avigilon
THE BEST EVIDENCE ™

White Paper
Capturing the Best Evidence

November, 2007

Contents

Capturing the Best Evidence – A New Approach to Surveillance

Avigilon
Pronunciation: a-vigil-on
Definition: To be perpetually alert and watchful

Anyone who has seen images from conventional surveillance systems will agree that the image quality captured by these systems is often very poor. Thankfully, a much higher level of image quality is now available thanks to recent advances in digital imaging, computers, and networking hardware. To achieve this new level of performance, a surveillance system must have been architected as a complete system that leverages the latest technologies available in each of its components. The Avigilon High Definition Surveillance System is such a system and has been designed with an underlying philosophy to:

1. Capture the best surveillance footage possible.
2. Preserve the surveillance footage exactly as it was captured.

By designing every element of the Avigilon High Definition Surveillance System with this philosophy in mind, Avigilon has developed a surveillance system with unmatched performance.

Figure 1: Key Components of the Avigilon High Definition Surveillance System

As shown in Figure 1, the Avigilon surveillance system has four key components:

- **Multi-Megapixel IP Cameras:** Avigilon offers a complete line of high definition surveillance cameras. Avigilon cameras feature both Gigabit Ethernet and 100BaseTX connectivity and use progressive scan CCD and CMOS sensors to deliver true high dynamic range images. Avigilon Professional series cameras are extremely sensitive across the entire visible spectrum and into near infrared wavelengths, Avigilon surveillance cameras see well beyond human vision.

- **Ethernet Transmission:** All Avigilon cameras transmit their images over Gigabit Ethernet as well as 100BaseTX connections depending on the level of compression and image rate. Gigabit Ethernet cameras can stream image data 100 times as fast as cameras that only support 10 megabit Ethernet. The high data rate provided by Gigabit Ethernet allows Avigilon cameras to deliver high-resolution images at high image rates

with lossless compression, while also supporting 100BaseTX connections when using Avigilon's advanced JPEG2000 progressive compression.

- **Progressive JPEG2000 Lossless Recording:** The use of low quality lossy compression in conventional surveillance recorders introduces image artifacts and destroys potentially important evidence. Avigilon recorders use progressive JPEG2000 lossless compression to capture image data exactly as it is produced by the camera's sensor, ensuring that all image evidence is preserved.

- **Enhanced Viewing:** Avigilon Surveillance software allows users to simultaneously view live and recorded multi-megapixel surveillance streams and has built-in image enhancement features to reveal details that normally would remain unseen.

Figure 2: Image Quality Comparison of Avigilon High Definition Surveillance System versus Conventional Surveillance Systems
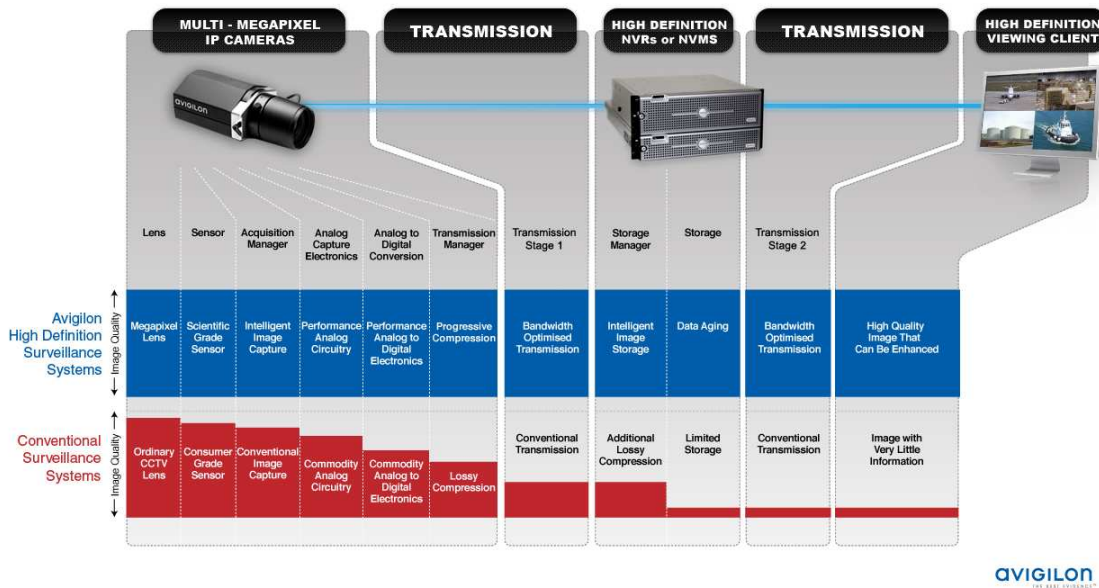
As shown in Figure 2, each component of an Avigilon High Definition Surveillance System is optimized to preserve image quality. Conventional surveillance systems, on the other hand, are not optimized for image quality, and as a result, the surveillance footage captured by these systems is of much lower quality. Detailed descriptions of each component required for a high definition surveillance system are provided in the following sections.

Cameras

Ranging in resolution from 16 megapixels to 1 megapixel, Avigilon offers a complete line of high definition surveillance cameras featuring Ethernet connectivity and progressive scan CCD and CMOS sensors to deliver unsurpassed image quality. Extremely sensitive across the entire visible

spectrum and into near infrared wavelengths, Avigilon surveillance cameras see well beyond human vision. Avigilon surveillance cameras consist of the following six sub-components:

1. Lens
2. Sensor
3. Acquisition Manager
4. Analog Capture Electronics
5. Analog-to-Digital Converter
6. Transmission Manager

The following sections describe the functionality of each camera sub-component, and the performance advantages it provides.
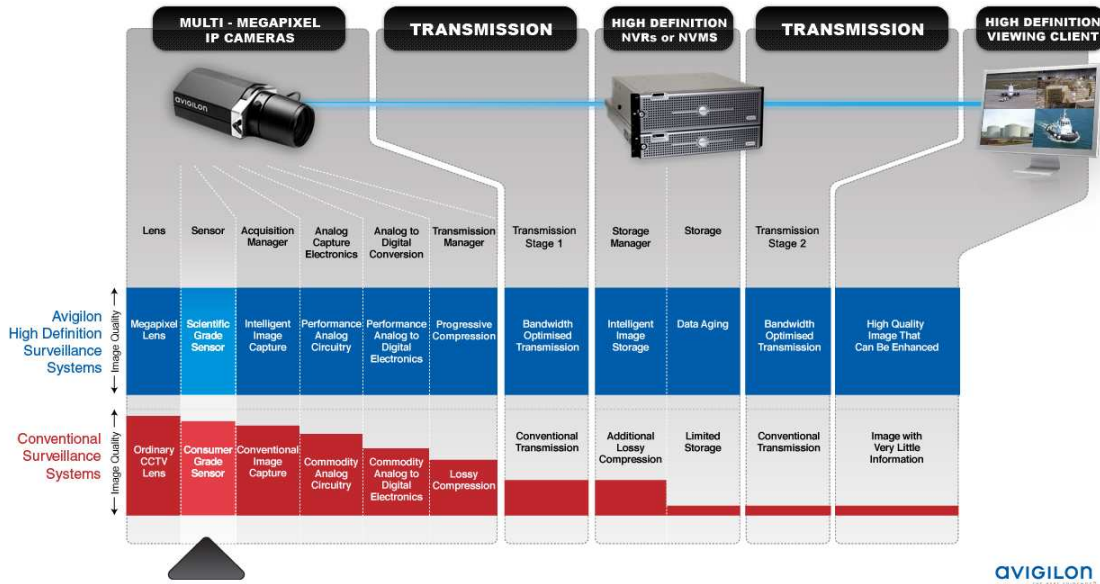
The Lens

Figure 3: Lens Highlighted in the Surveillance System
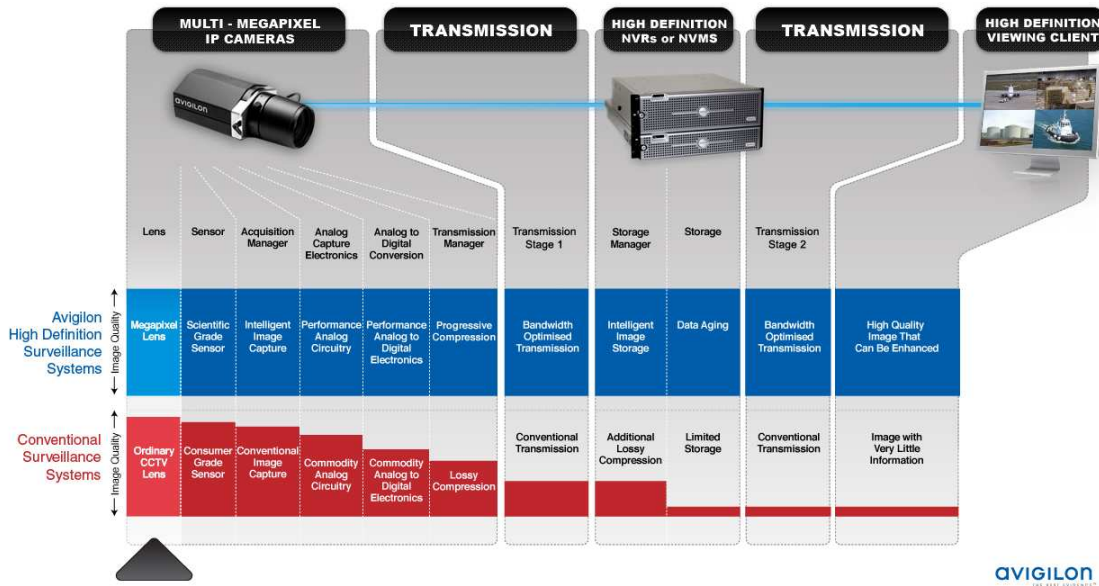
For surveillances purposes, the most important characteristic of a lens is its ability to resolve, or separate, fine details. Lenses that can resolve very small details are able to project very sharp images on the cameras sensor. If the lens is properly matched to the sensor, then the full benefit of the sensor can be realized. Most surveillance lenses simply do not perform at a level required for megapixel sensors and are only good enough for use with VGA sensors. Avigilon tests all lenses that are recommended with its cameras to ensure they deliver the required resolving power for maximum image quality.

The Sensor

At the heart of surveillance cameras is an image sensor made of light sensitive pixels. Light that is focused on the sensor by the lens is converted into an electrical signal that the camera converts into an image. The quality of the sensor determines the quality of the signal that it creates when exposed to light. Most image sensors in conventional surveillance cameras are consumer-grade sensors. High definition surveillance requires scientific-grade sensors which differ from consumer-grade sensors in the following ways:

1. Higher Quantum Efficiency

The higher the quantum efficiency of a sensor, the better it is able to "see" in the dark. Quantum efficiency is a measure of a sensor's sensitivity and expresses the efficiency with which the sensor converts light energy into electrical energy.

Although quantum efficiencies vary, typical conventional surveillance cameras with consumer-grade sensors are able to convert 20% of the light energy they are exposed to into a useful signal. Scientific-grade sensors, on the other hand, generally have quantum efficiencies that are up to 60%, or three times that of a consumer grade sensor. As a result, cameras with scientific grade sensors can see up to three times as much in low light conditions. In conditions where light is not limited, higher quantum efficiency provides other benefits, such as greater depth of field which allows more of an image to be in focus, and a better ability to capture sharp details on objects that are moving fast.

2. Higher Well Capacity

Well capacity impacts a sensor's ability to capture wide ranges in light intensities. To understand what is meant by the term "well capacity", imagine that each pixel on a sensor is a bucket that captures light. A sensor's well capacity refers to the size of each bucket. Because consumer-grade sensors have a lower well capacity, they become

saturated, or "overflow", with light energy much sooner than scientific sensors. In other words, due to their limited pixel well capacity consumer-grade sensors detect less detail in scenes that include both dark and bright areas. Sensors with higher well capacities create images that capture more detail in scenes that have a wider range of brightness. For example, if a surveillance camera were in an office lobby capturing footage of people entering a building, that camera would need a sensor with high well capacity in order to be able to capture details, both when the person is outside in the bright sunshine as well as when they enter the lobby and there is less light.

3. Lower Noise

When a pixel on a sensor is in complete darkness, it still outputs a small signal, called "noise". Scientific-grade sensors have much less "noise" than consumer-grade sensors; in very low light situations, scientific-grade sensors create a cleaner signal, resulting in a clearer image. Sensors with low noise are able to see fine details even in the dark.

4. Uniform Response across the Sensor

Due to stricter manufacturing tolerances, pixels in a scientific-grade sensor create exactly the same charge when exposed to uniform light. Most consumer-grade sensors tend to have problems achieving a uniform response. Non-uniform response can cause a fixed pattern or image distortion in the image. The uniform response of scientific grade sensors ensures that objects are not obscured by these artifacts and also provide consistent data for object recognition algorithms.

Figure 5: Result of Interlacing
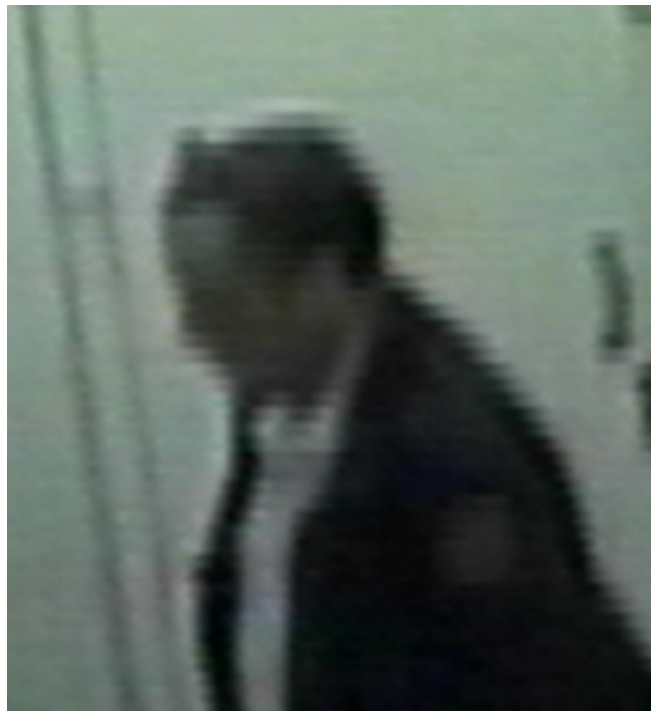
5. Progressive Scan

Scientific-grade sensors use progressive scanning to expose all pixels on the sensor at the same time. Progressive scanning allows sensors to capture sharp images even when

an object in a scene is moving. Most sensors currently used in surveillance, however, are interlaced which means the images that they create are actually composed of two image fields taken at different times. As a result, any moving objects in a scene that are captured with a camera using an interlaced sensor will have edges that resemble the teeth of a comb (see Figure). Avigilon cameras do not have these artifacts.

6. Linearity

Scientific-grade sensors respond to light in a more linear manner than consumer-grade sensors. Linearity is the ability to predictably determine the brightness of a scene based on image data.   For example, if there are two light sources in a scene and one source is exactly twice as bright as the other, a scientific sensor will record the brighter source as being exactly twice as bright as the other. Because conventional consumer-grade surveillance sensors do not always respond to light in a linear manner, it is not possible to determine the relative magnitudes of brightness of different areas of a scene, therefore the recorded surveillance evidence is not accurate.

The above-listed distinctions between scientific and consumer-grade sensors clearly demonstrate the advantages of cameras with scientific-grade sensors. All Avigilon cameras use scientific-grade sensors, ensuring that the resulting images are of the highest quality. In addition to the benefits of scientific-grade sensors, Avigilon surveillance cameras also have an intelligent acquisition manager which continually optimizes the camera's settings in order to always capture the highest quality images possible even when lighting conditions are less than ideal.

Acquisition Manager

To capture a high quality image with a camera, it is necessary to adjust the camera's settings in order to account for the amount of light available as well as the position and motion of the subject. If the settings are properly set for the conditions, the image will be rich in useful information. If the settings are not properly adjusted, portions of the image will appear too dark, too light or washed out, and the amount of useful information in the image will be small.

A major challenge of capturing a good image with a surveillance camera is that the illumination is often changing, and the location and motion of the subject is unpredictable. As a result of these challenges, Avigilon cameras are equipped with an acquisition manager which is able to analyze a scene in real-time and adjust the camera's settings accordingly.

The Avigilon acquisition manager captures the best possible image for the given conditions by constantly adjusting three camera variables: exposure time, lens aperture size and signal-to-noise ratio. Following is a brief explanation of the types of trade-offs that the acquisition manager is constantly balancing with each of the variables under its control:

1. Exposure time: If the exposure time is too short, not enough light energy reaches the sensor and the signal-to-noise ratio goes down which can make an image appear "noisy" or "speckled". If an exposure time is too long, the signal to noise ratio may be good but any moving objects in the scene may be blurred.

2. Lens aperture size: The lens aperture size is set by the iris and controls the amount of light that is allowed to pass through the lens to the sensor and also dictates the depth of field. Depth of field is the distance between the closest and furthest objects in an image that appear in focus. When the iris opening is small, the depth of field is long, but the signal to noise ratio drops. When the iris is opened wide, the sensor is exposed to all the light coming through the lens and the signal to noise ratio improves, but the depth of field becomes smaller.

3. Signal-to-noise ratio: The signal-to noise-ratio is a measure of the amount of useable information in an image compared to the background "noise" of the image. As the amount of light in a scene drops, the acquisition manager makes adjustments to the exposure time and iris opening to achieve the optimal signal-to-noise ratio while maintaining enough sharpness on moving objects and depth of field.

A significant drawback of conventional surveillance cameras is that they are not designed to intelligently adjust their image capture parameter settings. This design deficiency contributes greatly to the poor quality images that we have grown accustomed to seeing from conventional surveillance systems. Avigilon cameras, on the other hand, are designed so that the acquisition manager has full control of all the imaging parameters ensuring that the best possible images are always captured.

Once the acquisition manager has determined the optimal camera settings for a given scene, complex electronics are required to capture the signal coming from the sensor. These electronic components are described in the following sections.

Analog-Capture Electronics

Figure 6: Analog Capture Electronics Highlighted in the Surveillance System
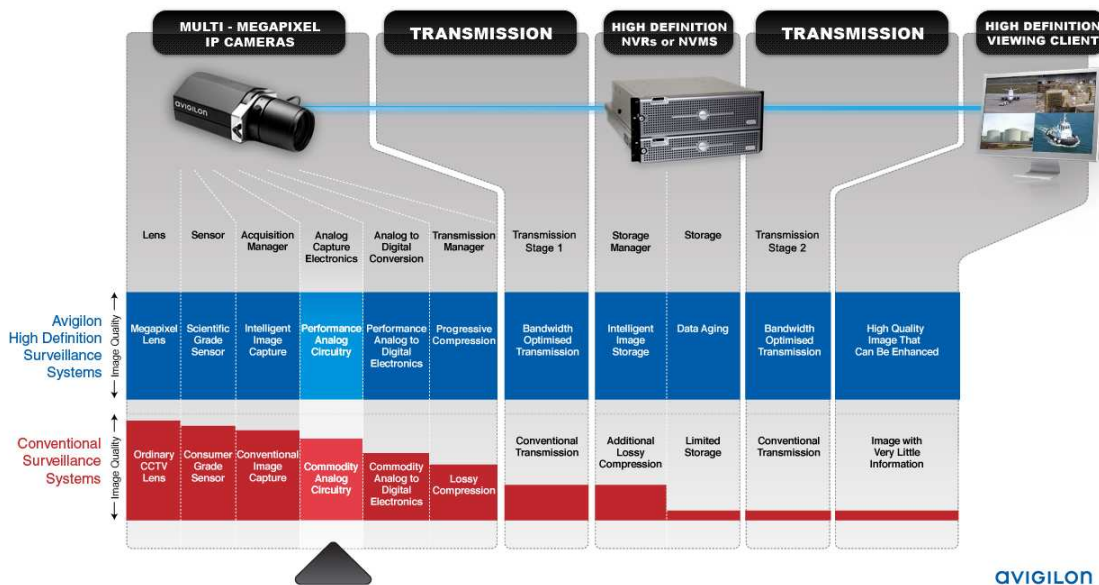
In a digital camera that has a scientific grade sensor, the output from the image sensor is an analog signal that is converted to a digital one by the camera. To capture and interpret the sensor's analog signal, high definition surveillance cameras must have sophisticated analog-capture circuitry that accurately reads the massive volume of data as it streams out of the sensor and also shields it from external electromagnetic interference.

Designing high performance analog capture circuitry is difficult and can be expensive, so, most conventional surveillance camera manufacturers use commodity analog-capture circuitry that is typically provided by the sensor manufacturer. The drawback of this approach is that commodity analog capture circuitry degrades the sensor signal in two ways:

Firstly, commodity analog capture circuitry is severely limited in its dynamic range and bandwidth. This forces the commodity analog capture circuit to make an approximation on which information is relevant and which can be discarded. Avigilon's performance analog capture circuitry, on the other hand, is able to capture more than the full dynamic range of every sensor in its product offering. The advantage is that Avigilon cameras do not need to approximate -- they capture all the information provided by the sensor and allow the user to decide what information is important at the time the footage is viewed.

Secondly, commodity analog capture circuitry is optimized for inexpensive manufacturing, which has the detrimental effect of introducing noise to the analog sensor signal prior to digitization. The noise often manifests itself in an image as "salt and pepper" or "ghosting". Avigilon performance analog capture circuitry, on the other hand, is designed for maximum imaging performance and is able to shield the sensor signal from external interference and does not introduce any image artifacts.

Once the analog capture circuitry has read the analog signal coming from the image sensor, the signal is passed to the analog-to-digital converter, which is discussed in the following section.

Analog-to-Digital Converter

Figure 7: Analog to Digital Conversion Highlighted in the Surveillance System
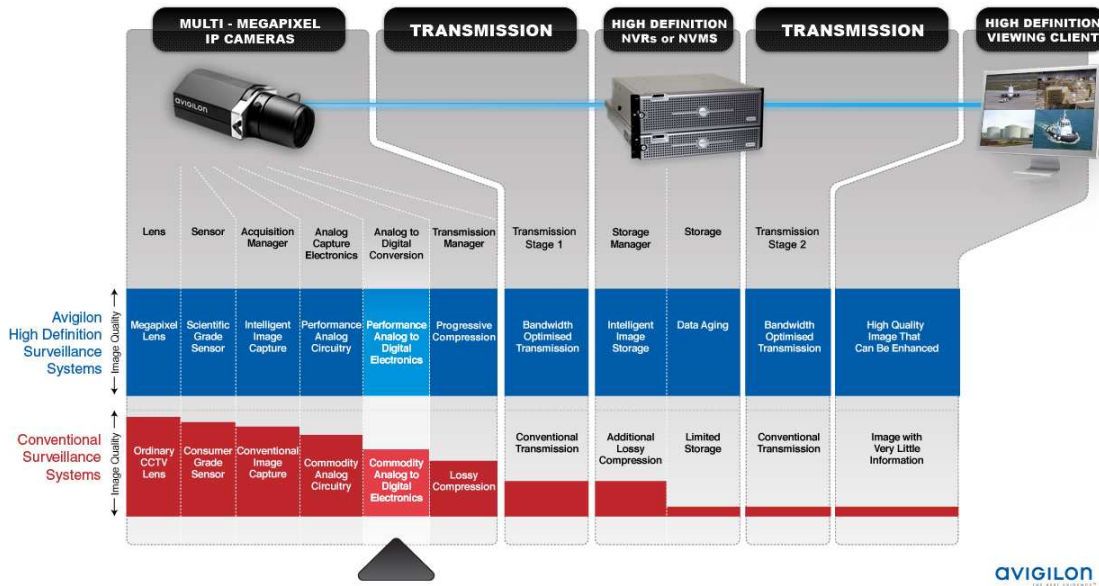
Digital cameras have an Analog-to-Digital Converter (ADC) that converts the analog signal captured by the analog capture circuitry into a digital signal—hence the name "digital camera". The ADC plays a key role in determining if a camera is able to capture a high quality image. Most surveillance-camera manufacturers choose to use commodity ADCs that are provided by the sensor manufacturers and integrated with the analog capture electronics. The drawback of commodity ADCs is that they are matched to the low performance of the commodity analog capture circuitry and therefore further degrade the image quality. Avigilon cameras, on the other

hand, use a performance ADC that is specifically designed for high performance imaging that matches the high quality analog capture circuitry to ensure no loss of image quality.

The importance of a digital camera's ADC lies in the fact that image sensors have two different types of resolution, spatial and dynamic.

1. Spatial Resolution

Spatial resolution describes, and is typically measured by, the number of pixels on the sensor; for example, VGA (about 300,000 pixels) or megapixel (more than one million pixels).

2. Dynamic Range Resolution

Dynamic range describes how accurately a pixel can sense small changes in light intensity over a wide range of intensities. The more accurately a pixel can detect small changes in light intensity over a wide range of intensities, the more accurate the resulting surveillance evidence.

If a camera's sensor has a very high dynamic range resolution, its ADC requires a high degree of granularity to describe the light intensity from each pixel. Consider, for example, a pixel that can only detect if it is light or if it is dark. For each pixel in each image, the ADC only has to record a 0 for black or a 1 for white. However, if the pixel can sense 256 different intensities of light, then the ADC has to be able to store a number between 0 and 255 for each pixel for each image. In this case 0 is black, 255 is white, and the 254 numbers in between are all the shades of gray that the sensor can detect between black and white. Note that the same principle applies to color sensors, because each pixel is only sensitive to one color.

Since ADCs encode everything as binary data, the possible levels of granularity are powers of 2, such as 256 (2^8), 512 (2^9), and 1,024 (2^{10}). The granularity with which the ADC encodes the light intensity for each pixel is called the bit depth. If a pixel can detect 256 different light intensities, then the dynamic range for that sensor can be described as having a bit depth of 8 (2^8=256). It is worth noting that while NTSC cameras have a dynamic range with a bit depth of around 7, human eyes have a dynamic range with a bit depth of approximately 8.

The best conventional surveillance cameras have a dynamic range of 8 bits (2^8=256 light intensities). In contrast, the scientific-grade sensors used in Avigilon Professional series cameras have a dynamic range of 14 bits (2^{14}=16,384 light intensities). As a result, Avigilon High Definition Surveillance Systems are able to discriminate 64 times (16,284 vs. 256) more light intensities than the human eye. When analyzing an image from a 14-bit surveillance camera, a region of an image that at first appears completely black or white to the human eye can reveal significant detail when enhanced with Avigilon's image-enhancement tools.

The 14-bit ADC used in Avigilon Professional series cameras is capable of outputting digital data that perfectly describes the analog signal generated by the scientific-grade image sensor. For example, if a sensor has one million pixels (megapixel), the data for one image would resemble that in Table 1, except with a million rows.

Table 1: Example of ADC Data from a Megapixel Sensor

Pixel Number	Intensity Reading
1	10100100101001
2	11100110101100
....	....
....	....
1,000,000	11100100101110

Along with the image data the ADC also records other information, such as an image number and the exact time the image was exposed. Once the ADC has properly digitized all the image information it sends it to the recorder. Image transmission is covered in the next section.

Transmission Manager

Figure 8: Transmission Manager Highlighted in the Surveillance System
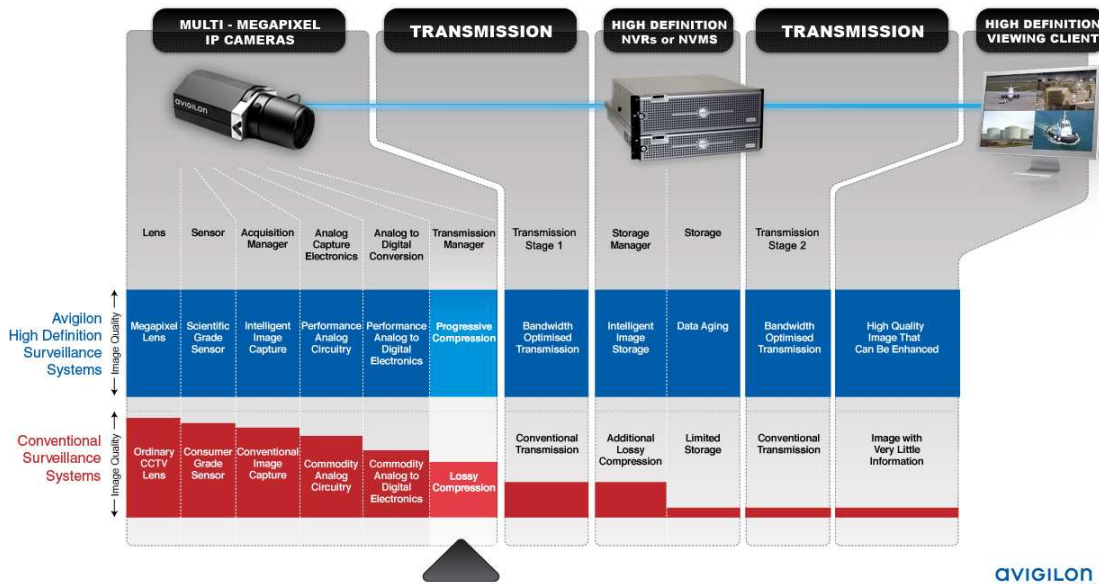
An image stream from a camera is simply data that represents the light intensity and color of a series of pixels that, when combined, create an image. To maintain the best possible

surveillance evidence, Avigilon cameras send all the data for each pixel to ensure that the image is perfectly preserved.

Often a compression algorithm is employed in the transmission manager to reduce bandwidth utilization. Most conventional surveillance systems destroy surveillance evidence by using low quality lossy compression to decrease the amount of information in the image stream. The choice of compression technology plays a significant role in the resulting image quality as well as how efficiently the image data can be transmitted to, and managed by, the recorder. Avigilon cameras use advanced JPEG2000 progressive lossless compression to provide the highest image quality possible using the lowest bandwidth in the industry. Typical lossy-compression techniques, including MPEG, M-JPEG, H.261 and H.263, were developed to match the capabilities of human vision for entertainment and video conferencing applications where retaining image integrity and dynamic range above 8-bits is not critical. JPEG2000 compression, however, is designed to handle the 14-bit high dynamic range and high resolution from Avigilon's multi-megapixel IP cameras without sacrificing image quality.

Avigilon's JPEG2000 progressive compression compresses each image on the camera to a camera specific user defined quality level. Lossless compression options allow the user to configure the key cameras in their surveillance system to return the highest possible quality images while other cameras can be configured for high quality compression that minimizes bandwidth and maximizes storage time.   Each image is compressed progressively so that once stored at the recorder additional unique features such as data aging and remote client bandwidth management are available that are not possible with conventional compression technologies.

Figure 9: JPEG2000 Progressive Transmission

Remote client bandwidth management allows a recorder to send a more compressed lower bandwidth version of the image to a remote client ensuring efficient bandwidth utilization. This is shown in Figure 9, where the progressively compressed image is modeled as a layered pyramid. The complete pyramid of image data is sent between the camera and the recorder ensuring all of the original image data is captured. When transmitting the image to a remote client the recorder will send only the top portion of the image data pyramid, a more compressed version of the image, ensuring minimal bandwidth utilization by the remote client. When the remote client

requires the complete high resolution image for incident review and analysis the recorder will send the complete pyramid of image data. Data aging and Avigilon HD Network Video Recorders are described in the following section.

Network Video Recorders

Commonly referred to as Network Video Recorders (NVRs) or Digital Video Recorders (DVRs), modern surveillance recorders are simply PCs connected to an Ethernet network running software that stores image data to hard drives.

One of a surveillance recorder's most important features is the rate at which it can write and retrieve data to and from the hard drives. If an incident occurs and all surveillance cameras in a system start sending data, the recorder must be able to capture all of the information.

Storage Manager

Figure 10: Storage Manager Highlighted in the Surveillance System
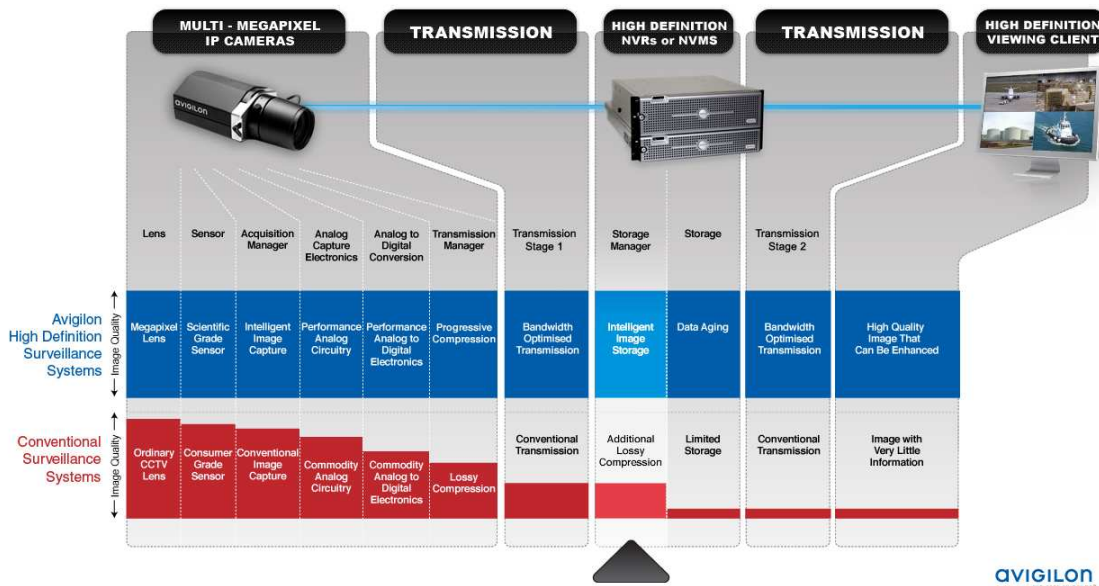
Conventional surveillance recorders have a restricted capacity to record and quickly become overwhelmed by the volume of data that is generated by multiple cameras when an incident has occurred. As a result, precisely when surveillance evidence is most needed, the storage manager of conventional surveillance recorders are forced to either degrade the images further with increased lossy compression or reduce the number of images per second that they record. Avigilon HD NVRs, on the other hand, have high recording capacities which allow them to continue to record at full image rates even when all cameras are sending images.

Storage

Figure 11: Storage Highlighted in the Surveillance System
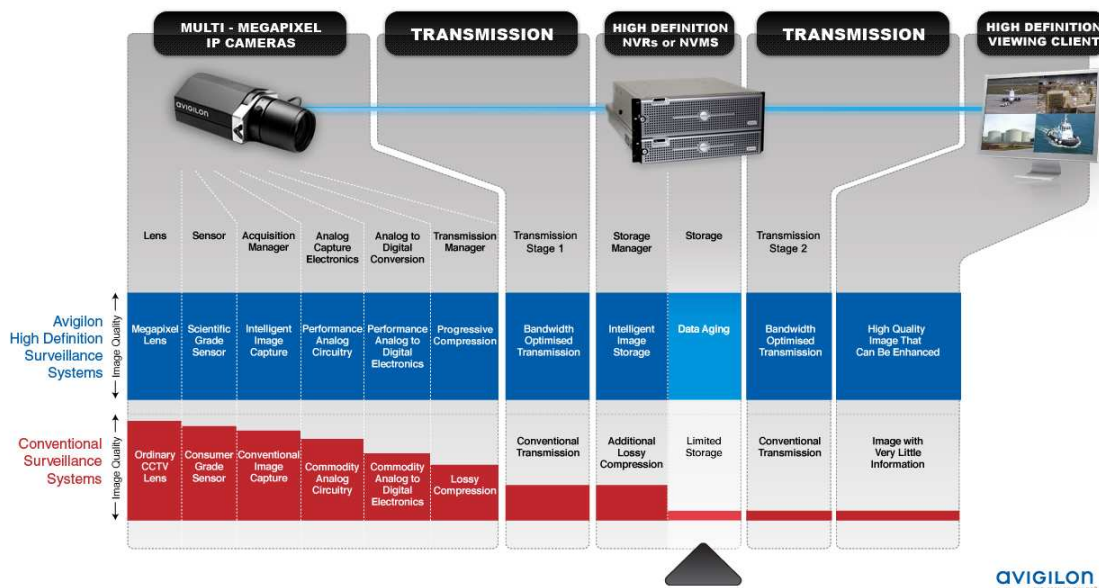
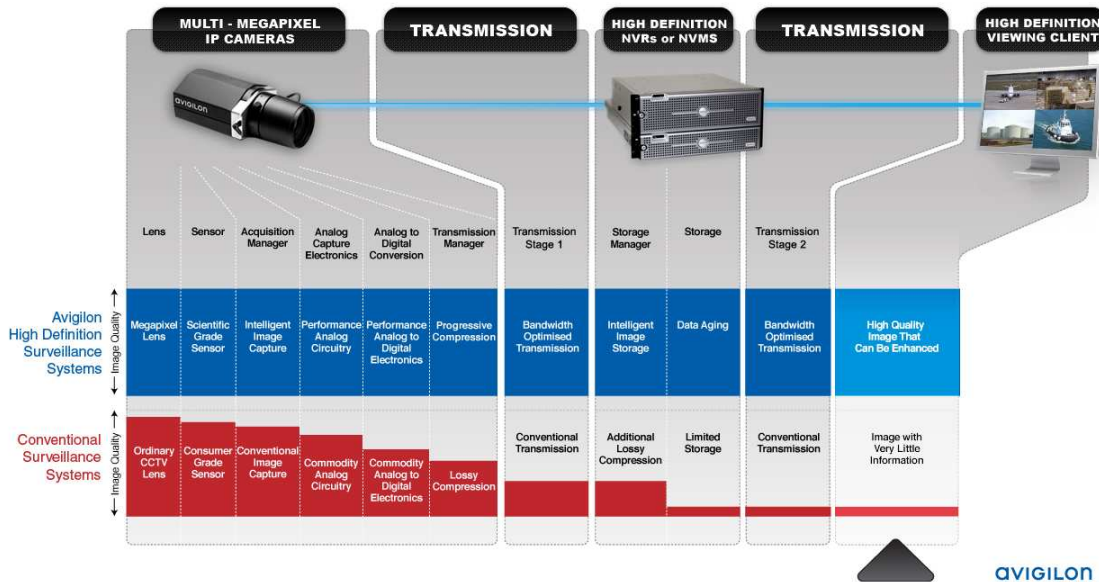With high definition surveillance systems, high-quality recordings intrinsically require large volumes of storage space because each image is rich in information. To ensure that sufficient recording time is possible, Avigilon recorders use the latest high density hard drives configured in fail-safe, industry standard, storage arrays. Fail-safe storage arrays ensure large volumes of data can be recorded and that the recordings are safe in the event of hard drive failure.

Avigilon HD NVRs also support a powerful feature called data aging. Data aging allows older surveillance to be stored at lower image rates and with higher compression to more efficiently use the available storage. With data aging the most recent time period, for example the most recent 2 weeks, of surveillance footage is recorded in the highest quality with the full image rate with low compression. As surveillance ages beyond a user defined threshold time the system will automatically manage the stored data to keep only half the frame rate and only a more compressed version of the image data.   Storing the most recent surveillance footage in the highest quality allows for incident review immediately after an event occurs using the highest possible quality surveillance footage while allowing older surveillance to use less storage and keep archival storage durations high.

Viewing Surveillance Recordings

Figure 12: Viewing Highlighted in the Surveillance System

	MULTI - MEGAPIXEL IP CAMERAS					TRANSMISSION	HIGH DEFINITION NVRs or NVMS		TRANSMISSION	HIGH DEFINITION VIEWING CLIENT
	Lens	Sensor	Acquisition Manager	Analog Capture Electronics	Analog to Digital Conversion	Transmission Manager	Transmission Stage 1	Storage Manager	Storage	Transmission Stage 2
Avigilon High Definition Surveillance Systems	Megapixel Lens	Scientific Grade Sensor	Intelligent Image Capture	Performance Analog Circuitry	Performance Analog to Digital Electronics	Progressive Compression	Bandwidth Optimised Transmission	Intelligent Image Storage	Data Aging	Bandwidth Optimised Transmission	High Quality Image That Can Be Enhanced
Conventional Surveillance Systems	Ordinary CCTV Lens	Consumer Grade Sensor	Conventional Image Capture	Commodity Analog Circuitry	Commodity Analog to Digital Electronics	Lossy Compression	Conventional Transmission	Additional Lossy Compression	Limited Storage	Conventional Transmission	Image with Very Little Information

By using high performance cameras, progressive lossless compression, and high capacity recorders, high definition surveillance systems capture and store images exactly as the image sensor detected them. Since high definition surveillance systems capture more image information than is visible with the unaided eye, image enhancement tools are necessary to reveal all the details that have been captured. Once image enhancement tools have been used on an image from a high definition surveillance system, the image details that appear are astounding to users that are accustomed to viewing footage from conventional surveillance systems.

To make it easy to reveal all the detail in high definition surveillance footage, Avigilon Surveillance software includes the following image enhancement features:

1. Contrast Enhancement: when viewing recordings, Avigilon's image enhancement automatically re-maps the dynamic range of the image to the dynamic range of the monitor. This ensures that the maximum contrast possible is displayed. Since the dynamic range of the images exceeds both that of the monitors and the human eye, regions of interest of the image can be selected and the contrast enhancement is automatically applied to the selected region. This feature is particularly useful when an image contains details in both dark and bright sections.

2. Non-Destructive Color Transformation: accurate and precise color representation is achieved with the image enhancement feature by transforming the color captured by the camera to a color that can be displayed on the monitor. Since different monitors display the same color in different ways, and Avigilon cameras are able to capture a wider range of colors than can be displayed by standard computer monitors,

Avigilon's image enhancement displays the closest approximation of the actual color captured that can be shown by the monitor being used. It is important to note that color transformation is achieved without modifying the original image data. Color transformation is useful with almost all surveillance footage that was captured in color and the result is surveillance images that have remarkably life-like colors.

3. Non-destructive Image Smoothing on Zoom: Built in image smoothing provided by the image enhancement reduces the effects of pixelation, which can make images appear blocky when "zoomed".

All Avigilon image enhancement features can be applied to still images or to streaming footage that is live or recorded and the application of image enhancement techniques never alters the original image data.

Conclusion

Recent advances in digital imaging technology, computers and networking hardware make it possible to usher in a new level of performance in surveillance systems. To benefit from these new technologies, however, a surveillance system must be architected from end-to-end with the goal of capturing and preserving image quality. Any weak link in the system can irreparably reduce image quality and therefore the evidentiary value of the surveillance system. As illustrated in Figure 12, Avigilon High Definition Surveillance Systems have been designed to:

1. Capture the best surveillance footage possible.
2. Preserve the surveillance footage exactly as it was captured.

Figure 13: Image Quality Comparison of Avigilon High Definition Surveillance System versus Conventional Surveillance Systems
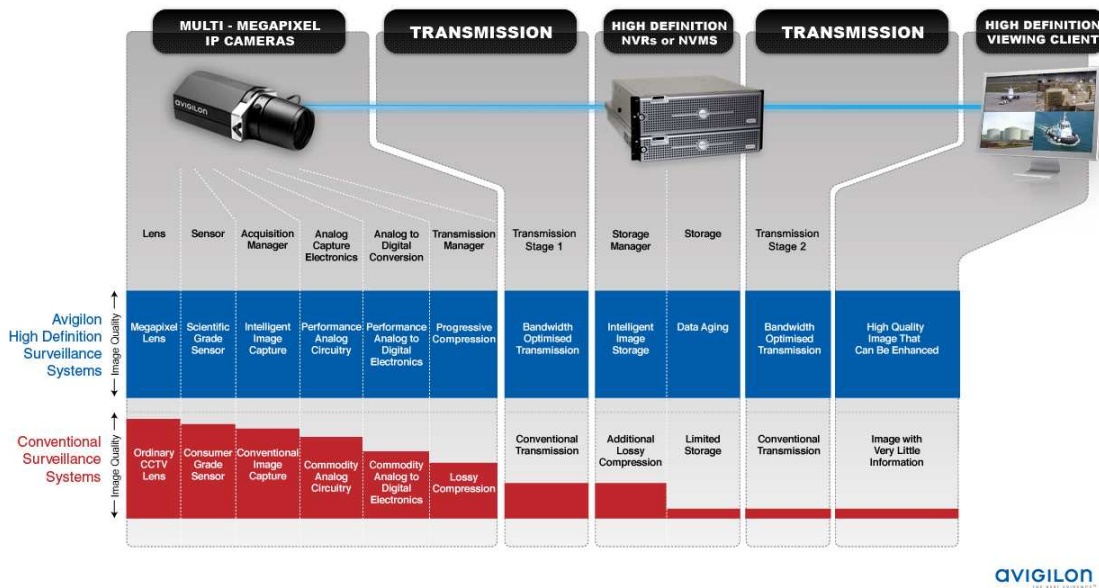
For more information on Avigilon High Definition Surveillance Systems, visit avigilon.com.