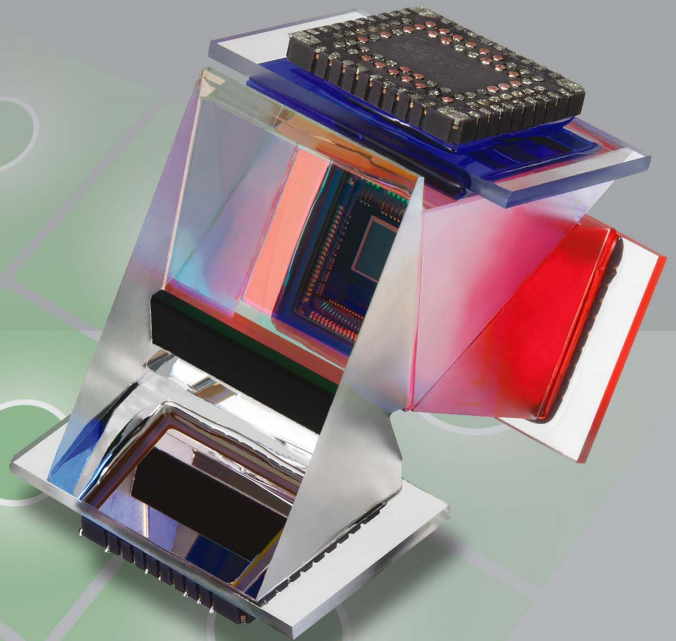


SONY[®]

ClearVid CMOS Sensor™
3 ClearVid CMOS Sensor™

Technology Guide



 **ClearVid**
CMOS*sensor*

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The Age of CCDs, and the Advent of High Definition

Today's digital imaging devices use semiconductor imaging sensors to capture images. Two sensor types are currently in use: CCD (charge-coupled device) and CMOS (complementary metal oxide semiconductor).

Although CMOS technology appeared on the scene first, CCD technology soon superseded it. Once initial problems were solved, CCDs offered better image quality and quickly became the technology of choice for digital video cameras, where quality concerns were paramount.

Sony took an early lead in the development of CCDs. Today, Sony's unrivalled development capabilities continue to drive ongoing advances in sensor technologies.

In the early days, CCD sensors suffered from significant levels of fixed pattern noise (FPN). Sony's development of HAD (hole-accumulation diode) technology overcame this problem, making CCDs viable for video applications and accelerating the move away from conventional pickup tubes. Sony soon followed through with other crucial breakthroughs, including the development and commodification of FIT (frame interline transfer) implementations to reduce smearing, and the incorporation of on-chip lenses to boost sensitivity.

With the advent of High Definition devices, CCD sensors were suddenly called upon to process six times as much information as before. The required pixel count jumped to about 2 megapixels, and-perhaps more importantly-the higher data volume and faster processing speeds drew considerably more power. As CCD sensors work best at low temperatures, heat generation became a major issue, and it became necessary to build in heat pipes and cooling fans to prevent overheating. (These cooling methods are still employed for CCDs used for astronomical observation.)

In recent years, broad advances in micro-fabrication technologies have enabled new low-powered designs throughout the semiconductor industry. This trend is particularly noticeable in the area of computers, where it is responsible for constantly rising CPU speeds. But it has also enabled the development of cooler and smaller CCD sensors for HD applications.

The Return of CMOS

Until quite recently, the consensus was that CMOS sensors could not match the image quality of CCDs. But breakthroughs in semiconductor fabrication technologies, together with advances in mass production techniques, have restored CMOS sensors to commercial viability.

The popularity of camera-equipped mobile phones played an important role in this development. The 680 x 480 low-resolution CCDs on early phone cameras were intended more as add-on features than as serious camera replacements. But pixel counts soon started rising in pace with higher display resolutions and growing storage capacities. Because CMOS sensors are easier to produce and can run on lower power, they were especially suited to this growing mobile phone market. Consequently, it was here that they began to stage their reappearance.

Backed by new technologies and years of accumulated expertise, CMOS design now began to improve at a rapid pace. Today, CMOS sensors are suitable for use in high-grade digital SLR cameras and professional camcorders, where they offer picture quality that meets or exceeds the capabilities of CCDs.

CCD and CMOS Compared

CCD and CMOS sensors both utilize photodiodes to convert incident light into the electrical signals that are used to recreate the image. Internal operation is quite different, however, as described below.

With a CCD, incident light at the photodiode area of each pixel is converted into an electric charge. The pixel charge moves into a vertical “conveyor belt” located at the side of the pixel, and an applied voltage then moves the charges along the vertical and horizontal conveyor belts until they pass through an amplifier and are converted into an electrical signal. (See Fig. 1) This design is susceptible to a problem called smear, which occurs when strong incident light leaks into the vertical conveyor belt and generates an excess charge that shows up as a bright vertical streak on the image. The design also requires high voltages to repeatedly open and close the gates that must be included on all pixels to control the timing and sequence of the charge outflow. Power consumption is particularly high for HD implementations (such as 1080p), where rapid readout of large numbers of pixels is required.

In CMOS sensors, an amplifier at each pixel immediately converts the pixel’s charge into an electrical signal, which then flows to the outside (Fig. 2). The problem with smearing is eliminated, as the electrical signal is unaffected by incident light (Fig. 3). In place of gates, the CMOS sensor uses switches and internal circuitry to control the signal outflow sequence. This use of internal switches significantly lowers the power requirements, while at the same time facilitating simultaneous readout of multiple pixels. Readout capability is therefore quite sufficient to support progressive HD imaging. On implementations using a single CMOS sensor chip, it becomes possible in principle to read out the R, G, and B signals simultaneously.

Because CMOS sensors offer low-power operation and rapid readout capability, they are well suited for use in the high-resolution cameras of the HD age. They are especially useful for HDV cameras, as they fully support compact size, low power consumption, and high-quality imaging.

Fig. 1 Structure of a CCD Sensor

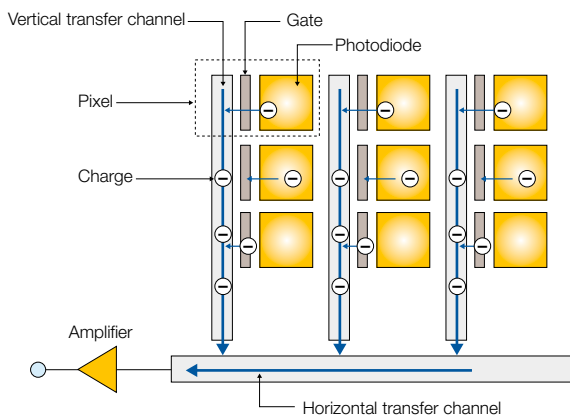


Fig. 2 Structure of CMOS Sensor

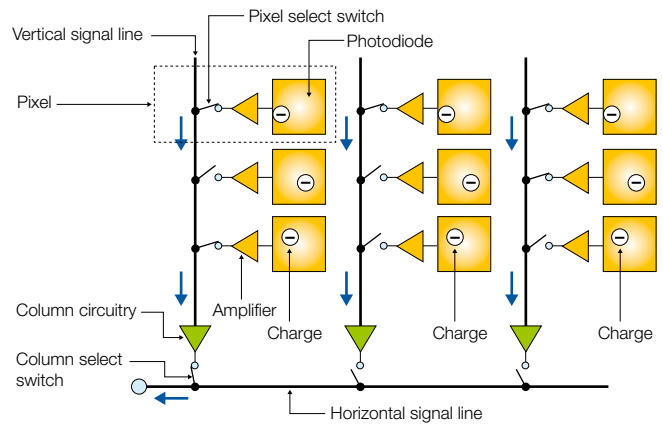


Fig. 3 Smearing



CCD shows smearing (vertical streaking) in very bright areas.



CMOS is not affected by smear.

*The image is simulated.

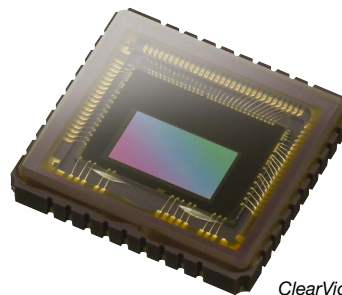
ClearVid CMOS Sensor™ and Pixel Interpolation

ClearVid CMOS Sensor Pixel Array Offers Higher Per-Pixel Area

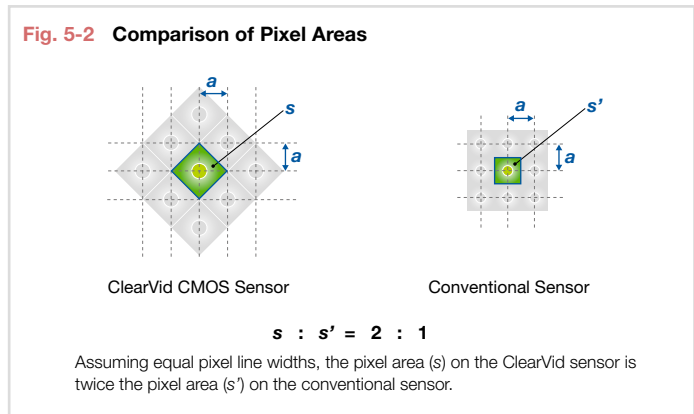
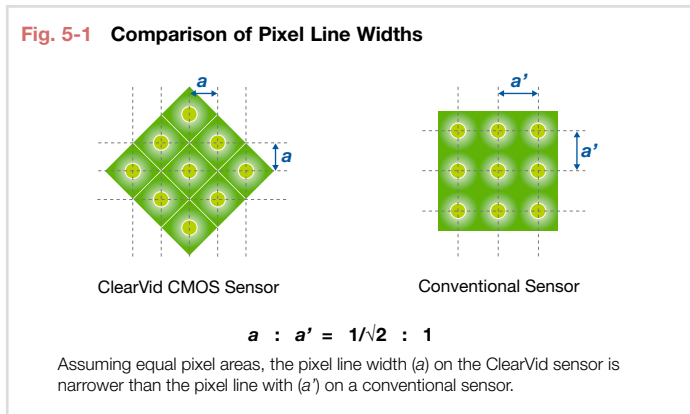
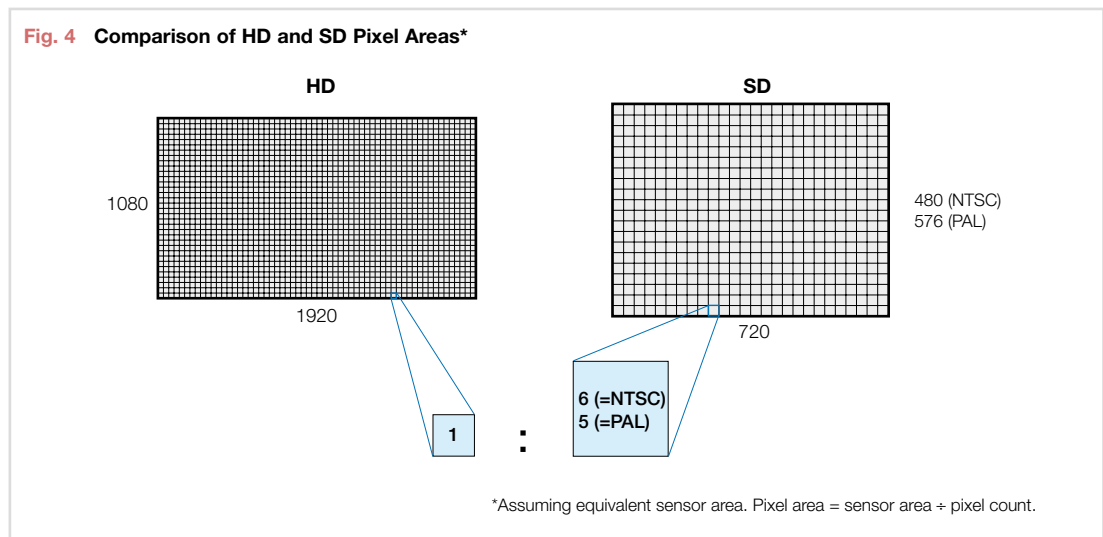
Pixel area has a considerable impact on performance. Because larger pixels have larger photoreceptive areas, they provide greater sensitivity and allow pictures to be taken even under poorly lit conditions. But the trend toward higher resolutions places limits on the pixel size. A true high-definition (HD) sensor has on the order of two million pixels, meaning that per-pixel area will be only 1/5 to 1/6 that of a standard definition (SD) sensor of the same size. Accordingly, the HD sensor will have that much lower sensitivity (Fig. 4).

Note also that some portion of the sensor area is consumed by non-photoreceptive transmission circuitry. CCD sensors are at a disadvantage in this respect, as they require relatively wide charge transmission channels that must be placed directly next to the pixels—requiring, in turn, that pixels be arranged in a rectangular grid. CMOS sensors, in contrast, use slimmer signal lines that can be arranged more flexibly on the chip, allowing for alternative pixel arrangements. Sony has taken advantage of this alternative in designing the ClearVid CMOS Sensor, where pixels are positioned diagonally.

This 45-degree rotation reduces the pixel line width by a



ClearVid CMOS Sensor



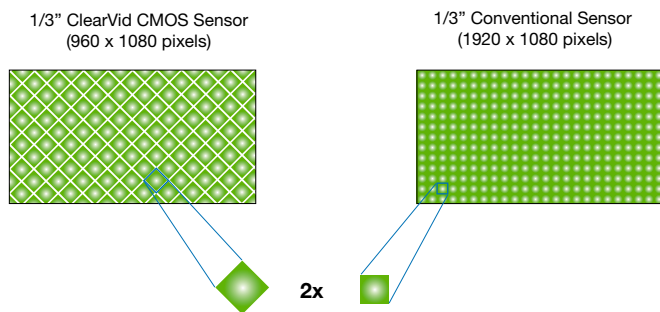
factor of $1/\sqrt{2}$, allowing for a higher-density array. This, in turn, also means that the ClearVid CMOS Sensor offers a per-pixel area that is twice that of a conventional sensor having the same pixel line width. (See Figs. 5-1 and 5-2) In short, the use of a rotated array allows the ClearVid CMOS Sensor to deliver more area per pixel.

A 1/3" ClearVid CMOS Sensor, with a 960 x 1080 pixel array, has twice the per-pixel area of a conventional 1/3" sensor with a 1920 x 1080 array. Indeed, the per-pixel area of the ClearVid CMOS Sensor is equivalent to the per-pixel area on a conventionally arrayed 1/1.89" 1920 x 1080 sensor. In other words, the ClearVid CMOS Sensor design offers very large

per-pixel area relative to the size of the sensor itself.* (See Figs. 6-1 and 6-2) The ClearVid CMOS Sensor can therefore deliver high density and high sensitivity despite its small size. Note that the larger pixel area of the ClearVid CMOS Sensor supports higher sensitivity in two different ways: directly, by providing a greater area for light collection; and indirectly, by allowing for more effective use of on-chip microlenses. A microlens over each pixel captures light that would otherwise fall on dead area and directs this light onto the receptor (Fig. 7), boosting sensitivity. This micro-lens performance is significantly enhanced by the relatively large per-pixel area delivered by the ClearVid CMOS Sensor design.

* Calculations are based on theoretical values and do not take into account the relative sizes of circuitry and other dead area. Note also that the sensitivity of a camera or camcorder is determined not only by sensor area, but also by lens fabrication technologies, noise reduction technologies, signal processing design, and more.

Fig. 6-1 Compared Against Conventional Sensor Array (1)



The 1/3" 960 x 1080 ClearVid CMOS sensor offers twice the per-pixel area of a 1/3" conventionally arrayed 1920 x 1080 sensor.

Fig. 7 On-Chip Microlenses

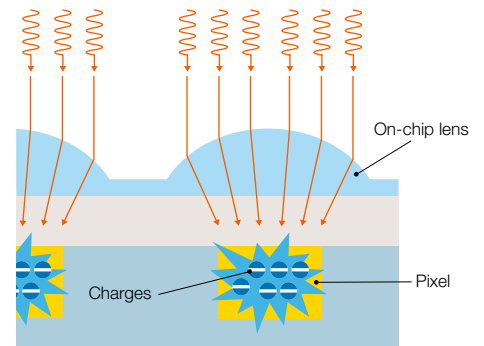
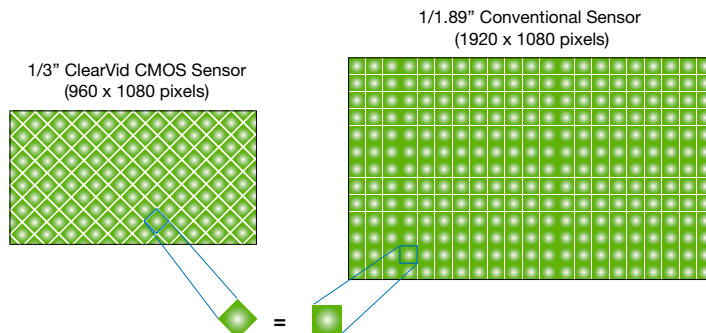


Fig. 6-2 Compared Against Conventional Sensor Array (2)



The 1/3" 960 x 1080 ClearVid CMOS sensor offers the same per-pixel area as a 1/1.89" conventionally arrayed 1920 x 1080 full-HD sensor.

Note: By convention, "1 inch" is equivalent to 16 mm when referring to sensors larger than 1/2", and to 18 mm when referring to smaller sensors.

Features of the 3 ClearVid CMOS Sensor

The 3 ClearVid CMOS Sensor system is comprised of three single ClearVid CMOS sensors. This system is currently used on Sony's HVR-Z7, HVR-S270, and HVR-V1 camcorders. Because the ClearVid CMOS Sensor uses a zigzag pixel layout, adjacent lines are offset by 1/2-pixel, as shown in Fig. 8. The arrangement might falsely suggest that the sensor is using conventional pixel offset interpolation technology. In fact, however, the 3 ClearVid CMOS Sensor design utilizes a more sophisticated interpolation system, as described below. In the conventional pixel offset interpolation approach, chips

are mounted on the prism such that the R and B chips are offset by one-half pixel relative to the G chip. Each pixel, therefore, contributes to two signals. This is shown in Fig. 9, where the G pixel contributes to signals $G+R1+B1$ and $G+R2+B2$. This technique nominally doubles the signal volume. In fact, however, meaningful improvements in resolution are achieved only in those areas where all three color signals are firing. This method does not produce impressive results when used with monochromatic subjects such as green lawns or red roses. (See Fig. 10) The 3 ClearVid CMOS Sensor takes a different approach that can provide maximum resolution regardless of the relative

3 ClearVid CMOS sensor

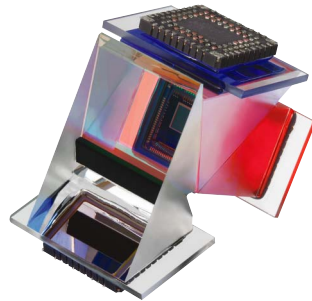


Fig. 8 Pixel Arrangement of the 3 ClearVid CMOS Sensor

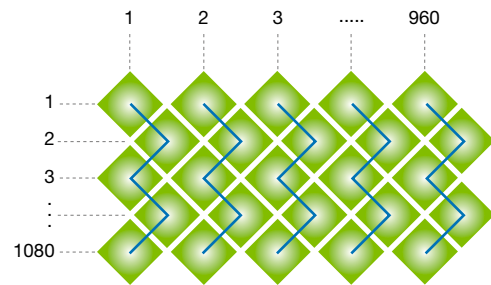
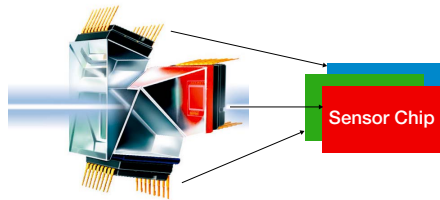
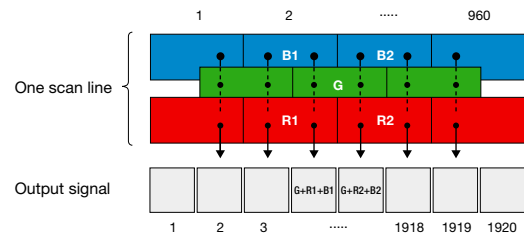


Fig. 9-1 Pixel Offset



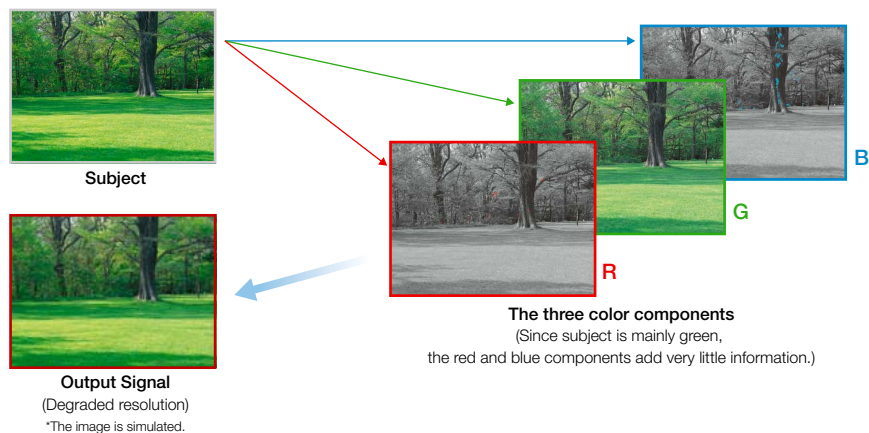
Sensor chips are mounted on the prism such that the R and B chips are offset by one-half pixel relative to the G chip.

Fig. 9-2 Principle of Pixel Offset



Each G pixel is associated with two R and two B pixels, resulting in the signal interpolation pattern illustrated above. Interpolation will be effective in increasing the resolution if all three color chips contribute information; that is, if the subject is richly colored.

Fig. 10 Interpolation by Pixel Offset



strength of the color signals. The 3 ClearVid Sensor delivers true HD resolution (1080 pixel lines) in the vertical direction, with 960 pixels in the horizontal direction. The horizontal resolution is increased up to full-HD resolution (1920 values) by interpolating a virtual pixel at each lattice point; this virtual pixel is created by the four surrounding real pixels. This interpolation is performed independently in each of the R, G, and B sensors; unlike the conventional approach, the effectiveness does not rely in any way on particular color mix. (See Figs. 11-1 and 11-2) The method works equally well with colorful subjects and with monochrome red, green, or blue subjects such as lawns and roses. Accordingly, camcorders that include the 3 ClearVid

CMOS Sensor offer superlative color resolution for all color combinations, as demonstrated in Fig. 12.

The interpolation processing described above is carried out within Sony's Enhanced Imaging Processor™. This processor makes it possible for the 960 x 1080-dot ClearVid CMOS Sensor to produce a 1920 x 1080-dot full-HD signal with superlative color reproduction.

The HRV-Z7 and the HVR-S270 both use 1/3" type 3 ClearVid CMOS Sensor system, while the HVR-V1 uses a 1/4" implementation. Note that the HVR-HD1000 uses the 1/2.9" type single-chip ClearVid CMOS Sensor. The 1/3" single-chip CMOS sensor on the HVR-A1 is not a ClearVid Sensor.



Enhanced Imaging Processor

Fig. 11-1 Interpolation Processing on the 3 ClearVid CMOS Sensor (1)

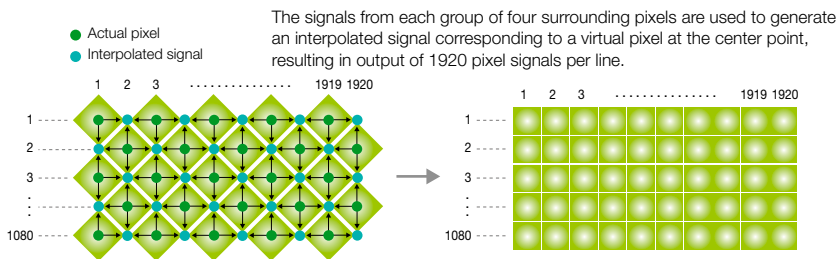
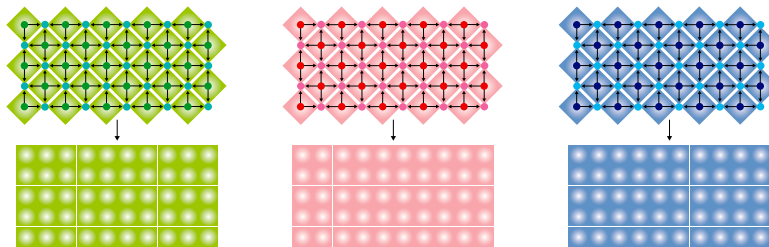


Fig. 11-2 Interpolation Processing on the 3 ClearVid CMOS Sensor (2)



Interpolation processing on the 3 ClearVid CMOS Sensor is performed independently on each chip (R, G, and B), assuring maximum resolution regardless of the subject's color mix.

Fig. 12 Comparison: 3 ClearVid CMOS Sensor vs. Conventional Pixel Offset



Sensitivity & Noise

Two general approaches are employed to enable the taking of properly exposed images under poorly lit conditions.

1) Improve the sensor performance

Sensitivity can be improved by raising the photoelectric conversion efficiency, increasing the pixel area, utilizing on-chip lenses, and taking other steps to improve sensor performance.

2) Amplify brightness electronically

Electronic brightness amplification can improve camcorder sensitivity, but it also amplifies the noise that is already within the signal, resulting in grainier images. The ability to suppress noise, therefore, can significantly contribute to camcorder sensitivity by allowing for the use of greater amplification levels.

Noise comes from various sources. Two typical noise sources are described below.

■ Fixed Pattern Noise

CMOS sensors have an amplifier at each pixel. A CMOS sensor in a high-definition device, therefore, contains well over a million amplifiers. It would be unreasonable to expect that all of these amplifiers will be exactly equivalent, as a certain degree of disparity is inevitably introduced during the production process. This non-uniformity among amplifiers results in a type of interference known as fixed pattern noise. Fortunately, this problem can be corrected by incorporating CDS (correlated double sampling) circuits to cancel this noise and restore the original signal.

■ Analog Noise

Where charge is transmitted in the form of an analog signal, the signal will pick up a certain degree of external noise during its travel. Noise will increase in proportion to the travel distance.

Exmor™ Noise Reduction Technology

Sony developed the new Exmor technology specifically for CMOS sensors. Under this system, an A/D converter is installed next to each pixel line (an arrangement referred to as column-parallel A/D conversion), so that the analog signals are almost immediately digitized.

In a conventional sensor, the analog signal generated by each pixel's amplifier must travel to a distant A/D converter (Fig. 13). Analog signals are very susceptible to noise, and become increasingly noisy the further they travel. Exmor brings the A/D converters much closer to the pixels, reducing the exposure to noise. The design also employs sophisticated digital CDS noise cancellation, which works by measuring the noise prior to conversion and then canceling the noise after the conversion. This new system, which operates both before and after conversion, is much more precise than conventional analog-only CDS implementations (Fig. 14).

As a result, camcorders with Exmor technology offer lower noise than those that use conventional HD CMOS sensors. This is especially significant under low-light conditions, where Exmor-equipped cameras perform very well.

This new Exmor noise reduction capability is included with the 3 ClearVid CMOS Sensor on Sony's HVR-Z7 and HVR-S270 camcorders. This new-generation CMOS implementation marks a significant advance over current designs.

For the detail information about Exmor, please also refer to "A Comprehensive Guide to CCD and CMOS Image Sensors Technology".

Exmor™

Fig. 13 Conventional Sensor

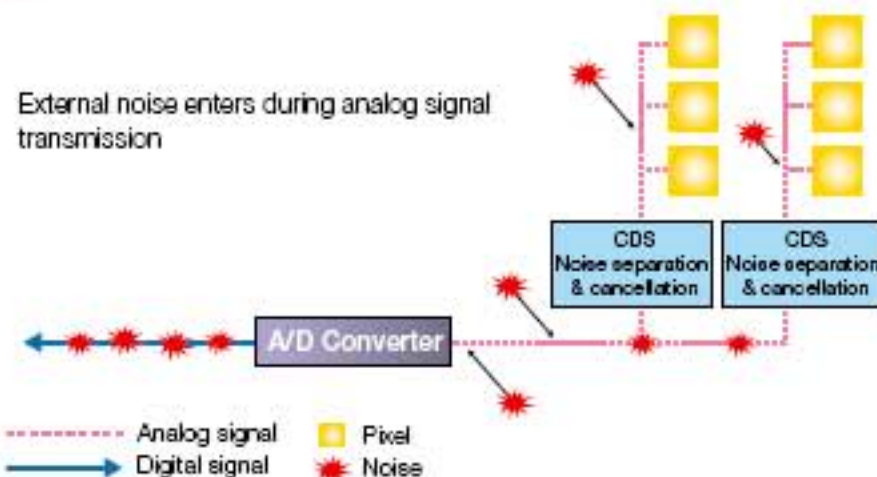


Fig. 14 Noise Cancellation with Exmor

