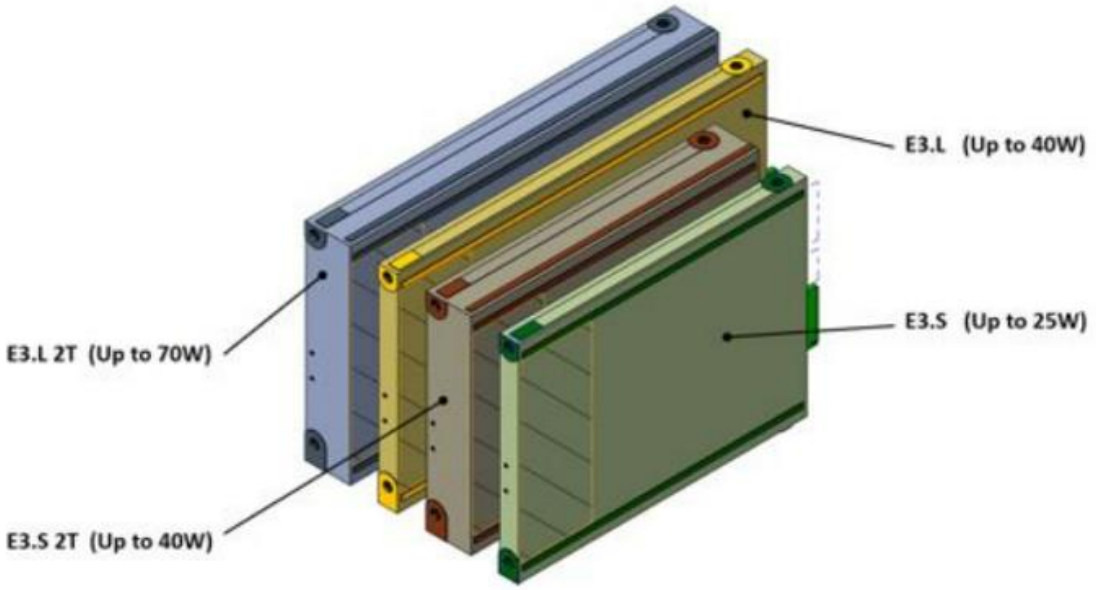
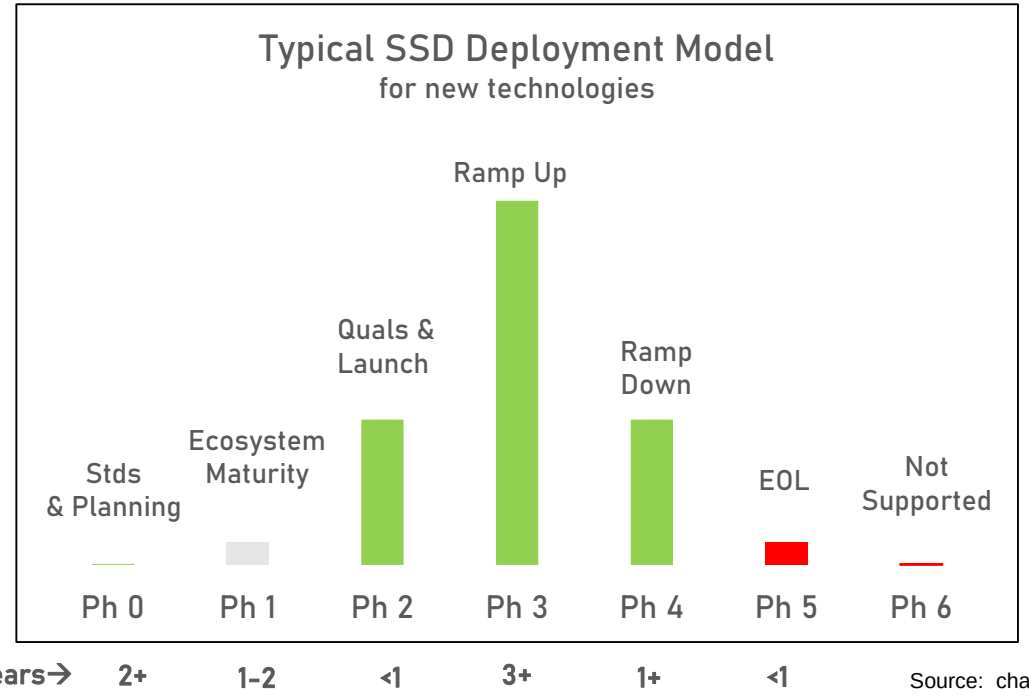


Image source: KIOXIA website and collaboration with SNIA

Industry consolidation around 1T thickness for NAND devices

PCIe® 6.0 SSD Ramp in the Market

KIOXIA's View



	2022	2023	2024	2025	2026	2027	2028
PCIe 3.0 SSD	Ph3	Ph4	Ph5	Ph6	Ph6	Ph6	Ph6
PCIe 4.0 SSD	Ph2	Ph3	Ph3	Ph4	Ph4	Ph4	Ph4
PCIe 5.0 SSD	Ph2	Ph2	Ph3	Ph3	Ph3	Ph3	Ph3
PCIe 6.0 SSD	Ph0	Ph0	Ph0	Ph1	Ph1	Ph1	Ph2

Source: charts are created by KIOXIA based on company's internal view.

- Customer qualifications take anywhere from 3 months to almost 2 years depending on end use complexity
- New major technology transitions always add to qualification times due to "growing pains"
- True ramp and volume of PCIe 6.0 won't take place until 2028[1]

1. Based on KIOXIA's internal view. PCIe is a registered trademark of PCI-SIG.

PCIe® 6.0: SSD Consolidation Enablement and Greater TCO

Consider an application that needs ~500 terabyte (TB) of compute storage

Metric (PCIe generation/capacity)	PCIe 5.0 w/ 7.68 TB Drives	PCIe 5.0 w/ 15.36 TB Drives	PCIe 6.0 w/ 15.36 TB drives
# of Drives	64	32	32
# of Servers	2	1	1
Raw Drive SR	896 gigabytes per second (GB/s)	448 GB/s	896 GB/s
Raw Drive SW	640 GB/s	320 GB/s	704 GB/s
Raw Drive RR	224M IOPS[1]	112M IOPS	224M IOPS
Raw Drive RW	25.6M IOPS	12.8M IOPS	24M IOPS
Total Drive Power	1,600 watts	800 watts	1,280 watts

PCIe 6.0 SSDs could reduce overall drive and server count by half without compromising performance or power consumption

[1]. IOPS stands for Input/Output Operations Per Second. PCIe is a registered trademark of PCI-SIG. Definition of capacity: KIOXIA Corporation defines a megabyte (MB) as 1,000,000 bytes, a gigabyte (GB) as 1,000,000,000 bytes and a terabyte (TB) as 1,000,000,000,000 bytes. A computer operating system, however, reports storage capacity using powers of 2 for the definition of 1GB = 230 = 1,073,741,824 bytes and therefore shows less storage capacity. Available storage capacity (including examples of various media files) will vary based on file size, formatting, settings, software and operating system, and/or pre-installed software applications, or media content. Actual formatted capacity may vary.

Key Takeaways

- New levels of PCIe® 6.0 performance bring higher power consumption, thermal dissipation requirements, and form factor consideration
- Likely application optimization needed to fully utilize PCIe® 6.0 saturation
- PAM4 and new signal integrity challenges
- New and growing storage related component ecosystem
- Expect slower ramp for PCIe® 6.0 NVMe™ SSDs vs PCIe® 5.0

Thank you

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Demos:

- Accelerating Artificial Intelligence (AI) Workloads (BAM, AiSAQ)
- Optical SSD
- RAID Offload
- Live Migration
- CXL®
- BiCS FLASH™ Generation 8 3D Flash Memory
- Automotive Solutions