

FireWire cameras

Spectral sensitivity and color formats

At the "input" of a camera, we have a CCD chip. It transforms photons into electrons. The **spectral sensitivity** of this transformation is an important characteristic of the "camera input".

At the camera's output, we expect an image data stream with a color format, such as "Y800" for monochrome cameras, or "UYVY" for color cameras.

In this white paper, the input and output behavior of The Imaging Source FireWire cameras will be examined.

Please note:

- It is the responsibility of an on-site engineer to correctly integrate FireWire cameras into real applications.

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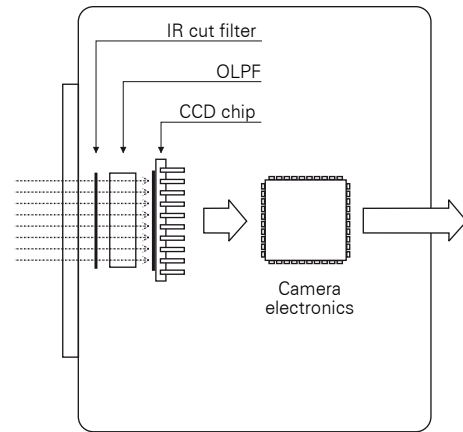
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All weights and dimensions are approximate.

Overview

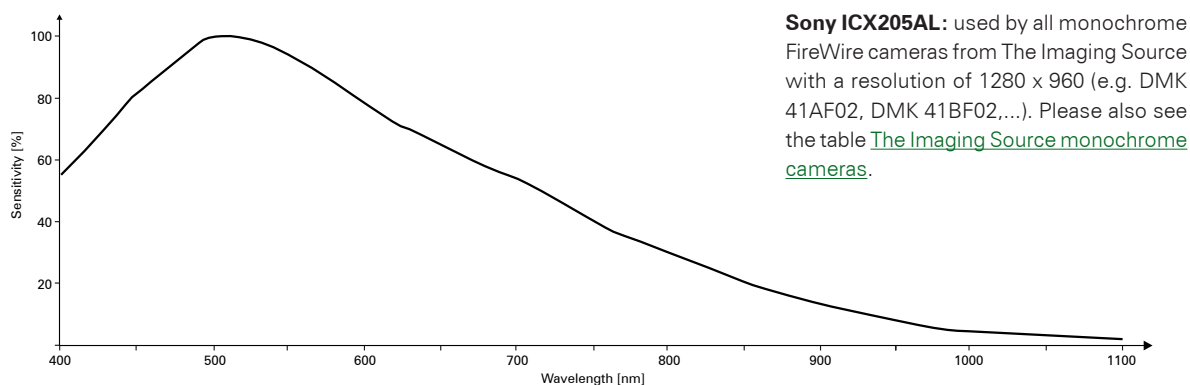
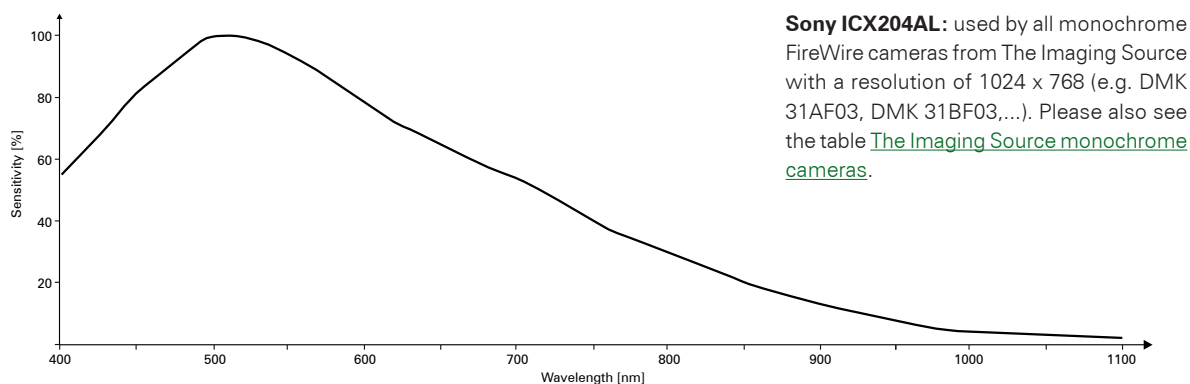
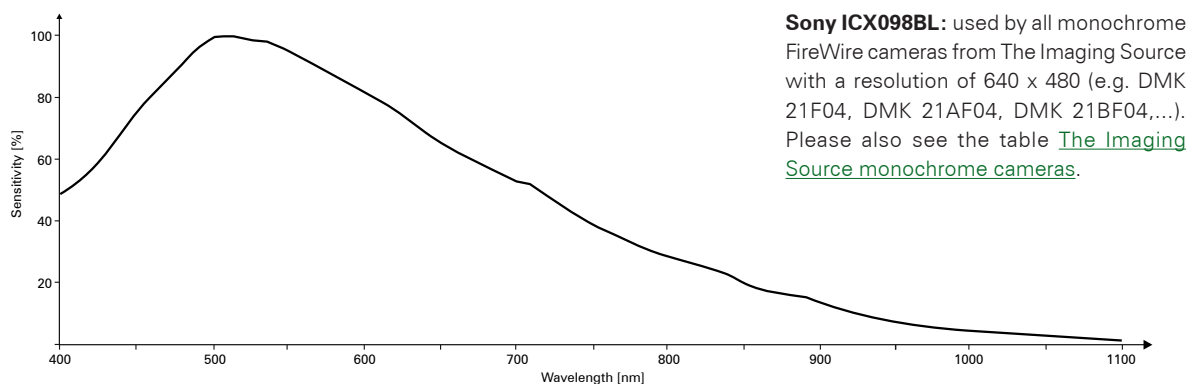
The camera's spectral behavior is determined by the following four components:

- The CCD chip transforms photons into electrons (photoelectric effect). A Bayer filter **inside** the color CCDs is responsible for the creation of colors (please see [CCD chips \(color\)](#)).
- In contrast to the human eye, CCD chips are also sensitive to near infrared light. In the case of color cameras this would lead to a predominance of red. An [IR cut filter](#) corrects this situation. However, cameras without IR cut filter provide more flexibility because they enable the users to apply their own filter depending on the particular requirements.
- If the object that is to be acquired shows fine and regular structures, moiré patterns may occur in the resulting image. An [optical low pass filter \(OLPF\)](#) reduces this effect.
- The camera electronics enhance the CCD chips' raw data. This enhancement can be controlled by adjusting different parameters (to learn more about this topic, please see the white paper [Camera Parameters - Maximizing the Image Quality](#)). In this white paper, the [color formats](#) created by the camera electronics are discussed.



CCD chips (monochrome)

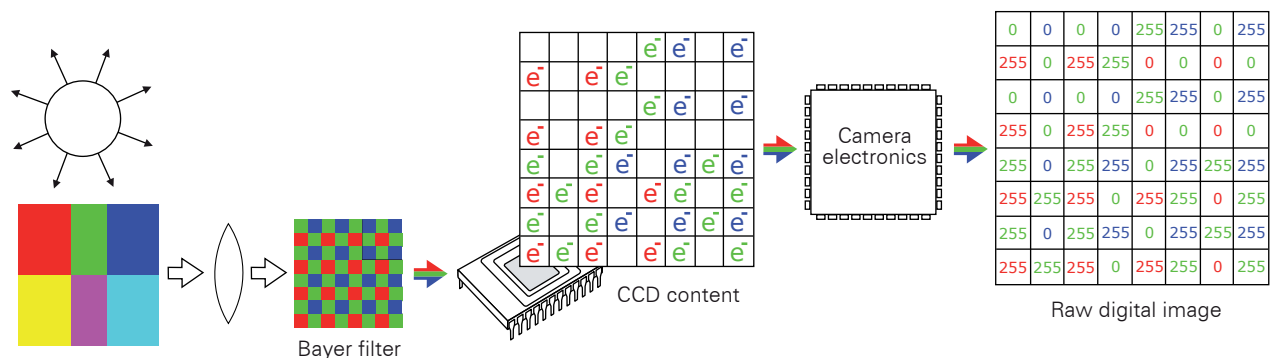
The Imaging Source uses three Sony CCD chips for its monochrome FireWire cameras. The spectral diagrams have been taken from the manufacturer's data sheet. Please note that the manufacturer does not specify deviations to the specified values.



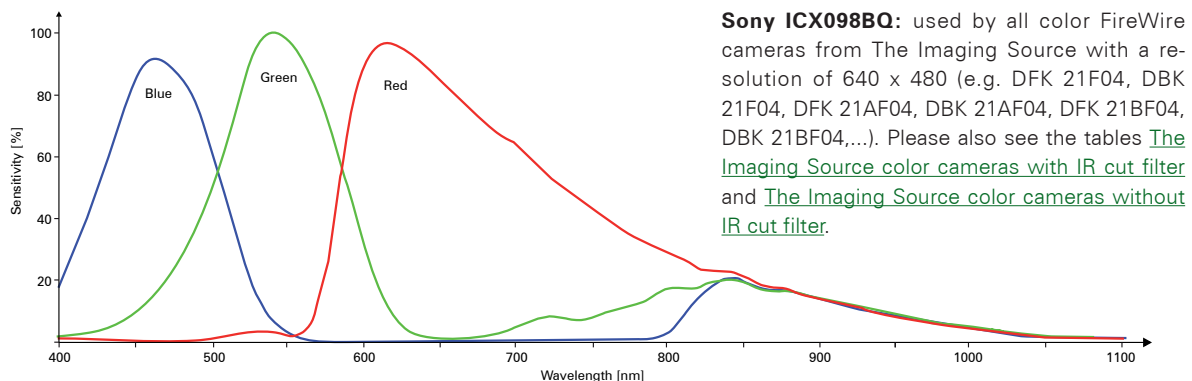
CCD chips (color)

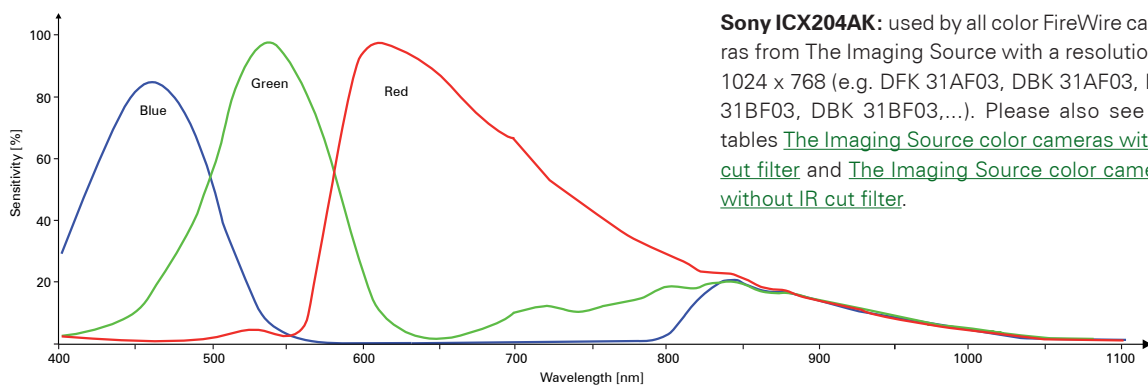
CCD chips convert photons into electrons due to the photoelectric effect. Unfortunately, during this process important information gets lost: the photon's wavelength. Thus, CCDs are "color-blind". In 1976 Bryce E. Bayer obtained the US patent 3,971,065 for the solution of this problem. He equipped every second pixel with a green filter and distributed blue and red filters evenly to the remaining pixels. Because of this mosaic-like arrangement a Bayer filter is also called mosaic filter.

Thus, with the aid of these filters, the pixels do not only provide luminance values but a pixel is more or less red, green or blue. The following spectral diagrams illustrate the meaning of "red", "green" and "blue" in case of the CCDs used by The Imaging Source.

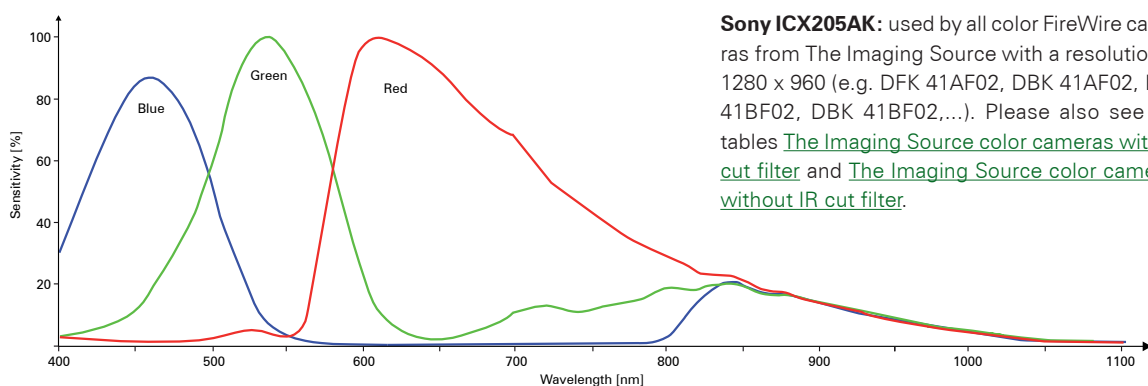


The Imaging Source uses three Sony CCD chips for its color FireWire cameras. The spectral diagrams have been taken from the manufacturer's data sheet. Please note that the manufacturer does not specify deviations to the specified values.





Sony ICX204AK: used by all color FireWire cameras from The Imaging Source with a resolution of 1024 x 768 (e.g. DFK 31AF03, DBK 31AF03, DFK 31BF03, DBK 31BF03,...). Please also see the tables [The Imaging Source color cameras with IR cut filter](#) and [The Imaging Source color cameras without IR cut filter](#).



Sony ICX205AK: used by all color FireWire cameras from The Imaging Source with a resolution of 1280 x 960 (e.g. DFK 41AF02, DBK 41AF02, DFK 41BF02, DBK 41BF02,...). Please also see the tables [The Imaging Source color cameras with IR cut filter](#) and [The Imaging Source color cameras without IR cut filter](#).

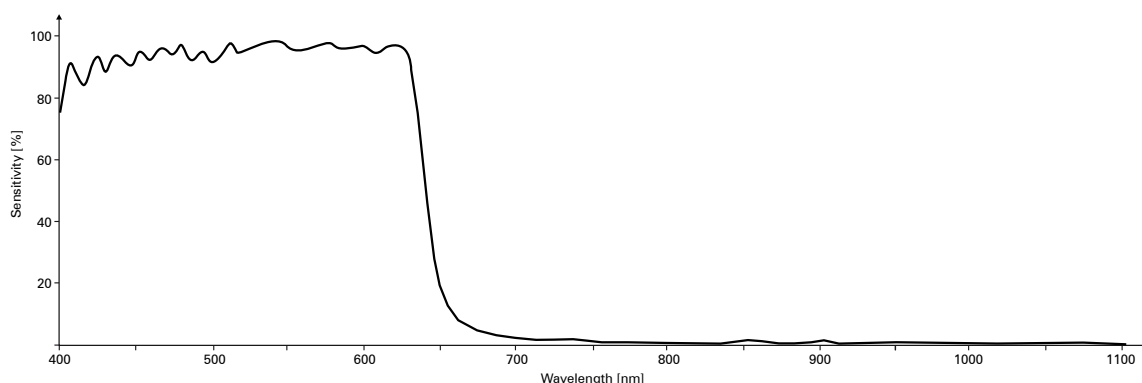
IR cut filter

In contrast to the human eye, CCD chips are also sensitive to near infrared light (NIR). Daylight as well as the light emitted by filament lamps show a significant amount of NIR. There are two main reasons to protect CCD chips from being influenced by the NIR:

- Lenses (or other optics) that are not IR-corrected "process" the NIR incorrectly, and thus, would decrease the image quality.
- In the case of color cameras the NIR would lead to a predominance of red. Correct white balance would not be possible.

For this reason many manufacturers equip their cameras with an IR cut filter.

Ideally, an IR cut filter should be completely transparent for the visible part of the spectrum, while blocking all IR light. The following diagram depicts the actual behavior of the IR cut filter used in The Imaging Source FireWire cameras:



Please note:

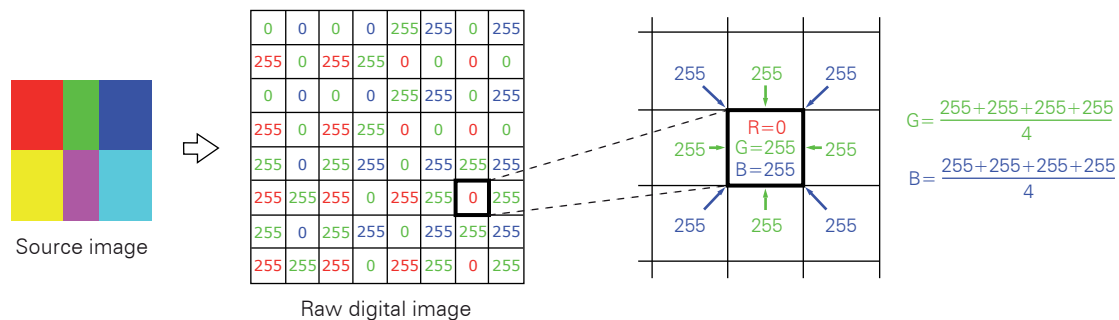
Cameras without IR cut filter provide higher flexibility because they enable the users to apply their own filter depending on the particular requirements. Thus, The Imaging Source does not equip its own monochrome FireWire cameras with an IR cut filter. Additionally, The Imaging Source offers a series of color FireWire cameras without IR cut filter. The product code of these cameras starts with "DBK".

Color interpolation

In the chapter "CCD chips (color)" we got to know the Bayer filter (also called mosaic filter) as a simple method to realize color CCDs. Due to its simplicity, the vast majority of color CCDs is based on this method. However, there is one crucial drawback: a pixel can only represent one color, that is either "red" or "green" or "blue". The format of this image is called "RAW".

Naturally, we expect a pixel to provide all three colors. The missing two colors of a pixel are created by the so-called color interpolation. Other names are "color space interpolation", "demosaicing" and, especially in case of the digital photography, "RAW conversion".

The following image outlines a simple but effective method of color interpolation, the so-called "bilinear interpolation". It is based on the mean values of neighboring pixels:



The increasing use of digital cameras led to the idea to interpolate colors in the computer instead of inside the camera. There are three basic advantages:

- The amount of data of RAW color images equals that of monochrome images. Therefore, such color images can be transferred just as fast as monochrome images.
- There are various methods of color interpolation. Executing them by the computer, the user is free to use any interpolation method.
- From the point of view of image analysis, color interpolation would be a completely unnecessary manipulation of measurement data (the raw image).

Therefore, all The Imaging Source color FireWire cameras - except the low cost series Dxx 21F04 - allow color interpolation to be switched off. The user simply selects the color format BY8 (RAW) for this purpose. All The Imaging Source software shipped with the cameras is compatible to this RAW format and offers various methods of color interpolation.

Please note: Digital photography increasingly makes use of the RAW format. At first glance these images seem to be much bigger than the interpolated ones. Actually, these images are not only interpolated but also compressed (JPG). Leaving these interpolated images without compression, they would become bigger as the RAW images..

Details may be studied in the white paper [How Color Cameras work](#).

Optical low pass filter (OLPF)

Fine and regular structures in the object that is to be acquired may lead to moiré effects in the resulting image. An OLPF reduces this effect, but causes slightly blurred images.

Please note: Moiré effects may also be reduced by slightly defocussing the lens. The basic advantage of an OLPF that is integrated in the camera is the easy handling. Independently of the lenses setting there is always a protection from moiré effects - but there are also always slightly blurred images. Thus, the use of any high quality optics makes almost no sense.

Therefore, The Imaging Source only uses OLPFs in the low-cost color cameras DFK 21F04, DFM 21F04 and DFM 21F04-ML (please also see the table [The Imaging Source color cameras with IR cut filter](#)).



Original image without moiré effect



Moiré effect



The OLPF's effect

Color formats

Color formats define the coding of the information "color" in a digital image data stream. Unfortunately, this coding lacks standards and thus there is a vast number of such formats. Often they only differ in their names. The Imaging Source color formats are based on the nomenclature described on the web site www.fourcc.org.

Monochrome cameras

The Imaging Source monochrome FireWire cameras use the format Y800. It provides 256 graylevels per pixel.

Color cameras (color interpolation switched off)

From a pure technical point of view, cameras running in this mode also offer the format Y800. However, unfortunately this term often leads to a fundamental misunderstanding: although running "traditional" color cameras (as for instance The Imaging Source low cost series Dxx 21F04) in monochrome mode, they execute the color interpolation but output the luminance values only.

Running modern The Imaging Source color cameras (Dxx 21AF04, Dxx 31AF03, Dxx 41AF02, Dxx 21BF04, Dxx 31BF03, Dxx 41BF02) in monochrome mode, color interpolation is switched off. In this case, the format Y800 indicates the output of the RAW digital image.

To avoid any misunderstanding, the **drivers** of The Imaging Source color FireWire cameras additionally offers the proprietary format BY8 (RAW). This format indicates to subsequent programs that the image's format is RAW.

Color cameras (color interpolation switched on)

If color interpolation is active, The Imaging Source color FireWire cameras use the format UYVY. It provides 256 graylevels (Y) for every pixel and alternating 256 color values (U) and 256 color values (V) for every second pixel.

The low-cost color cameras DFK 21F04, DFM 21F04 and DFM 21F04-ML additionally offer the format Y411. It provides 256 graylevels (Y) for every pixel and alternating 256 color values (U) and 256 color values (V) for every fourth pixel.

The Imaging Source monochrome cameras

The following table gives you an overview of the features of different The Imaging Source monochrome FireWire cameras:

Camera	Format	Resolution	fps	Trig	Int	OLPF	IR	CCD
DMK 21F04	Y800	640 x 480	30	-	-	-	-	Sony ICX098BL
DMK 21AF04	Y800	640 x 480	60	-	-	-	-	Sony ICX098BL
DMK 21BF04	Y800	640 x 480	60	✓	-	-	-	Sony ICX098BL
DMK 31AF03	Y800	1024 x 768	30	-	-	-	-	Sony ICX204AL
DMK 31BF03	Y800	1024 x 768	30	✓	-	-	-	Sony ICX204AL
DMK 41AF02	Y800	1280 x 960	15	-	-	-	-	Sony ICX205AL
DMK 41BF02	Y800	1280 x 960	15	✓	-	-	-	Sony ICX205AL
		fps : max frame per second Trig : trigger input and I/O Int : color Interpolation inside the camera OLPF : Optical Low Pass Filter IR : IR cut filter CCD : type of CCD chip						

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The Imaging Source color cameras **with** IR cut filter

The following table gives you an overview of the features of different The Imaging Source color FireWire cameras **with** IR cut filter:

Camera	Format	Resolution	fps	Trig	Int	OLPF	IR	CCD
DFK 21F04	UYVY	640 x 480	15	-	✓	✓	✓	Sony ICX098BQ
	Y411	640 x 480	30	-	✓			
	Y800	640 x 480	30	-	✓			
DFK 21F04*	UYVY	640 x 480	15	-	✓	-	✓	Sony ICX098BQ
	Y411	640 x 480	30	-	✓			
	Y800	640 x 480	30	-	✓			
DFK 21AF04	UYVY	640 x 480	30	-	✓	-	✓	Sony ICX098BQ
	BY8	640 x 480	60	-	-			
DFK 21BF04	UYVY	640 x 480	30	✓	✓	-	✓	Sony ICX098BQ
	BY8	640 x 480	60	✓	-			
DFK 31AF03	UYVY	1024 x 768	15	-	✓	-	✓	Sony ICX204AK
	BY8	1024 x 768	30	-	-			
DFK 31BF03	UYVY	1024 x 768	15	✓	✓	-	✓	Sony ICX204AK
	BY8	1024 x 768	30	✓	-			
DFK 41AF02	UYVY	1280 x 960	7.5	-	✓	-	✓	Sony ICX205AK
	BY8	1280 x 960	15	-	-			
DFK 41BF02	UYVY	1280 x 960	7.5	✓	✓	-	✓	Sony ICX205AK
	BY8	1280 x 960	15	✓	-			
		* : produced as of 07/2005 fps : max frame per second Trig : trigger input and I/O Int : color Interpolation inside the camera OLPF : Optical Low Pass Filter IR : IR cut filter CCD : type of CCD chip						

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The Imaging Source color cameras **without** IR cut filter

The following table gives you an overview of the features of different The Imaging Source color FireWire cameras **without** IR cut filter:

Camera	Format	Resolution	fps	Trig	Int	OLPF	IR	CCD
DBK 21F04	Y800	640 x 480	30	-	-	-	-	Sony ICX098BQ
DBK 21AF04	UYVY	640 x 480	30	-	✓	-	-	Sony ICX098BQ
	BY8	640 x 480	60	-	-			
DBK 21BF04	UYVY	640 x 480	30	✓	✓	-	-	Sony ICX098BQ
	BY8	640 x 480	60	✓	-			
DBK 31AF03	UYVY	1024 x 768	15	-	✓	-	-	Sony ICX204AK
	BY8	1024 x 768	30	-	-			
DBK 31BF03	UYVY	1024 x 768	15	✓	✓	-	-	Sony ICX204AK
	BY8	1024 x 768	30	✓	-			
DBK 41AF02	UYVY	1280 x 960	7.5	-	✓	-	-	Sony ICX205AK
	BY8	1280 x 960	15	-	-			
DBK 41BF02	UYVY	1280 x 960	7.5	✓	✓	-	-	Sony ICX205AK
	BY8	1280 x 960	15	✓	-			
		fps : max frame per second Trig : trigger input and I/O Int : color Interpolation inside the camera OLPF : Optical Low Pass Filter IR : IR cut filter CCD : type of CCD chip						