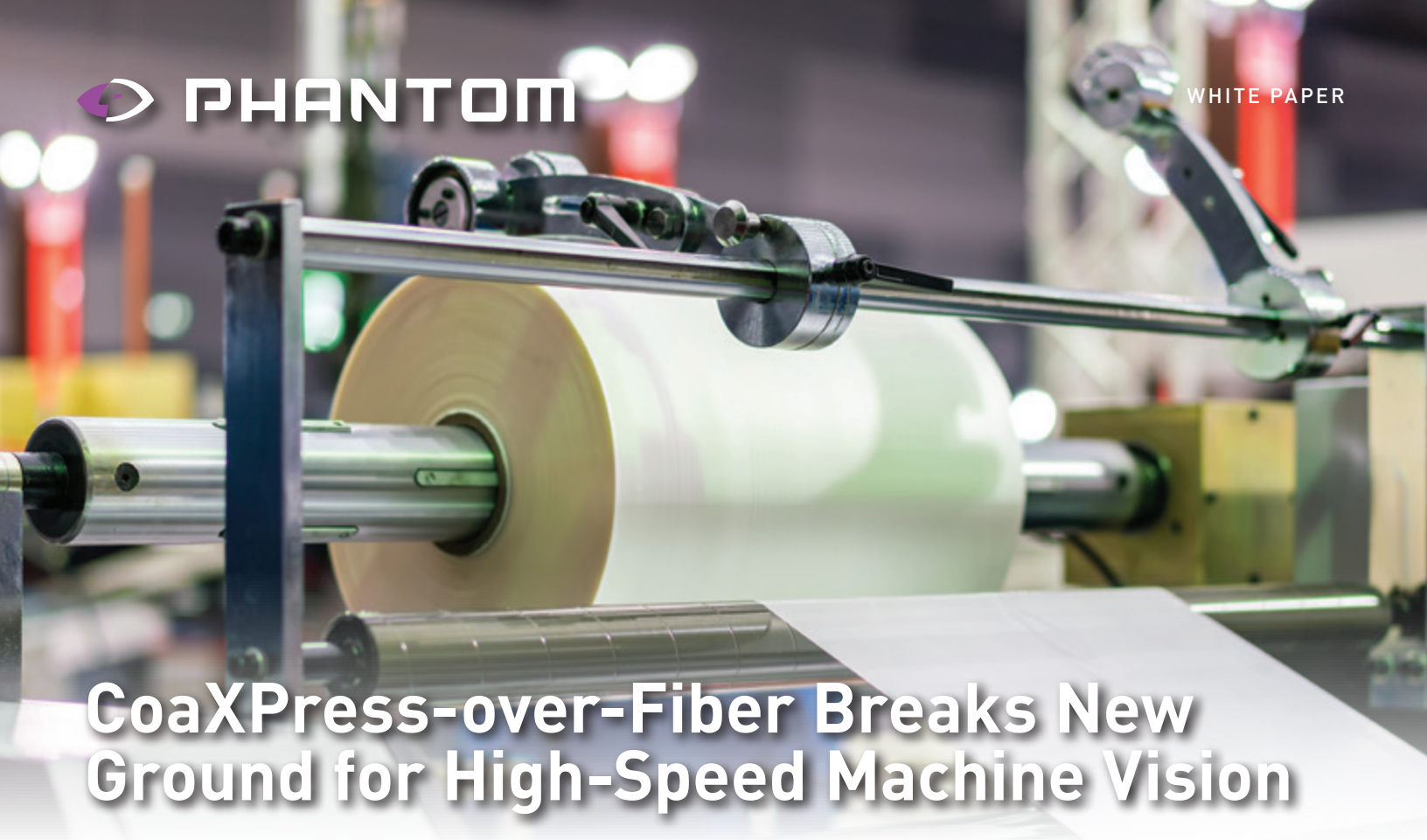

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WHITE PAPER

CoaXPress-over-Fiber Breaks New Ground for High-Speed Machine Vision

Exploring an innovative way to run the CoaXPress protocol over a standard Ethernet connection, improving throughput in high-speed machine vision applications.

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High-speed digital imaging expands the benefits of traditional machine vision (MV), transforming it from a process control tool into a diagnostic tool. Traditional MV systems use commercial off-the-shelf imaging sensors, lighting modules and processors to guide, inspect or identify parts moving along production lines. Compared to human operators, these systems are fast, accurate and repeatable, increasing productivity in fast-paced manufacturing environments.

High-speed streaming cameras build on these capabilities to capture what traditional MV systems cannot. Thanks to their high resolution, fast frame rates and streaming capabilities, these advanced cameras enable MV in challenging applications that require real-time analysis or long record times like semiconductor inspection, 3D printing and space shuttle launches.

These streaming cameras are just one part of the MV equation, however. To truly reap all the benefits these systems have to offer, they must be paired with cable technologies that can support transferring and processing vast amounts of image data at high speeds. This is where CoaXPress cable technology comes in.

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The CoaXPress interface standard for high-speed imaging — and in particular, its recent CoaXPress-over-Fiber extension — significantly improves throughput for MV applications, all while increasing bandwidth, lowering costs, reducing system complexity, enabling recording at longer distances and much more.

AN INTRODUCTION TO CXP CABLE TECHNOLOGY

As the world's leading protocol for high-speed imaging, copper CoaXPress (CXP) cable technology is a powerful standard for moving high-speed serial data from a camera to frame grabber. In addition to MV, it plays a role in many professional and industrial imaging applications like medical imaging, life sciences and defense. Hosted by the Japan Industrial Imaging Association (JIIA), CXP has been adopted as a global standard via the G3 alliance between JIIA, the European Machine Vision Association (EMVA) and the Automated Imaging Association (AIA) in North America.

Many high-speed streaming cameras use the CXP standard to maximize their usability, enabling the cameras to transfer large amounts of image data directly to backend frame grabbers. There, the data is processed on the fly via the frame grabber field programmable gate array (FPGA) or via the graphics processing unit (GPU) that is plugged into the computer motherboard using the Peripheral Component Interconnect Express (PCI-e) bus standard. In a process called stitching, the camera divides the transmitted images by rows and then interleaves the images as they arrive in the frame grabber FPGA. Using a simple algorithm, each image is then "stitched" back together. This streaming ability avoids the time-consuming process of saving data to a camera's RAM before downloading it to a computer in long-record applications.

Under the CXP-6 standard (revision 1.1) released in 2011, each copper cable is equipped to handle data transfer rates of 6.25 Gigabits per second (Gbps) from the camera to the backend receiver machine. On the Phantom® S990 high-speed streaming camera, for example, users can utilize up to 16 standard CXP-6 channels. The more recent CXP-12 standard (revision 2.0) released in 2019 effectively doubles this rate, making both CXP-6 and CXP-12 ideal for high-speed cameras requiring high throughput.

The more recent CXP-12 consists of a 12.5 Gbps link over a coaxial copper cable, while four CXP-12 links can easily achieve bandwidths of 50 Gbps with link aggregation. In terms of connectors, CXP-6 uses DIN 1.0/2.3 connectors with a push-pull latching system, while CXP-12 uses Micro-BNC (HD-BNC) connectors with trusted push-and-turn, bayonet-style positive locks for quick and easy connection/disconnection.

Use Cases for CoaXPress-over-Fiber

Automated optical inspection (AOI). CXPoF expands AOI applications significantly, as the miniaturization of printed circuit boards requires the three-dimensional detection of smaller defects, driving up the amount of image data that must be acquired and processed.

LCD to OLED inspection. Organic light-emitting diode (OLED) structures are two times smaller than light-emitting diodes (LED), effectively doubling the number of inspection steps. For these reasons, inspecting OLEDs involves four-times as much image data to transport and process.

Printing inspection. These applications require very high-resolution color line-scan cameras, while large printing machines require long cables.

Industrial environments. CXPoF accommodates the need for long cables in noisy industrial environments while providing the necessary resistance to electromagnetic interference.

Stadium imaging. These applications involve long cable distances and require many cameras. CXPoF consolidates multiple localized CXP (copper) cameras over a single fiber — a CoaXPress-over-Fiber accessory.

Interface	Bandwidth	Frame Rate 4MP Camera	Cable Length
GigE Vision	1.0 Gbps	25 fps	100 m
USB3	5.0 Gbps	90 fps	3 ~ 7m
Camera Link	Base: 2.0 Gbps 80-bit: 6.8 Gbps	- 180 fps	6 ~ 10 m
CXP-6	1x: 6.2 Gbps 2x: 12.5 Gbps 4x: 25.0 Gbps	~ 150 fps ~ 300 fps ~ 600 fps	40 m
CXP-12	1x: 12.5 Gbps 2x: 25.0 Gbps 4x: 50.0 Gbps	~ 300 fps ~ 600 fps ~ 1200 fps	40 m

CoaXPress Benefits at a Glance

- High-speed data rates: up to 12.5 Gbps over a single coax cable and scalable for multiple cables. Four cables achieve 50 Gbps, while eight cables achieve 100 Gbps.
- Long cable lengths in excess of 100 meters at 3.125 Gbps and 35 meters at 12.5 Gbps.
- Real-time behavior with fixed, low-latency transmission.
- Precise triggering capabilities.
- Single cable integration for image data, communication, control and power.
- Cost-effective cabling options.

CoaXPress-over-Fiber Benefits at a Glance

- Extremely high throughput.
- Ultra-high data and frame rates.
- Many cabling accessories.
- Low CPU overhead, latency and image jitter.
- Higher bandwidth: 10 and 25 Gbps per fiber.
- Immune to electrical noise.
- Meets JIIA and IEEE standards.

ACHIEVING HIGHER THROUGHPUT WITH CXPoF

An add-on to the more recent CoaXPress 2.0 specification, CoaXPress-over-Fiber (CXPoF) provides a way to run an unmodified CXP-12 protocol over a standard Ethernet connection including fiber optics. In other words, it uses standard electronics, connectors and cables designed for Ethernet, but the protocol is CoaXPress instead of Ethernet or GigE Vision.

Because CXPoF combines the CXP-12 standard with optical fiber, this upgraded standard eliminates the need for multiple CXP-6 copper cables. Vision Research recently incorporated this technology into its latest MV camera, the Phantom S991 (see sidebar). As one of the industry's first CXPoF camera models, it requires just two fiber cables as opposed to the 16 copper cables required by its predecessor, the Phantom S990. The Phantom S991 includes an 8-bit output option to provide higher frame rates in the larger resolutions and reduce data throughput. It also has resolution increments of 128 (horizontal) x 8 (vertical), allowing users to maximize resolution for the required frame rate.

In terms of bandwidth, CXPoF achieves 4 x 10 Gbps on a single Quad Small Form-Factor Pluggable (QSFP+) transceiver module for a total of 40 Gbps per camera — the same net bandwidth as four CXP-12 links over four copper coaxial cables.

The Phantom S991 is one of the industry's first CXPoF camera models.

Key Specifications of the Phantom S991

Compared to traditional MV cameras, high-speed streaming cameras feature custom-designed complementary metal-oxide semiconductor (CMOS) sensors up to 9 megapixels (Mpx), as well as exposure times as low as 1 microsecond (µs) and speeds up to 680,000 frames per second (fps). For example, the world's highest-throughput machine vision camera, the Phantom S991, combines world-class high-speed image quality with direct data transfer speeds up to 9 gigapixels per second (Gpx/sec), or 70 Gbps, and can capture 938 fps at full 9-Mpx resolution. Other key specifications include:

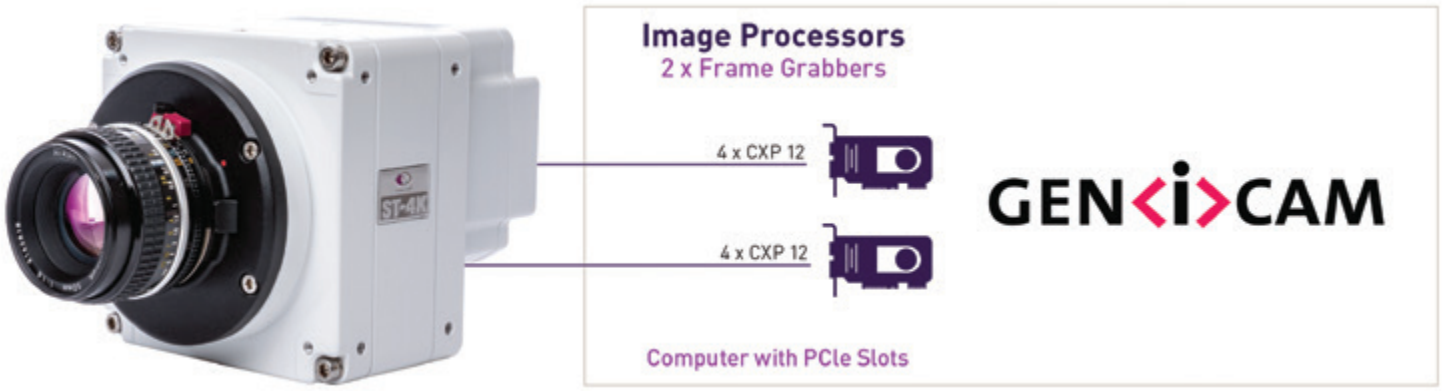
- 9-Mpx sensor (4096 x 2304)
- Throughput: 9 Gpx/sec (70 Gbps)
- Maximum frame rate at 4096 x 2304: 938 fps
- Maximum frame rate at reduced resolutions: 52,080 fps
- Minimum exposure: 5 µs
- Rolling (R) and global (G) shutters
- Daylight ISO: 1,600 (Mono), 400 (Color)
- EVMA data:
  - Quantum Efficiency (QE) at 532 nanometers (%): 59.5 (G); 57 (R)
  - Dark noise (e-): 30.04 (G); 10.02 (R)
  - Dynamic Range (dB): 55.8 (G); 68.6 (R)

The Phantom S991, for example, provides the same throughput as the S990, but it uses only two QSFP+ transceiver modules and fiber cables. The S991 also uses Kintex® UltraScale+™ FPGA with Euresys CXP-12 IP Core and CoF Bridge. Within the camera, this bridge converts CoaXPress packets to XGMII (10 Gigabit Media-Independent Interface) packets going toward the Ethernet Physical Coding Sublayer (PCS) or Physical Medium Attachment (PMA) block. Within the frame grabber, the bridge also converts the XGMII packets to CoaXPress packets.

The Phantom S991 provides the same throughput as its predecessor, the Phantom S990, but it uses only two QSFP+ transceiver modules and fiber cables.

THE BENEFITS OF CXPoF

The CoaXPress standard has been successful due to its unique combination of high bandwidth, low latency, high stability and excellent reliability. When integrated into high-speed cameras, it improves the data transfer process, enabling users to obtain high-quality images at extremely fast frame rates. CoaXPress-over-Fiber keeps and builds on these benefits. For example, because CXPoF is an add-on to the existing CXP standard, high-speed imaging experts can leverage the same programming when upgrading their camera.



The setup for high-throughput streaming applications.

Because it uses Ethernet components, CXPoF also only requires standard Ethernet connectors and cables, keeping costs low. At the same time, it takes advantage of the "free" evolution of Ethernet as it progresses toward higher bandwidths — like the eventual 400 Gigabit Ethernet.

Printing inspection is one of the many use cases for CoaXPress-over-Fiber technology.

In addition to reaping the benefits associated with Ethernet, users can enjoy all the advantages of fiber optics. These cables are small and lightweight. Fiber optic technology can also handle higher bandwidths compared to copper cables, and it is immune to electrical noise — an ideal characteristic for noisy production floors and medical applications.

CXPoF opens the door to new high-speed MV applications while, at the same time, simplifying those applications where high-speed MV is already in use.

For example:

- **CXPoF eliminates complex, error-prone repeaters.** Prior to the CXP-12 standard, users had to deploy expensive repeaters to translate the CXP-6 standard into fiber, driving up costs by several thousands of dollars. This setup also created very bulky cable interfaces with many potential points of failure. CXPoF simplifies this setup, eliminating the need for repeaters and their associated failure points.
- **CXPoF enables recording at longer distances.** CXPoF expands MV to applications requiring recording at longer distances — an undertaking that previously required the use of many costly, complex repeaters. Now, users can simply set up their MV camera up to several miles away without worrying about the added complications associated with connecting external equipment. And with the availability of single-mode transceivers and cable, there are no limits in cable length. This ability also simplifies the process of bringing MV to applications that involve ballistics or explosives, which, by their nature, require camera operators to remain far away from the recording process.
- **CXPoF reduces system complexity.** Reducing failure points even further, CXPoF requires only two frame grabbers instead of four. Regardless of recording distance, the number of transceiver connections also drops from 16 copper cables to two fiber optic cables, creating a lightweight, stable and more mobile cable setup.

LEARN MORE

A game-changing cable technology for high-speed imaging, CXPoF technology provides many benefits to support extremely high throughput in MV applications. By combining the CXP-12 standard with fiber optic cable technology, CXPoF balances high bandwidth with low latency, and is poised for future increases in bandwidth, all while using standard Ethernet components.

To learn more, visit:
www.phantomhighspeed.com/Support

ABOUT VISION RESEARCH

Vision Research, a business unit of the Material Analysis Division of AMETEK Inc, designs and manufactures high-speed cameras. The Phantom camera brand is known for unparalleled light sensitivity, image resolution, acquisition speed and image quality — necessities for analyzing high-speed events.

Vision Research offers both standard and machine vision high-speed cameras to meet the needs of a variety of industries. Standard cameras with on-board memory from the VEO Series to the TMX Series are perfect for research and development applications. Phantom Machine Vision cameras offer the same high-quality imaging performance for applications that require real time processing or long-record times. They provide the performance needed for challenging applications such as deformation cytometry and detailed electronics inspection.

PHANTOM® VISION RESEARCH AMETEK®

*Certain Phantom cameras are held to export licensing standards. Please visit www.**phantom**highspeed.com/export for more information.*