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WHITEPAPER

LDX Series™ Cameras with Xensium-FT Imagers

A Superior Replacement for CCD Technology

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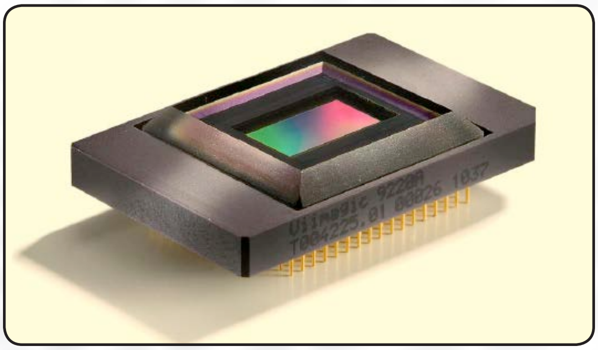
While CCD technology was the best choice for imagers in broadcast applications for many years, the latest generation of CMOS imagers now offers a range of advantages over CCD. This includes better sensitivity in progressive video modes today, and the potential for higher resolution, extended dynamic range, and higher frame rates in the future. CMOS is setting the new standard for high-end broadcast applications.



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LDX Cameras with Xensium-FT Imagers: A Superior Replacement for CCD Technology

Some may find the positioning posed in the title of this section a strong statement. Surely, CMOS imagers are widely used in many camera applications today, but in broadcast cameras they have not yet seen wide use.

Nearly all still cameras and camera phones have been using CMOS sensors for some years. So too, do the latest breed of 35 mm equivalent digital cinematography cameras. The commonality among these devices is that they offer very high resolutions and are based on single chip designs with color separation on the chip—usually by means of the Bayer pattern.

Grass Valley® believes the current generation of CCDs found in system cameras is the last, and they will be replaced by a new generation of CMOS imagers. Since its broadcast camera introduction in 1987, CCD technology has experienced significant development, but for some time, it has been clear that CCDs have reached their practical limits and large improvements cannot be expected.

Conversely, there is undisputable potential with CMOS imagers in broadcast applications for further improvements around faster readout of the imagers for super slow-motion applications, extended dynamic ranges, and higher resolutions. Up until now, these potential advantages have been offset by the disadvantages of the rolling shutter which was present with all CMOS imagers used in broadcast applications. These effects also have been over-exaggerated by some manufacturers, mainly because they need to protect their investments in their aging CCD technology. Additionally, most of the potential benefits of CMOS imaging technology were not yet applicable to broadcast applications.

Today, the technology landscape of CMOS imagers for broadcast has changed. The latest improvements in CMOS imaging have solved the rolling shutter issue. There is now a clear advantage toward CMOS imagers as a replacement for CCDs.

The new Xensium-FT imagers from Grass Valley are based on a 5T design of the pixels (see Figure 1). This permits the isolation of the exposure period from the transfer period. Because of this, the Xensium-FT imager provides what is called global shutter behavior, similar to all CCDs. The Xensium-FT imagers do not have any of the limitations of previous CMOS imagers with a rolling shutter, such as sensitivity to fast camera movements with short exposure time, and sensitivity to short light flashes. In this aspect, the new Xensium-FT imagers are not different from any of the best CCD imagers used today.

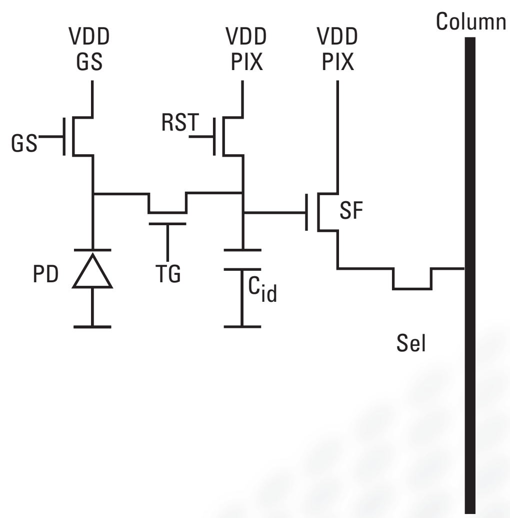


Figure 1 – *Xensium-FT CMOS imagers are based on a 5T design of the pixels.*

Advantages

What are the advantages of today's CMOS imaging technology over CCDs? The answer begins with what initially seems to be a distinct disadvantage of CMOS imaging technology.

CCD imagers have always offered the advantage of being able to add the signal charge of two adjacent pixels to double the signal charge. As CMOS imagers convert the signal charge into a voltage inside the pixel, this additive property cannot exist.

However, when addressing progressive formats, the problem shifts to CCD imagers, as they no longer have a combining charge, so a factor of 2 (one F stop) in sensitivity is lost. Additionally, the CCD needs a higher readout speed, where the CMOS is read out in parallel at lower speeds. Noise goes up with the square root of the bandwidth, so doubling this for progressive modes means losing an additional square root—or 3 dB—in noise performance, making a total of at least 9 dB.

Therefore in interlace modes, CCD imagers offer more than double the sensitivity when compared to progressive formats. With CMOS, the sensitivity in interlace modes and in progressive modes will be practically the same. Up until now, 1080i scanning modes have been used as the reference for sensitivity specifications, primarily because it showed the best figures for cameras which use CCD imagers.

In the future however, progressive formats (1080p50 or 1080p59.94) will become much more important, especially as the high-resolution formats of the future (such as 4k, 8k, and beyond) will only be implemented using progressive modes.

When used in 1080i, the new Xensium-FT imagers offer at least equal, if not better, sensitivity in most cases than any CCD imager on the market. But in progressive formats, Xensium-FT imagers offer a 6 dB improvement in the sensitivity over any CCD camera on the market. This single feature alone makes it clear that the end of life for the CCD technology in broadcast applications is upon us.

	Xensium-FT	IT CCD (typical)
1080i	F12	F11
1080p	F12	F8

Figure 2 – *F-stop sensitivity of the Xensium-FT imager as compared to an IT CCD imager.*

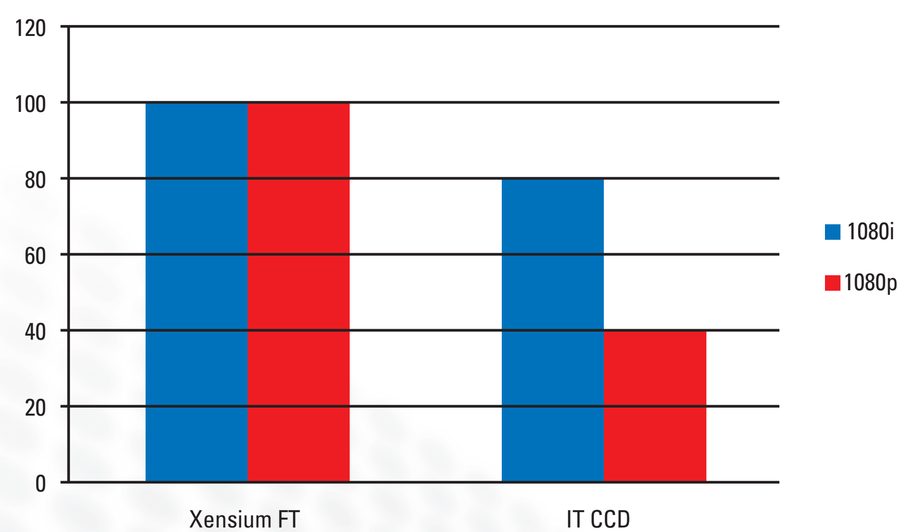


Figure 3 – *Relative sensitivity of the Xensium-FT imager as compared to an IT CCD imager.*

Sensitivity

Why are the new Xensium-FT imagers more sensitive when compared to today's currently used CCD imagers? It all starts with the quantum efficiency (QE) or incident photon to converted electron (IPCE) ratio. It is the percentage of photons hitting the device's photo reactive surface that produces charge carriers. QE is measured in electrons per photon or as a percentage which describes how many electrons are produced by photons hitting the surface. With current CCDs, this value is around 40%, whereas the new Xensium-FT imagers achieve a QE value of around 65%. In other words, much less light is needed to produce the same amount of signal charge.

This increased sensitivity has now been combined with the introduction of the global shutter, which solves the single point which could be used as an argument against CMOS imaging technology—the rolling shutter. Improved sensitivity in progressive modes now offers a clear advantages for CMOS imaging technology over today's CCDs.

CMOS & CCD Comparisons

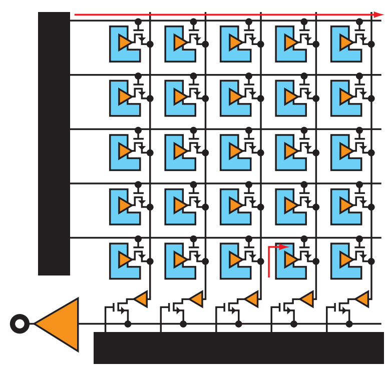
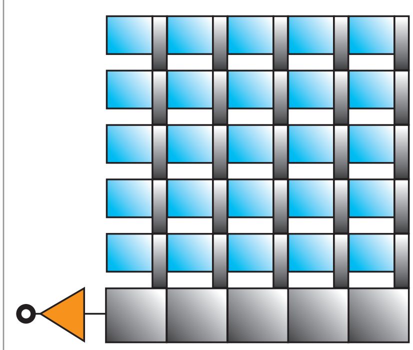
Design	Xensium-FT CMOS	IT CCD
CMOS – Grass Valley: • Low internal clocking speed • Direct addressing of pixels • No overflow • No lag • Multiple A/D converters, timing and read-out circuits integrated on chip **IT CCD:** • High internal clocking speed • Higher temperature • Vertical smear because of transport column in image section • External A/D converter • External driver and clocking circuits	 **Xensium-FT CMOS:** The charge of each pixel is sampled individually in each pixel and converted to a voltage. The voltages of each pixel are addressed through a matrix and sent to the output. This process does not need much energy. Low power consumption. Low heat.	 **CCD:** The charge of each individual pixel is moved through the CCD to a single sample and hold where it is converted from a charge to a voltage. This process needs a lot of energy and produces much heat.

Figure 4 – *Structure of Imagers.*

There is a fundamental difference between the structure of CMOS and CCD imagers. Most important is that the manufacturing process for CMOS is somewhat similar to the process of making memory chips. That means that CMOS imagers can be produced in many wafer plants all over the world and can be made in a very economic way compared to the dedicated process as needed to produce CCDs.

CMOS & CCD Comparisons (cont.)

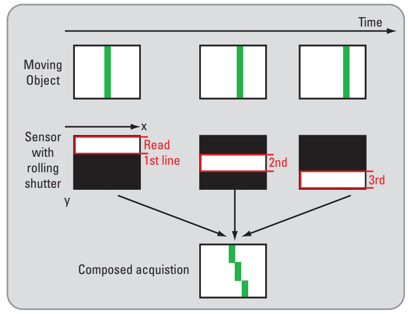
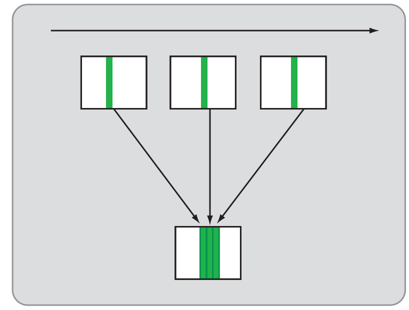
Design	Regular CMOS	Xensium-FT / IT CCD
There are two different types of exposure: Regular CMOS: Line-by-line scanning Xensium-FT / IT CCD: Frame exposure Each has its own characteristics.	 The rolling shutter of the regular CMOS imager produces images similar to scanning from a Plumbicon tube, because of line-by-line scanning. Shorter exposure times will increase the visibility of the skewing effect.	 The global shutter from the Xensium-FT imagers and IT CCDs will expose each frame for 1/50 or 1/60 of a second and show some blurring effects on fast moving objects. Shorter exposure times can be used to get sharper pictures, however this can create some shuttering effects.

Figure 5 – *Scanning Methods.*

The rolling shutter of the CMOS imager produces images similar to scanning from a Plumbicon tube, because of line-by-line scanning.

The global shutter from IT CCDs in broadcast cameras will expose each frame for 1/50 of a second and show some blurring effects on moving objects. Shorter exposure times for each frame are used (such as for sports) to get sharper pictures, however this creates some shuttering effects.

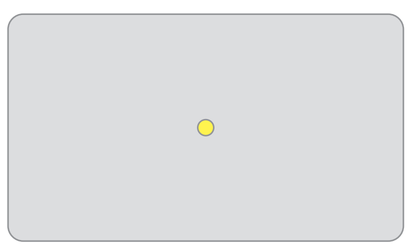
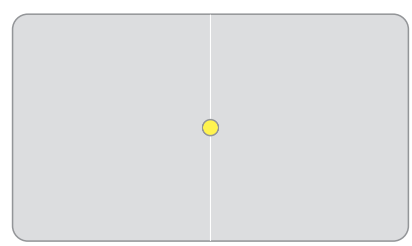
Circumstance	Xensium-FT CMOS	IT CCD
Indoor: • Spot lights • Shining jewelry Outdoor: • Shot into sun • Reflections on water	 No highlight smear under any condition.	 Specification of smear level is typically around -135 dB. But smear becomes much more noticeable when shorter exposure times are used: at 1/2000 sec. smear level is only around -100 dB.

Figure 6 – *Extreme Lighting.*

The difference in imager design will show a remarkable difference in performance under extreme highlight conditions. The IT CCD, because of its design with transport columns in the image part, will show overflow effects with highlights that are visible as white or even colored vertical stripes on top and under the highlight. A typical vertical smear level is -135 dB.

If IT CCDs are switched to short exposure times, such as for sports events in daylight conditions, this vertical smear effect can get really visible if there are highlights in the scene.

CMOS imagers, because of their structure, will never show any highlight smear or streaking effects.

CMOS & CCD Comparisons (cont.)

Figure 7 – *Strobe Flash (Medium Intensity).*

The rolling shutter of a regular CMOS imager and the global shutter of the Xensium-FT or IT CCD will show a different reaction to short light flashes. In a Xensium-FT or CCD, a strobe flash will show an effect in the frame during which it happened and it can be seen as one frame with an increased brightness. In a regular CMOS imager, the strobe flash will show an effect in the frame in which it happened as well as one following frame.

With a regular CMOS, the first frame will have increased brightness from the point when the flash occurred through the bottom of the image.

In the second frame, there will be an increased brightness from the top of the image until the point when the flash happened in the previous frame. This can easily be seen in still picture mode when moving from picture to picture. However, in a running video sequence with 50 or 60 fields/frames per second, this effect is almost invisible, being perceived as increased brightness in one complete frame (similar to Xensium-FT and CCD).

There is a more noticeable effect with a regular CMOS imager if short exposure times are used. In this case, the brightness of only a part of the image will be increased, and this can be more disturbing than a full frame of different brightness. Since reduced exposure times are used for sensitivity control in mobile phone cameras and some other low-end camera applications, this effect can be regularly seen from those devices. Reduced exposure times are hardly used in applications with system cameras.

CMOS & CCD Comparisons (cont.)

Xensium-FT CMOS	IT CCD
All cameras, for all applications will be designed only with CMOS imagers Potential for new developments are: • Fast readout • Higher resolutions • Extreme dynamic range The technical issue of the rolling shutter (which was never that big an issue in broadcast camera applications) has been solved entirely in the new Xensium-FT imagers	No new developments for CCD expected In time, there will be no CCD cameras available on the market

Figure 8 – *The Future.*

No major new developments are expected from manufacturers for CCDs. The performance of CMOS for broadcast cameras has improved greatly over the last few years and is now at a stage that broadcast customers are choosing CMOS technology for their new cameras.

Reported technical differences with CCDs are seen as non-issues in a practical broadcast environment.

Grass Valley will continue to improve CMOS-based cameras for the entire broadcast camera line.

Resolution

Another aspect of imagers is resolution. There is increasing discussion about 4K cameras. The Xensium-FT imager implementation compares favorably in this aspect as well.

Full 4K workflows are being evaluated for non-live applications such as cinema style productions. Several film productions have been done with such a workflow already. 4K is becoming an established cinema standard, and for the very large screens in cinemas the extended resolution of a true 4K RGB image offers a real advantage over 1920x1080 HD images. For a digital cinematography camera, the larger size imagers are not a disadvantage but even requested for artistic reasons as the so-called "film look" is the shallow depth of field which is achieved by larger sized imagers. In addition, prime lenses or zoom lenses with a very limited zoom ratios are mainly used for theatrical productions, and they can be built with a reasonable size and weight, even when used with larger imagers.

All of the available 4K cameras today use a single large-sized imager, whereas broadcast HD cameras use three 2/3-inch full HD imagers.

On a camera with a single imager, the color information is generated by separating the light by colored filters in front of the pixels. In most cases a Bayer pattern filter is used to accomplish this. There the 4,000 pixels per line which will be divided into 2,000 green pixels at every line and into 2,000 red pixels or 2,000 blue pixels at every second line. In other words, only one-half of the imager's resolution will be used for the green channel and only one-quarter of the resolution will be used for red and blue channels. Under certain conditions, aliasing artifacts can be created.

Using three 2/3-inch 4K imagers will result in a significant loss in sensitivity. Using three large-sized 4K imagers would require new lenses that would be prohibitively large in size and weight.

Xensium-FT imagers have full 1920x1080 pixel resolution and the separation of the three primary colors is accomplished with a prism beam splitter. Therefore, the full 1920x1080 resolution is available for all three channels—green, red, and blue—without any compromise.

Compared to the resolution of a single 4K imager camera that uses Bayer pattern color filters, a camera using three Xensium-FT imagers offers distinct resolution advantages, especially with the emerging use of 1080p for production. This two megapixel progressive format significantly increases resolution, and lends itself to being an excellent mastering format producing high-quality conversions to formats such as 4K, 1080i, and 720p. Therefore, for live broadcast applications, using Xensium-FT imagers will provide the best image resolution.

Conclusion

Although CCD imagers have been the standard for broadcast television production for many years, they have reached the end of their lifecycle, with no new technological developments expected.

The Xensium-FT imager is the first of a new generation of CMOS imagers which combines all of the positive characteristics of CMOS imaging technology with the global shutter behavior of CCD technology.

The real benefit is the picture. Xensium-FT imagers produce a better quality picture compared to today's CCDs—even under the most difficult lighting conditions.

Xensium-FT imagers: A superior replacement for CCD technology!

CAM-4086M