Introduction to Video
101
Second Edition

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**Introduction**

This document provides basic information about solid-state (semi-conductor based) video cameras used in industrial, scientific, medical, and defense applications. It discusses sensor types, video interfaces, and common camera features. If you have questions about cameras beyond the information provided here feel free to contract JAI’s technical staff at 408 383-0300 or 800 445-4444. Phones are normally answered from 8 a.m. to 5 p.m. Monday through Friday, except on holidays.

JAI has attempted to make the information contained here simple, but useful to all levels of camera users.

**Video Imaging**

A video camera is designed to capture an image – either a single “frame,” or a series of frames, over a period of time. Prior to solid-state cameras, video cameras used photosensitive “tubes,” similar to television or cathode ray tubes (CRT), to convert incoming light into an electronic signal that could be sent to a monitor or transmitter, or to video recorders which used magnetic “heads” to capture images on coated (magnetic) tape.

In the 1970s, a new style of video camera was born, in which images were captured by focusing incoming light on a semiconductor device containing rows of light sensitive areas called “pixels.” When combined with the rise of computers, these solid-state cameras provided users with the ability to digitally compare and analyze video frames, and to store a stream of images on computer memory through an onboard frame grabber.

**Light Sensitivity of Solid-State Cameras**

Modern solid-state cameras can capture images in a broad range of light conditions. It is possible to produce an image using a shutter speed of less than 1/800,000 second, or to leave a shutter open for many seconds to accumulate necessary light. Cameras are designed to work in both of these extremes. Examples would be a time exposure to photograph a dim star, or an extremely quick shutter speed to capture a bright explosion.

Video cameras also experience infra-red noise. Heat tends to lead to interference or artifacts on the image. Most modern video cameras are capable of operating ranges and image quality that compare to, or exceed, traditional film cameras.

JAI rates the sensitivity of its cameras using the lux unit of measure, which is based on the amount of light falling on a given area (1 lux = 1 lumen per square meter). This rating provides an indication of the minimum illumination level at which the camera can produce a reasonable image, and is determined by JAI without a lens attached to the camera. A lens with an aperture of f/1.4 reduces the specified sensitivity number by roughly a factor of 10. So, a camera rated at Lux $10^{-1}$ would perform at Lux 1 with an f/1.4 lens attached.
Solid state video cameras such as those made by JAI can accommodate a wide range of lighting conditions from bright sunlight for applications such as intelligent traffic systems, to specialized intensified cameras capable of capturing images in lighting conditions below $10^{-7}$ lux, also known as night vision applications.

**What is a Pixel?**

A *pixel* describes a single unit that contains a photo-sensitive area (or photodiode) on a solid-state image sensor. Different sensors have different numbers of pixels. Pixels may be arranged in a single line (line scan) or in multiple rows and columns (area scan). A typical pixel is very small. Pixels on the sensors used in JAI cameras can measure as little as 4.6 microns square (a grain of salt measures about 60 microns on a side). Note that not
all of a pixel’s area is necessarily light sensitive. Depending on the sensor architecture, a pixel often contains the light-sensitive photodiode (the element capable of electronically capturing incoming photons the way a bucket captures falling raindrops) and a variety of other circuitry, occupying as much as 70 percent of the total pixel area.

Although early sensors often had rectangular pixel areas, more recent cameras typically feature square pixels to allow users to rotate images without distortion, and to make pixel-based measurements without having to compensate for different X and Y pixel dimensions.

**Major Sensor Types**

Most solid-state video cameras use one of two major types of image sensors: **CCD** (charge coupled device) or **CMOS** (complementary metal oxide semiconductor). Both devices essentially do the same thing – convert light, or photons, into electrical energy, or electrons. However, the different manufacturing processes used to make these devices give each type of sensor various advantages and drawbacks, depending on the application.

CCDs are manufactured on dedicated production lines, while CMOS sensors can be manufactured on standard semiconductor lines. This gives CMOS sensors a price advantage, and also allows CMOS sensors to more easily incorporate on-chip signal processors, amplifiers and output circuitry. On the other hand, by using dedicated production lines, CCDs have, to date, been able to achieve better dynamic response (less noise) than their CMOS counterparts, resulting in better overall image quality for high-end, high resolution applications.

The rest of this document will focus primarily on CCD-based cameras, as this is the most prevalent type of solid-state camera currently being used for industrial applications.

**Linear Array CCD**

As noted earlier, a CCD may be designed with just a single line of pixels. These linear array CCDs, (also called line scan CCDs) are incorporated into line scan cameras that capture images of rapidly moving objects one line at a time. The line scan approach is often used for a fax machine or scanner. How does a line scanner work? It captures a single column of images, and adds row after row until the frame is complete. If a cylindrical object was turned in front of a line scan camera, it would create a flat (two dimensional) representation of the object.

An industrial use for a linear array CCD might be inspecting the printing on a bottle or can. Line scan cameras are also used to inspect fast moving “web” material, such as rolls of paper or sheet metal. And, by triggering the camera to start and stop image capture as an object passes it, line scan cameras can be used to capture images of passing boxes or other items, even though the objects may vary in size.
Area Array CCD

The area array CCD is different from the linear array CCD. Instead of a single row of pixels, the area array CCD uses light sensitive pixels to create a rectangular image capture surface. While the resolution of a line scan CCD might be expressed as simply “1024 pixels,” the resolution of an area array CCD is typically described by listing the number of pixels in the horizontal direction followed by the number of pixels in the vertical direction. Multiplying these two numbers yields the total resolution of the CCD. For example, if a CCD offers a resolution of 1392 x 1040 pixels, the total resolution can also be described as 1.4 megapixels (1.4 million pixels).

Area array cameras are the most common type of industrial camera in use today. Resolutions range from standard television formats (768 x 494 or 752 x 582) up to formats with four megapixels, five megapixels, or more. Aspect ratios, the relationship between the number of horizontal pixels and the number of vertical pixels, commonly include traditional 4:3 “TV format”, wide-screen 16:9, and square 1:1. As an example, a four megapixel camera with a square aspect ratio would feature a CCD image sensor with an array of 2048 x 2048 pixels.

CCD Architectures

When light falls on a CCD, an electric charge is built up in each pixel in accordance with the number of photons that strike the pixel. In order to create an image, however, these
electrical charges must be transferred out of the array to a video monitor or to a computer system for display or processing. Two basic architectures have been developed for moving the electrical charge out of the CCD. These architectures are called frame transfer and interline transfer.

**Frame Transfer CCD Architecture**

A frame transfer CCD features two adjacent arrays of pixels. One set of pixels is exposed to the incoming light, while the other array is shielded with an opaque material and used as a storage area. The exposed pixels of the sensor are allowed to build up a charge for a period of time called the *integration time*. This is the equivalent of the exposure time in a standard film camera. Once integration is complete, the charges are transferred from the active pixels to the storage area until all charges have been stored. The stored charges can then be read out of the CCD, in analog or digital format, while the active pixels are capturing the next frame of video information.

Because the storage area is located away from the image capture area, active pixels in frame transfer CCDs sacrifice only a small amount of space to non-photosensitive circuitry. For this reason, frame transfer CCDs are capable of a *fill factor* of close to 100% – which means that they are able to capture nearly 100% of the light that falls on each pixel. This makes the frame transfer architecture particularly good for low light applications. However, because of the distance between the active pixels and the storage area, frame transfer CCDs tend to be slower than interline transfer CCDs, and are also more susceptible to smearing, a degradation of the image caused by light striking the CCD during the transfer process.
In the illustration, each square represents a pixel. The arrows show the travel of photoelectrons to the storage area, and ultimately to the horizontal shift register.

**Interline Transfer CCD Architecture**

The *interline transfer CCD* (sometimes abbreviated as *IT*) is the most common imaging architecture in industrial video cameras. The interline transfer CCD includes the photodiode and the storage element as part of each pixel. This is accomplished by running a vertical shift register between each column of photodiodes—hence the term *interline*. The vertical shift register contains segmented storage areas for each active pixel, and connects to the active area by means of a transfer gate. A horizontal shift register at the bottom of each column collects the information from each vertical shift register. The information arriving at the horizontal collector of an area array CCD is timed so that it feeds sequentially to the processor, resulting in a continuous feed of correctly organized image packets for processing.

Because the storage area for each pixel is immediately adjacent to the photodiode in interline transfer CCDs, charges move more rapidly in the interline architecture than frame transfer CCDs. This enables cameras built around IT CCDs to minimize smearing, and to utilize higher shutter speeds.

Since the interline architecture supports extremely fast shutter speeds it has become prevalent in industrial applications where crisp imaging of moving objects is often critical. However, the transfer gate and vertical shift register circuitry consume a large amount of the pixel’s space, reducing the photodiode area, and lowering the potential fill factor to as little as 30 percent of the pixel. To compensate for this, interline transfer CCDs typically have small *lenslets*, or *micro lenses*, positioned above each pixel to
gather and focus as much light as possible on the photodiode portion of the pixel. Through the use of lenslets, IT CCDs are able to reach fill factors of 60 to 70 percent, which is more than sufficient for all but the most demanding low-light applications.

Interlaced Images

Interlacing was developed to allow flicker-free CRT displays. A CRT image is created by drawing “lines” of video information onto the screen from left-to-right and top-to-bottom, the same as lines of text on the page of a book. Early technology used for CRT image display was not capable of refreshing all the lines on a standard sized television screen fast enough to prevent the human eye from detecting flicker. As a result, a process called “interlaced scanning” was developed.

An interlaced image is made up of two fields. The odd field consists of all the odd lines on the screen, while the even field consists of all the even lines. Interlaced scanning alternates drawing the odd field, then the even field, at a frequency determined by the standard wall current (either 60 cycles per second or 50 cycles per second, depending on where you are in the world). Using this approach, a full frame of new video information requires both fields be drawn, resulting in a frame rate of either 30 frames per second or 25 frames per second. However, by alternating the odd and even lines at a much faster rate, the viewer is able to subconsciously combine the two fields to view a sharp, flicker-free, picture.
Interlaced Image Applications
Since the two fields of an interlaced image are scanned separately, although very close together from a time perspective, interlaced imaging is best for stationary, or slow moving objects. If no movement has occurred the image fits nicely together as a single whole. If movement has occurred it can result in blurred images, or a comb effect, such as in the illustration. This can be problematic in industrial applications where capturing clear images of moving objects is often a key requirement.

One method that has been developed to facilitate interlaced cameras in industrial applications is to use carefully-timed strobe lights to cause the odd field pixels and the even field pixels to be exposed at the same time. This enables interlaced scanning to produce a reasonably sharp image of a moving object. However, image integrators using interlaced scans for moving objects need to know some of the disadvantages of strobe lighting. Strobes tend to have short bulb life and the light source decays over time. There is also a risk of physiological effects on workers from the constant strobe lighting. It is usually necessary to shroud the inspection area to protect workers and prevent ambient light from degrading the camera image.

Benefits of Interlaced Image Transfer
Because image standards were developed before the digital age, and carried over into the earliest digital imaging efforts, interlaced image capture is widely supported. Interlaced cameras, frame grabbers, video recorders, and monitors are all readily available, easily interface with each other, and comply with accepted standards. Since interlacing is a mature technology, interlaced cameras are generally less costly.
Progressive Images

Progressive image transfer, or progressive scanning, exposes the entire CCD array at the same time, and transfers the information sequentially to the processor or display. Progressive scanning is the method used to display video information in many new high-definition television sets. With progressive image transfer, it is not necessary to reassemble partial images into a frame with the accompanying risk of blurring and combing. Modern technology allows a full frame to be captured and redrawn fast enough so that no “flicker” is detected.

Benefits of Progressive Image Transfer

The obvious benefit of progressive scanning is that it alleviates the previously described problems with interlaced scanning and moving objects. Progressive scanning is also better suited to the use of high-speed shuttering for capturing clean images of fast moving objects. This is because progressive scanning exposes all pixels at once. So, even in the case of a very short shutter period, progressive scan CCDs capture a full image, where interlaced CCDs produce only odd or even lines.

One drawback of progressive scan output is that it is typically incompatible with standard television monitors for real-time display. However, since most machine vision, medical, and scientific applications today utilize computer-based processing, real-time display is achievable, or multiple images are captured and compared in the computer’s memory, with frames or image montages being displayed on the computer screen only when needed.

Because they can support higher resolutions and different aspect ratios, and can provide direct digital output to computer-based processing systems without the time consuming processing required by traditional interlaced output, progressive scan CCDs are being used as the basis for the vast majority of new solid-state video cameras being built today.

Color Imaging

As previously described, a photodiode in a solid-state image sensor responds proportionally to the amount of light that strikes it. This is true regardless of the color (wavelength) of the incoming light. Thus, a basic CCD is only capable of producing black and white (monochrome) images. In order to produce color images, several different methods have been developed.

Color Filter Array Imaging

The most common method for color CCD imaging is the use of a color filter array (CFA). CFA imaging uses an array of red, green, and blue filters arranged in a pre-defined pattern (mosaic). This filter array is placed in front of the pixels, causing each pixel to become sensitive to only one of these three colors. An RGB color value for each pixel is then estimated by looking at the pixel’s own value, plus the values of a small group of surrounding pixels. This process is called interpolation and can be performed inside the camera, or by application software running on a host computer.
interpolation software needs to be configured for the specific filter pattern being used, the most common being the “Bayer” pattern, which features twice as many green pixels as red or blue pixels in order to simulate the color sensitivity of the human eye.

3CCD Color Imaging
The 3CCD color imaging method uses an elaborate prism with three identical and precisely-aligned CCD sensors attached. The prism breaks the incoming light into three color bands which are then directed to each of the CCDs. By outputting the values from the same pixel location on each of the CCDs, an accurate RGB value can be derived for every pixel in the image. The 3CCD method is a much more accurate color system than interpolation, but it requires a larger camera housing and uses unique hardware which is more costly and difficult to assemble.

![Color Line Scan Imaging](image)

Color Line Scan Imaging
The previous examples referred to the color imaging methods used with area array CCDs. Several different methods have also been developed for use with line scan CCDs.

3CCD Line Scan Color
The first method is the 3CCD approach. This is virtually identical to the 3CCD approach used for area array CCDs, with the only difference being that the CCDs attached to the prism structure feature only a single line of active pixels. As before, the use of the prism ensures that each CCD is seeing the image through the same optical plane, with no compensation required for focal distance or angle of view. This makes 3CCD line scan cameras capable of being used in web inspection applications, as well as a wide variety of conveyor belt applications, where precise color values are required.
Tri-Linear Line Scan Color
A second method for producing color line scan images is the *tri-linear* approach. A tri-linear line scan camera uses a single CCD with three separate lines of active pixels. Filters are used so that each line of pixels captures either red, green, or blue color wavelengths. Unlike 3CCD cameras, the spacing of the three lines of pixels means the tri-linear CCD views the image through three different optical planes and that each line of pixels “sees” the same line at a slightly different time than the other lines. This requires precise compensation for both the speed of the object being imaged and the focal distance of each optical plane. When these variables can be controlled (such as in a typical web application where the camera is placed perpendicular to a flat surface), the lower cost of the tri-linear sensor makes this approach a reasonable alternative to 3CCD line scan cameras. However, when objects must be viewed at an angle, or when surfaces being inspected have varying topographies, the tri-linear approach becomes unacceptable due to parallax problems caused by the multiple optical planes.

Image Transfer and Timing Standards
At one time video was tied to the RS-170A standard, which is the standard black and white video format used in the U.S. This standard predated the solid-state camera. It was defined by the EIA (Electronic Industry Association) as 525 lines at 30 frames per second using interlaced scanning. The RS-170A television standard was used primarily in North America, parts of Japan, and a few other locations in the world.

The CCIR standard covers most of Europe. It uses a 625 line and 25 frames per second interlaced format. The color portion of the video signal used to broadcast the color information part of the television signal is covered by the NTSC (National Television Systems Committee) in the USA, and PAL (phase-alternating line) in Europe.

Outside of the television formats no standard was universally adopted until the High Definition Television (HDTV) standard. Although standards for television are generally accepted, machine vision (or industrial video) has taken a different route, with no common standards currently in place to define output or timing options.
The industry’s first non-television format camera was designed by PULNiX, and featured a 768 X 494 resolution, using an interline progressive scan CCD. It was the first non-interlaced progressive output camera, and the first 8-bit digital output camera relying on differential RS-422 for its output standard. However, PULNiX did not deviate much from the television format; the camera had onboard memory and could be configured to television format and interlaced output with the flick of a switch. This allowed traditional RS-170 users to get progressive scan (full frame) images on the CCD and reformat them in memory to interlace each field out. This allowed the use of traditional television monitors or frame grabbers (plug-in acquisition boards designed to take video camera output and reformat it for processing and display by a computer). The progressive scan output pushed industrial video camera out of the television standard and gave designers freedom to try a variety of new formats.

Cable and Output Compatibility

At the same time that new output formats were being investigated, development was taking place on new standards for physically connecting and moving the image information from the camera to processing devices.

The first digital progressive scan cameras produced RS-422 8-bit output. RS-422 is a differential output. This output uses a twisted pair cabling scheme that provides good noise immunity to a distance of about 10 meters, depending on the camera’s pixel clock frequency. The higher the clock rates the shorter the distance that the RS-422 interface can drive effectively.

The digital RS-422 interface was replaced with the RS-644 LVDS (low voltage differential signaling) digital output. The LVDS signal is still a differential signal but with a lower voltage swing to give the digital interface greater noise immunity. A major drawback to the RS-644 interface was that cabling was not standardized in the machine vision industry, which made cabling cumbersome and expensive. Some interface cable schemes required two cables to mate: one from the camera and one from the frame grabber. It was cumbersome to rig cable(s) to interface between the camera and grabber.

To facilitate ease of cabling, camera maker PULNiX and frame grabber manufacturer National Instruments started a campaign to offer a new interface called Camera Link. The Camera Link standard was based on Channel Link™, a data transmission method created by National Semiconductor, but included a variety of camera control and cabling considerations to make it more suitable for the industrial video industry.

The Automated Imaging Association (AIA) adopted and became the governing board for the Camera Link standard. The Camera Link logo on a camera or frame grabber now assures that two devices can interface through a Camera Link cable. Camera Link cables meet stringent standards which deal mostly with signal skew tolerances. When components of the interface have the Camera Link logo the component must follow the Camera Link specification.
Gigabit Ethernet Interface

The most recent camera interface is GigE Vision (Gigabit Ethernet). The AIA is also overseeing this machine vision standard for the camera industry. The GigE interface essentially converts digital data to packets, and sends the packets through an internal gigabit interface at a rate of 1000 Mbps (million bits per second). The packets are received through a gigabit computer NIC (network interface card). The NIC software converts the packets back to digital (graphic) data, and they are either saved to memory or the image is displayed. The GigE Vision standard makes this possible by providing a compatible interface for vision applications and allowing the plug-and-play software to communicate between cameras and imaging software.

The GigE interface offers several advantages. It can effectively carry data to 100 meters, and further with switches. The signals can be carried on Cat5E or Cat6 network cabling at a cost much lower than the cost of LVDS or Camera Link cabling. The overall system cost is also lowered by enabling the use of lower cost NICs, thus eliminating hardware such as the frame grabber.

The GigE hardware interface is state-of-the-art technology, and has promise for the future, with 10 Gigabit Ethernet coming into increasing use.

Sensor Size Format

Resolution is determined by the number of photosensitive pixels. Sensor size format (sometimes called optical format) is different; it is the measurement of the optics needed to image a scene on a particular CCD. If we are going to fill all of our CCD imaging area, what size of a lens is needed? If a ½-inch format lens is used on a camera that requires a 1-inch lens, the CCD will have a large number of pixels that are not properly exposed; the final image may appear as a vignette or masked image. If a 1-inch lens is used where a ½-inch lens is required, then only a portion of the image received by the lens will fit on the CCD.
The measurements used to describe sensor size formats (2/3-inch, ½ inch) are not the actual dimensions of the CCD. Instead they are derived from the old Vidicon television camera. The Vidicon camera used lenses and a tube to focus a specified size of image onto the receptor. Vidicon camera tubes were made in 1-inch, 2/3-inch, and ½-inch diameters to create 4:3 aspect ratio images as specified by the RS-170A television standard. As solid-state image sensors were developed, they adopted the Vidicon terminology to describe the size of the sensor in terms of the proper lens format needed. Most early solid-state cameras featured ¼-inch, 1/3-inch, ½-inch or 2/3-inch CCD formats.

More recently, increases in sensor resolution, as well as changes in aspect ratios, has resulted in new sensor size formats. New CCDs no longer feature only the 4:3 aspect ratio of standard television. Instead, these CCDs feature 1:1 “square” formats, as well as various “wide” formats such as the 16:9 HDTV standard. Resolutions have risen up to 4 megapixels or higher, with 11 and 16 megapixel CCDs currently under development. Newer CCDs have already necessitated the use of 1-inch or 1.2-inch lens formats, most of which still utilize the C-mount “screw-in” method of attachment. As the need for larger format lenses grows, many camera manufacturers may start designing cameras to utilize other lens mount standards, such as the Nikon F-mount standard. Because these lenses were designed for the 35 mm camera market, they support larger CCD sizes, and have developed a sizable aftermarket, which gives users numerous choices to meet their optics requirements.
Camera Features

Most solid-state video cameras provide certain functions that enhance the ability of a camera to address a wide range of applications. Some common features are:

The Electronic Shutter

The purpose of the electronic shutter is to capture sharp images where the human eye might see only a blur. Typically, when a fast-moving object is photographed, it results in a blurred image because when the photo is taken, the shutter inside the camera opens to capture an image over a period of time (known as exposure time). During the exposure the object moves across the camera image plane; the end result is a blurred image. To prevent blurring it is necessary to shorten exposure time. With a short enough exposure time the object being photographed does not move on the image plane, and the blur is eliminated (see 1 and 2 in the following graphic). While typical consumer cameras normally use mechanical shuttering, CCD video cameras accomplish shuttering through electrical means.

How does electronic shuttering work? In free run mode the camera pixels fill with light. After a preset exposure time based on the frame rate, the light is converted to electrons and either transferred out as an image, or dumped. The maximum amount of time the pixels have to fill with light is determined by the frame rate. Typically software will allow the user to choose from a selection of settings.

An electronic shutter works by first dumping any charge in the pixels, and then allowing the pixels to receive light for a period of time shorter than the frame rate. At the end of the normal frame cycle, the electron charges that were captured during the shuttering period are transferred to the output registers. This cycle repeats as long as the camera is running.

Since objects are typically moving during the inspection process, many machine vision applications require shuttering. Higher shutter speeds often demand bright lighting conditions since shorter exposure times mean that the pixels receive less light. As noted
earlier, an interlaced CCD gives only a single field (half of a frame) resolution when using electronic shutter. Progressive scan cameras capture a full frame of video, regardless of the shutter speed used.

While electronic shutters are capable of speeds of 1/100,000 or more, such speeds are used only in situations where the light is extremely intense, such as photographing an explosion. More common shutter speeds in the inspection industry are in the 1/1000 second range.

Although the shutter may be set at 1/1000 of a second, it does not mean that the camera will create 1000 images in a second. It means that the shutter will be open for 1/1000 of a second to capture light. The number of images captured during a second is controlled by the frame rate. If the frame rate is 30 frames per second, the camera will output only 30 frames per second, even though each frame may have been exposed for only a small portion of the frame rate.

Asynchronous Reset
The asynchronous reset capability allows the camera to reset the internal vertical drive (sync) to start the next scan. Asynchronous mode usually incorporates a sensor to trigger the camera to begin scanning, based on some event (such as when a box passes a set point on a conveyor), resulting (with some user adjustments) in an image being captured in the center of the frame as shown in 3 on the preceding illustration. This feature is used when an application requires a camera to scan at a specific time. Machine vision usually requires a camera to capture an image of a moving object at a specific time and place to assure it will be in the center of the FOV (field of view).

For example, to verify the quality of a printed bar code, a business may locate a camera to capture a bar code image and the side of a box on a moving conveyor. When the box reaches a position next to the camera a sensor is triggered to initiate a camera scan.
includes the entire bar code in the FOV. This allows the image processing side (computer) of the application to capture the image and either to accept or reject (Go/No-Go) the bar code based on the camera image. If the camera in the example was free running when the box was in the FOV it would probably only capture a portion of the bar code, resulting in the image processing rejecting the box. Note that in applications such as this example, shuttering would be used in conjunction with the asynchronous reset. Each camera model has unique asynchronous timing; users should refer to the specifications for each camera model to determine available trigger methods.

**Integration**
Long term integration exposes a number of fields or frames at the same time. A photographer might refer to this as a time exposure. Integration refers to the time that the pixels are accumulating a charge (light). Long term integration is defined as an exposure time longer than one field or frame.

In some low light situations a pixel must be exposed to light for a longer period of time than the duration of a single frame. Cameras handle integration in a variety of ways. In some situations where the image is being fed at a set rate there are black frames while the frame is being exposed. If the camera is showing the image as it is received, there may be an occasional bright image surrounded by black frames. The eye will perceive a flickering bright frame. Instead of feeding a black frame, more modern software may repeat the last “good” image until a new image is received, avoiding the bright then blank frames repetition.

The limiting factor in this type of application is usually the thermal noise that accompanies long term integration since pixels are somewhat sensitive to heat. The longer the integration time the more noise is present. Cameras require an external signal
to control the integration feature. It is necessary to use a field or frame grabber to store (freeze) the exposed image.

**Automatic Exposure Adjustment**

Some cameras have an auto exposure feature that automatically sets the shutter exposure time based on incoming video. This feature is popular with unmanned security applications, such as outdoor surveillance cameras.

**Automatic Gain Control**

AGC (automatic gain control) allows a camera to adjust the video to the light conditions. While this feature helps ensure usable camera output, it is not recommended where there are extreme light variations. First, the AGC does not work in extreme light conditions. In applications such as machine vision it is advisable to use artificial light to control camera exposure, since constant adjustments using AGC take considerable processing time and can delay video processing.

**Gamma Correction**

Gamma correction allows adjustments to camera light sensitivity. In a dark environment the light sensitivity can be adjusted so that the pixels accept more light when they are first exposed. In extremely bright environments gamma correction can aid by decreasing initial light sensitivity.

The top line of the chart shows a camera adjusted for low light. At first the light rapidly fills the pixel. As the exposure continues the gamma adjusted setting takes in light more slowly than a non-adjusted setting.
The bottom line is a gamma adjustment for bright light. The pixels accept light slowly at first. Pixel speed is adjusted so that the exposure is completed during the gamma adjustment; the benefits of gamma adjustment are negated by a lengthy exposure. The idea is to use the gamma adjustment to change the exposure time to benefit the image. In low light the pixels take an image more quickly than normal and the benefit of less blurring and heat noise is realized. In bright light the adjustment slows the speed the pixels accept light, effectively shortening the exposure time to help prevent overexposure.

Once the exposure time is equal to normal exposure time any benefit from the gamma adjustment is effectively nullified.

The most common gamma correction for low light is gamma .45. The gamma correction is accomplished by the vision system and a corrected video signal is sent to the monitor. This correction level has proven effective; and in the early days of video cameras, could be “turned on” at a preset level of .45. JAI sets their black and white cameras to Gamma off, or Gamma 1, which is very similar to normal human vision. Some cameras now provide user adjustable gamma settings.

**Look Up Tables:**
Dual *look up tables (LUT)* are a feature of AccuPiXEL and Dual Tap AccuPiXEL cameras. This control allows adjustments to the input video to change the appearance of the output. The controls allow for two breaks (knees) in the LUT control. This helps to enhance contrast levels between similar gray level objects or surfaces. The dual look up tables also allows you to change to two different conditions very rapidly from frame to frame. This rapid change is useful in areas where the scene contrast may change from scan to scan; for example, a pick and place application where the background varies making the positioning (during the placement of components) very difficult due to hot spots (saturated pixels in the image).
**Lens Mounts**
Optics is as important to an overall system as the camera behind the optics. C-mount is the industry standard lens mount format. The format size of the CCD specifies the required lens size. For example, the 1024 X 1024 CCD resolution camera is a 1-inch format CCD. This means the user needs a 1-inch format lens to assure that the entire active area (focal plane) of the CCD is illuminated by the FOV. The M42 or P/Mount is a threaded mount being added to more recent cameras as lens trend toward larger sizes. The F-mount is also being offered on 1-inch format CCDs.

**Lenses:**
A FOV is comprised of horizontal width (H) and vertical height (V) dimensions. Based on the distance (L) and the total FOV, it is possible to select a lens for a particular application. Lenses are described based on their focal length (FL) in millimeters. The focal length is defined as the distance from the center of the lens to the CCD array surface. The focal length specifies the view angle through the lens, which will determine the FOV based on the distance to the scene. Magnification (M) is a number expressing change in object-to-image size. The human eye has a magnification of 1 (M=1). A 1-inch format camera with a 25 mm focal length lens (∼1") also has M=1. A 2/3-inch format camera with a 16mm lens has M=1 and a ½-inch format using a 12.5 mm lens gives M=1. This explains why a change in the CCD format size without an accompanying change in the lens changes the field of view. This is frequently overlooked when changing camera format sizes in an existing application. F/Stop (F/Number, F/#) refers to the speed in which a lens can transmit light. A typical lens would be a 25 mm with f/1.4. This translates into a 25 mm focal length with an F-Stop of 1.4. The F/Number can be calculated by dividing the focal length of the lens by its diameter. As the F/Number gets larger, the light speed decreases, usually resulting in a lower contrast level or image quality.

<table>
<thead>
<tr>
<th>Format</th>
<th>1”</th>
<th>2/3’’</th>
<th>½’’</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>12.8 X L</td>
<td>8.8 X L</td>
<td>6.4 X L</td>
</tr>
<tr>
<td></td>
<td>f</td>
<td>f</td>
<td>f</td>
</tr>
<tr>
<td>V</td>
<td>9.6 X L</td>
<td>6.6 X L</td>
<td>4.8 X L</td>
</tr>
<tr>
<td></td>
<td>f</td>
<td>f</td>
<td>f</td>
</tr>
</tbody>
</table>
Typically, the faster lenses have larger diameter optics that transmit more light and usually cost more than the slower speed lenses. Always consider lighting conditions when selecting lens speeds. Use the following formulas to determine the focal length, which will determine the relative size of the viewed object.

\[ f = \text{Focal length of the lens (mm)} \]
\[ H = \text{Horizontal object dimensions (mm)} \]
\[ V = \text{Vertical object dimensions (mm)} \]
\[ L = \text{Distance from the lens to the object (mm)} \]

The JAI web site provides the names of optical businesses that can offer information regarding optics.