2022
CASE STUDY

Faster Than a Speeding Bullet

How the TMX ultrahigh-speed camera balances frame rate, resolution and light sensitivity in high-speed ballistics applications.

CineSpeed, a production company specializing in high-speed videography for scientific and cinematic applications, has been making a name for itself with its unique, highly detailed and often colorful videos of explosions. Another area that is keeping the company busy is ballistics.

"We've been experiencing a big push toward ballistics, particularly as it relates to material tests and ammunition analysis," says Ryan McIntyre, CineSpeed owner and certified Phantom camera technician. For example, the company has recently recorded material tests for a manufacturer of bullet-proof fences. Its high-speed recordings have also enabled ammunition manufacturers to verify a bullet's rotational speed or velocity. "Because we know the size of the caliber and how far the bullet travels over time, we can confirm its speed," McIntyre explains.

Critical to slowing down the fast-moving bullets is the Phantom TMX 7510, an ultrahigh-speed camera that leverages powerful back side illumination (BSI) sensor technology. "Thanks to the TMX, we've been able to capture our best ballistics shots to date," McIntyre says. Although previous high-speed cameras have gotten the job done, when pushed to their limits they sometimes exhibited artifacts in the ballistics image. The artifacts not only look unattractive, but more importantly they can interfere with motion analysis software.

"The TMX has given us highly detailed closeups of each bullet as it escapes the barrel," McIntyre says. "The resulting images have blown us away. They're really clean, and we're always excited to show our clients."

DELIVERING TRUE HIGH-SPEED PERFORMANCE

To properly record extremely fast-moving phenomena like ballistics, high-speed camera operators often reduce their camera's resolution to increase recording speeds. However, relevant information that occurs during the event may fall outside of the reduced resolution range. To prevent this from happening, camera operators should aim for the highest resolution possible at their required frame rate. For most ballistics applications, the sweet spot for frame rates is 100,000 to 300,000 frames per second (fps).

In addition to fast recording speeds and high resolution, ballistics applications require high-speed cameras with extremely fast exposure times to freeze an instant of time without leaving behind motion blur artifacts. At the same time, the camera must be able to capture sufficient light to deliver high-contrast images. The TMX camera offers a 1-microsecond (μs) minimum exposure time, as well as a 95-nanosecond (ns) minimum exposure time with the export-controlled FAST option. Although these short exposure times typically require high levels of illumination to compensate for the short time the pixel receives light, the TMX camera addresses the issue using its BSI sensor technology.

Thanks to the BSI sensor, high-speed camera operators no longer have to choose between frame rate, resolution and light sensitivity. Due to its efficacy at capturing light, this sensor delivers unprecedented resolution and speed combinations, enabling high-speed camera operators like McIntyre to capture unique, highly detailed and clean shots of speeding bullets, ammunition tests and other ballistics events.

BSI SENSORS PROVIDE A DIRECT ROUTE FOR LIGHT

Until now, the complementary metal oxide semiconductor (CMOS) sensors on high-speed cameras have featured front side illuminated (FSI) architectures, in which the sensor's metal circuitry sits above the pixels' photodiodes that face the light source. This metal circuitry prevents some incident light from reaching the pixels, reducing the sensor's sensitivity.

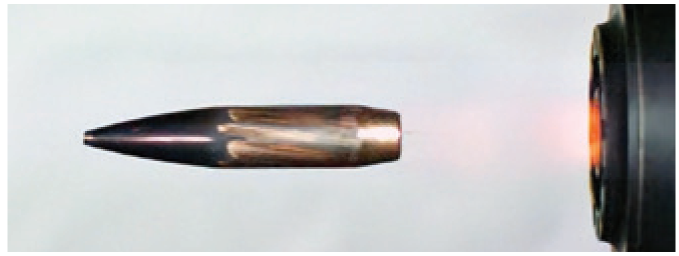
BSI sensors, which capture light more effectively than CMOS sensors, are designed with a thick carrier wafer at the top of the metal stack — an arrangement that exposes the diodes facing the light source and the metal surface behind them. This design improves the BSI sensor's fill factor, which refers to the percentage of the pixel surface area that can capture photons.

Because the metal circuitry blocks or reflects some of the light, a typical FSI sensor will only have a fill factor between 50 and 60 percent. On the other hand, by relocating the circuitry and providing a direct route for light to reach the light-receiving surface, BSI sensors achieve a fill factor close to 100 percent.

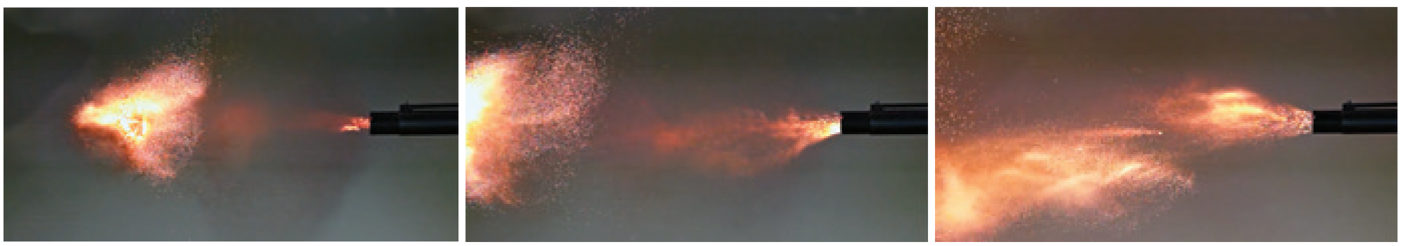
FROM BULLETS TO DRAGON'S BREATH

With the TMX camera in his high-speed arsenal, McIntyre has been able to achieve cleaner ballistics images at the desired resolutions and frame rates (100,000–300,000 fps), enabling him to capture and analyze a variety of ballistics events including ammunition tests for 9mm, .338 Lapua Magnum and dragon's breath cartridges.

High-speed footage of a ballistics test featuring a 9mm round. 187,500 fps at 1024 x 320.



High-speed footage of a ballistics test featuring a 338 Lapua Mag. 308,823 fps at 1024 x 192.



High-speed footage of dragon's breath, an incendiary-effect round for 12-gauge shotguns. 86,065 fps at 1024 x 704.

In a series of shots involving the 338 Lapua Mag, McIntyre recorded the bullet's reflection in a special, single-sided mirror that minimizes flash, creating the illusion that the bullet is traveling toward the viewer as it leaves the barrel. "When you watch the high-speed footage, it looks like the bullet is coming toward you," McIntyre says. "The level of detail is phenomenal. You can see the bullet rotating as it leaves the barrel, along with the little explosion behind it."

The down-the-barrel shot of the 338 Lapua Mag. 308, 823 fps at 1024 x 192.

For some of the ballistics tests, McIntyre has applied a speckled paint pattern to the bullet as part of Digital Image Correlation (DIC) analysis. This non-contact technique uses high-speed cameras and specialized software to optically measure deformation, displacement and strain, and it is rapidly growing in popularity in the defense industry. Once the speckled pattern is applied to the surface of the object under study, the high-speed camera and DIC software record and analyze the pattern's movement in response to force, revealing areas of strain and displacement.

PHANTOM BINNING MODE

For his recent high-speed work with ballistics, the slowest frame rate McIntyre used was 76,086 fps, while the highest was 617,647 fps with binning mode. This feature, which produces monochrome images, allows Phantom camera users to unlock a wider variety of resolutions without sacrificing speed. The TMX 7510 achieves extremely high frame rates in binning mode with FAST option: 1.75 million fps at 640 x 64.

McIntyre applied a speckled pattern to the 338 Lapua Mag cartridge as part of DIC analysis. 308,823 fps at 1024 x 192.

THE TMX 7510 ULTRAHIGH-SPEED CAMERA

The TMX 7510 offers the fastest frame rates at the largest resolutions available today. With 75 Gpx/sec of throughput, it achieves speeds up to 76,000 fps at full resolution and over 300,000 fps at 1280 x 192. Designed with data management in mind, the TMX 7510 also provides up to 512 GB of memory and 8 TB of CineMag secure storage. For fast data transfer, 10Gb Ethernet is standard. The Export Controlled FAST option is required for performance of 1 million fps or higher and exposure time under 1 µs. Historically, the resolutions associated with frame rates above 1 million fps were too low for nearly all scientific uses, but 1280 x 32 represents a truly usable resolution in a wide range of applications.

Thanks to the TMX 7510 high-speed camera, the CineSpeed production team has captured clean, highly detailed ballistics images for a variety of applications — from ammunition tests to DIC analysis.

To learn more about the Phantom TMX 7510, please visit ***www.phantomhighspeed.com/tmx****.*

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