PHANTOM

2021
CASE STUDY

BSI at Full Blast

Thanks to the Phantom TMX 7510, a high-speed camera that leverages powerful BSI sensor technology, one production company is capturing unique footage of combustion events.

From exploding dynamite to shock charges, new footage of explosions is sending shock waves through the world of high-speed combustion imaging.

The creative force behind this footage is CineSpeed, a team of content creators that specializes in high-speed videography using Phantom high-speed cameras. At the helm of CineSpeed, which offers its services for various scientific and cinematic purposes, is Ryan McIntyre, company owner and certified Phantom camera technician. "Using the TMX 7510, we've been able to get a lot of clean, highly detailed shots of explosions that were not previously possible," he says.

To effectively record exploding dynamite, shape charges and other combustion events — which require hundreds of thousands of frames per second (fps) — high-speed camera operators must often reduce their high-speed camera's resolution. Although helpful in some instances, reducing the resolution creates some challenges:

- Pixel resolution must be reduced to achieve 100,000 or more fps, reducing the final video quality and increasing the potential that relevant information will be missed. The more resolution at the required frame rate, the better.
- Short exposure times, as well as the result of the high frame rate and detonation speed, may not be enough to achieve good frame exposure following the self-illuminating event, leading to unusable images.
- Combustion events require high-speed cameras that can handle extreme contrast. It is important to light the scene before and after the bright flash without overexposing the subject.

The Phantom TMX camera family overcomes these challenges thanks to its use of back-side illumination (BSI) sensor technology, which has enabled McIntyre and his team to unlock unprecedented resolution and speed combinations while shooting explosions. "Because the camera can handle lower-light scenarios, we can capture explosions at higher frame rates," McIntyre says. "The TMX has also given us cleaner, better-looking images at the resolutions and frame rates we want. As a result, we can now see and analyze things we couldn't before due to the limited resolutions of our previous cameras."

The TMX achieves unprecedented resolution and speed combinations thanks to its use of BSI technology. Footage of detonation cord and foam cans. 86,065 fps at 1280 x 704.

ACCOUNTING FOR EXTREMES

Finding the right amount of light to properly illuminate a scene is a common issue in the world of high-speed imaging — and it becomes even more complicated in combustion applications. This is because the sudden flash of bright light that occurs during an explosion overexposes pixels and causes critical data to be lost. To avoid these issues, it's not uncommon for experts to use small explosives or specialized flash bulbs to light the scene prior to the event of interest — a task that can require extra materials, extensive setups and precise timing. They may also use multiple cameras to capture different aspects of the same event: One camera, which is set to record the event during and after the flash, is paired with a second camera with a lower exposure time to capture the flash itself.

Although using light-emitting diodes (LEDs) is a common way to illuminate scenes in many high-speed applications, according to McIntyre, the technology is not advanced enough for combustion events — though it is close. "I expect within the next year or so, we'll have new LED prototypes that can expose our shots closer to what the explosion exposure actually is."

To help McIntyre preserve important imaging details before, during and after the light flash, the TMX 7510 integrates an Extreme Dynamic Range (EDR) feature. "EDR is a helpful tool for shooting any event that has very high contrast," McIntyre explains. "In our case, we want to capture not just the explosion, but the events before and after it too. This means transitioning between dark and extreme light quickly."

EXTREME DYNAMIC RANGE EXPLAINED

Image exposure is typically adjusted using lens aperture and exposure time to see detail in the darkest parts of the image. However, these adjustments also cause the brighter parts of the image to become overexposed and saturated. EDR, which is a standard feature of Phantom TMX high-speed cameras, overcomes this challenge by providing users with two exposure times for a single frame.

At a certain point during the frame exposure, the camera will reset all the pixels that are above a preset threshold to a level between black and full saturation. The camera will then allow all the pixels to continue being exposed. In other words, EDR "puts the brakes" on the pixels that are on their way to becoming saturated before the exposure time is up. The result: these pixels are less likely to saturate, with usable detail in the bright flash areas of the image. It should be noted that EDR is most effective in monochrome cameras.

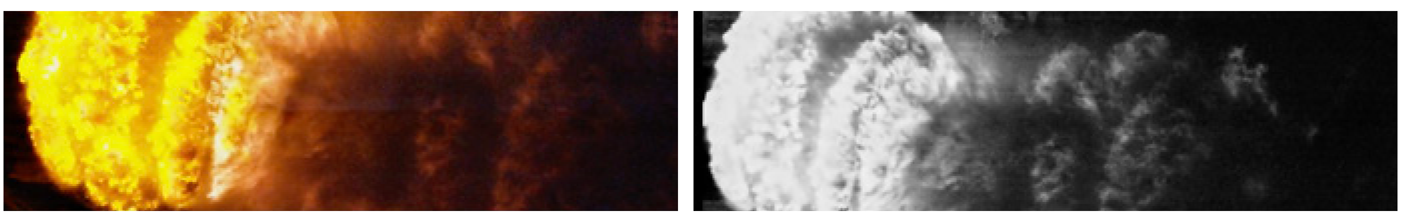
A second way to avoid losing important data during the light flash is to adjust the high-speed camera's Exposure Index (EI), which is a fast way to boost the image and ensure the details are being exposed. In the end, finer details become visible when combined with post-processing techniques. "I'd often turn the camera's EI all the way up so that we could barely make out the image because it was so grainy," McIntyre explains. "Recording events in the dark like this meant we were also capturing a lot of detail. After getting the shots, I'd move the EI back down in post-production, making all the details visible."

FROM COLORFUL FLASH BULBS TO SHAPE CHARGE REFLECTIONS

For his high-speed work with explosives, the slowest frame rate McIntyre has used is 6,000 fps, while the highest he has used is 617,647 fps with binning mode, which allows Phantom camera users to achieve a wider variety of resolutions without sacrificing speed. Although the TMX 7510 achieves extremely high frame rates in binning mode — 1.75 million fps with a resolution of 640 x 64 — this feature produces monochrome images.

Capturing images in color offers its own set of unique benefits. "For example, if you have the white balance set up correctly, you can see the colors associated with chemical reactions which can be a valuable data point," McIntyre says. "Color also provides so much more visual information at one time. When we filmed the flash bulbs in color, for example, the shots looked like galaxies were forming. We would have missed all this detail with a monochrome camera."

Vintage flash bulbs filmed in color at 100,000 fps.



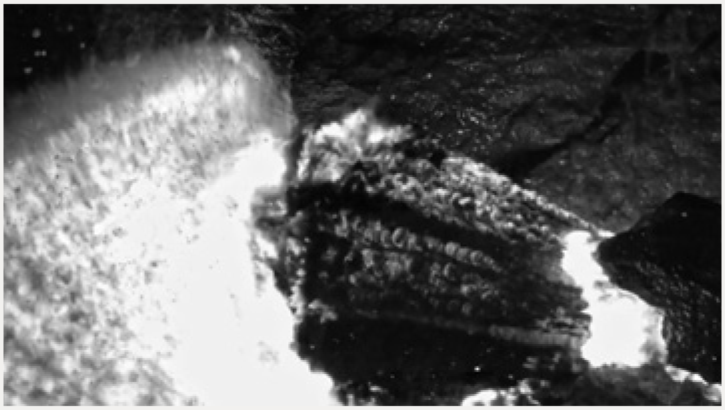
Filming high-speed combustion events like this detonating cord and TNT in color (233,333 fps at 1280 x 256) versus monochrome (308,823 fps at 640 x 384) can provide additional details about the event despite the lower frame rates.

Exploding dynamite in color (233,333 fps at 512 x 256) versus monochrome (617,647 fps at 512 x 192).

TMX 7510 EXPOSURE TIMES

Perfect for intense light flashes, the TMX 7510 supports minimum exposure times as fast as 95 nanoseconds (ns) with the Export Controlled FAST option. Thanks to this capability, the camera can capture explosive events without motion blur, which can be a limiting factor in obtaining high-quality images for combustion analysis.

The TMX 7510 enabled McIntyre to capture highly detailed images of this shape charge explosion, as well as the events before and after it. 617,647 fps at 512 x 192 resolution.



Another combustion event McIntyre has filmed is shape charges, which are explosive charges, often used for demolition purposes, that focus their energy based on their shape. In one recent application, a company hired McIntyre to record how exploding dynamite, when used in conjunction with shape charges, can create a larger, more effective detonation effect.

"The energy from a shape charge cuts like a knife, while the energy from dynamite pushes," McIntyre explains. "We were hired to test the theory that arranging dynamite in the shape of a pyramid would push energy in the direction the pyramid was made. Thanks to our high-speed footage, we verified that this theory holds true."

In another series of shots, McIntyre, in order to see the directional path of a shape charge explosion, filmed the reflection of one using mirrors. "We arranged the shape charge in the shape of a V," McIntyre explains, "and that V ends up inverting as soon as the explosive goes off. We wanted that V, and all the molten copper, to look like it was coming toward the camera, and so we zoomed in on the mirror during filming. It was also really cool to see the shock waves breaking the glass."

Exploding shape charges filmed using a mirror. 456,521 fps at 640 x 256.

RUGGED CONDITIONS CALL FOR RUGGED CAMERAS

For as sensitive as the TMX 7510 camera is, one might think it's a delicate piece of hardware — but that couldn't be further from the truth. The camera's rugged construction makes it a perfect fit for the demanding environments many explosions must be filmed in. "We recorded a lot of our shots in a rock quarry," McIntyre says. "It was very dusty. And at one point, we were caught in a downpour."

A sturdy, 20-pound unit, the TMX 7510 integrates active cooling and can handle temperatures from -10 to +50°C. Among its many environment specifications, it is rated according to MIL-STD-202H and MIL-STD-202H shock and vibration tests, respectively.

TRIGGERING PHANTOM CAMERAS FOR EXPLOSIONS

The TMX 7510 provides several features for triggering explosive events, including Image-Based Auto-Trigger (IBAT), software triggering and hardware triggering via a dedicated BNC.

IBAT is a standard Phantom camera feature that lets users trigger one camera — or a number of connected cameras — based on motion detected in the live image. This capability makes it possible to record fast-moving or unpredictable events without having to manually trigger the camera. To set up this feature, users must first select a rectangular area within the image. As the camera captures each frame, it compares the image in the Auto-Trigger region to an earlier copy of the region that has been stored in the memory. Following this comparison, the camera updates the image in the memory to the current image for future use and determines if a trigger must be generated. Any pixel being compared is considered "active" if its level has changed — i.e., brightened or darkened — by more than a preset threshold. The number of active pixels for a given frame is counted, and if it exceeds a set number, the camera generates the trigger.

For the larger explosion shots like the dynamite, McIntyre outfitted his TMX 7510 with a lens that enabled him to trigger the camera safely from a distance. "We couldn't get close to the explosive, so we set our camera up roughly 100 yards away," he says. "Despite the distance, we still got a lot of highly detailed images because of the zoom lens." For many of these shots, McIntyre also used two TMX cameras — a monochrome and color version — enabling him to compare the dynamite explosions using different frame rates and resolutions.

"Using Ethernet cabling, we had a router running into each camera and then back to our van, and I triggered them together using my laptop." For distances greater than 100 meters fiberoptic repeaters are required for the Ethernet to limit signal delay. When synchronizing cameras it is important to hard-wire the trigger to the camera, so long runs of BNC cable are also required. This ensures the trigger frame matches perfectly on each camera.

A BRIEF INTRODUCTION TO BSI SENSOR TECHNOLOGY

BSI sensors capture light more effectively than CMOS imaging sensors. Until now, the CMOS sensors on high-speed cameras have been based on 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, which in turn affects the fill factor and reduces the sensor's sensitivity.

BSI sensors are designed with a thick carrier wafer at the top of the metal stack — an arrangement that allows the bulk silicon to be thinned and flipped, exposing the diodes facing the light source and the metal surface behind them. This design brings two significant advantages to BSI sensors in high-speed combustion applications: improved fill factor and increased processing speeds.

McIntyre and his team filming in a stone quarry in Pennsylvania.

Another important feature for McIntyre is the camera's range of onboard control options. These include programmable I/O for flexible signal control, on-camera controls and video monitoring for computer-free operation and a wide range of signal ports to adapt to different application needs. These features are key to being able to trigger the camera remotely and accurately. They also improve efficiency in outdoor, fast-paced environments. "Using the on-camera controls to set up and manage the images is quicker and so much more efficient," McIntyre says. "It lets me quickly move around and adjust things on the fly. Having to set everything up with computers would be so much more time-consuming."

THE TMX 7510 ULTRAHIGH-SPEED CAMERA

Leveraging the power of the new BSI sensor, the TMX 7510 — the fastest member of the Vision Research TMX series of ultrahigh-speed cameras — 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 camera, which uses groundbreaking BSI sensor technology, high-speed experts like Ryan McIntyre and his production team have been better able to balance their need for fast recording speeds, high resolution and adequate illumination — a combination that finds a natural home in high-speed combustion applications.

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

PHANTOM

VISION RESEARCH

AMETEK®
MATERIALS ANALYSIS DIVISION

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