# Technical Presentation

## CCD Camera Systems

### Understanding Camera Resolution

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To understand the methodology of high-speed, web inspection defect detection using CCD technology, you must first understand camera resolution and how that resolution is derived versus size of fault, machine speed and process manufacturing environment. Since the invention of the *Charged Coupled Device* (CCD*;* A semiconductor device that stores energy and transfers it sequentially to an amplifier and/or detector, *Figure 1*) back in the 1960's by Bell Labs, CCD technology has become an industry-standard image sensor. In particular, CCD line scanning technology has become the most widely used imaging platform for non-contact, electro-optical measurement of various defect faults commonly found in many paper, paperboard and conversion operations.

***Figure 1 – 2048 Pixel Line Scan CCD Chip***

Of the available CCD line scanning arrangements (i.e., 512, 1024, 2048 and 4096); most suppliers base their standard platform off of the 2048 pixel formats (RKB uses both 1024 and 2048 platform). This device is a monolithic component generally containing a single row of 13µm (0.00051 inches) square light sensing elements (pixels or photosites)[1] (*Figure 2*). Light energy or the lack thereof received by the pixels generates electron charge packets proportional to the product of integration time and incident light intensity. The electron charged packets are then transferred in parallel to processing circuitry for delivery to signal amplifiers where they are converted into proportional voltage levels. Additionally, CCDs contain additional processing pixels (non-active sensing pixels) used internally by the sensor for other various functions. All CCD cameras operate with two differential clock signals, a data rate clock (fixed) with a preset frequency that determines the frequency which the video data is clocked out of the camera and a line rate clock (individually adjustable) which specifies the camera scan rate and integration period.

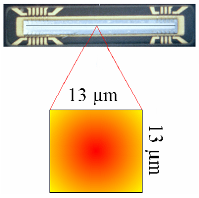

***Figure 2 – Detailed view of the Pixel Dimensions***

CCD camera based web inspection suppliers typically define system resolutions (or minimum defect size) as the field of view (FOV) per sensor in the cross machine direction divided by the number of pixels contained within that sensor. That means a 2048 pixel linear array camera viewing 20 inches (50.8 cm) of material in the cross machine direction should have a resolution of slightly less than 10 thousandths of one inch (0.254 mm) or the size of the pixel resolution in the cross machine direction (Table 1).

| **TABLE 1** | | | | |
|---|---|---|---|---|
| FOV | ÷ | P | = | SR |
| 20 | ÷ | 2048 | = | SR |
| | | 0.010 inches | = | SR |
| | | 0.254 mm | = | SR |
| **System Resolution** | | | | |

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[1] Photosites or pixels are silicon based energy packets similar in function to phototransistors.

It, therefore, is also true that a 1024 pixel camera with a 10-inch (25.4-cm) field of view cross machine direction would have approximately the same resolution. The subtle difference is that this resolution may only be true for non-moving or static material, thus it is most accurately called ***"Static Resolution"*** *(figure 3)*.

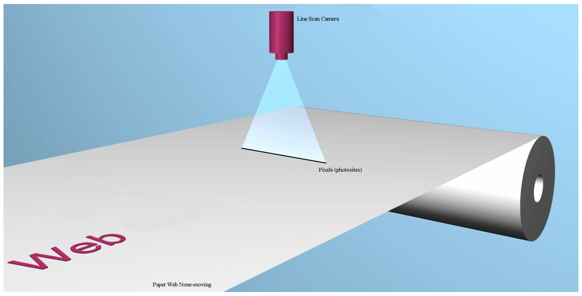

***Figure 3 - Cross machine pixel resolution on a stationary web or "Static Resolution"***

In reality, the actual resolution of any CCD camera based video imaging inspection solution is more difficult to calculate precisely, especially when applied to material that is manufactured at high rates of speed such as coated paper. Unfortunately, there are too many unknown factors that can affect the overall resolution of any given CCD camera based system to accurately pinpoint the systems finite resolution in any given application. Light intensity, machine speed variances, vibration, environmental conditions, applicable data and scan rates actually used in and/or by camera sensors, camera sensor placement from the focal point, to name a few can all adversely affect the expected output of any CCD camera based system, no matter who supplies the system.

Another factor, which has a direct affect on system resolution capability, is Nyquist Theorem. In 1928, Henry Nyquist determined that, when sampling at a given rate, the highest frequency that can appear in the sampled signal is half the sampling frequency. If the sampled signal contains frequencies higher than half the sampling frequency (higher than 4 kHz when sampling at 8 kHz as is the case for µ-law), these higher frequencies will appear folded down to below half the sampling frequency when the signal is reconstructed. This is the Aliasing problem. This problem, commonly referred to as Nyquists' Law of Unambiguous Detection Measurement, states that the "Defect or event being inspected must be 3 times the diameter of the actual pixel coverage size to guarantee that the defect fault or event covers at least one full pixel under any circumstance (Figure 4).

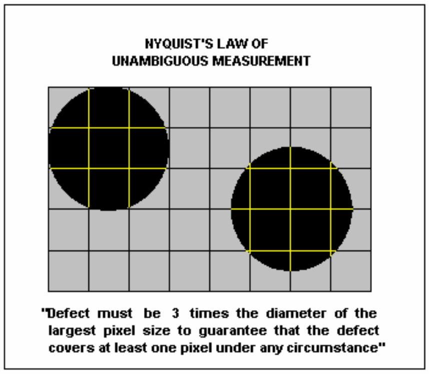

***Figure 4 – Nyquists' Law of Unambiguous Measurement***

Since *"Static Resolution"*, as described above, does not account for web movement during the time interval that the CCD array is collecting and reading off the energy, true pixel array resolution cannot be determined for any applicable application. Actual resolution or *"Dynamic Resolution"* of any CCD array must be calculated to include the web material process speed, which can have a dramatic affect on overall resolution capabilities of any CCD Array. To determine, within reason, the approximate true resolution of a CCD Array, we must know two things; the web material process speed and the actual scan rate used by the equipment supplier to drive the CCD Array. As we should all know by now, CCD arrays measure the amount of energy falling on them over some time interval. The length of the interval is a function of the number of pixels within the CCD array, and the clock rate used to drive the array. Pixel count and clock rate are normally provided by the inspection system supplier or listed on the system suppliers' product literature[2].

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[2] Be wary of the clock rate figure provided as many suppliers will provide the maximum allowable rate, but not necessarily the rate that is actually used by them for inspection.

It is fairly easy to estimate what true resolution can be expected for any CCD array as applied to any potential inspection application. Thus, a best-case and worst case resolution scenario can be determined. First of all, two pieces of data are required to effectively calculate the true resolution of any CCD camera based solution. You need to know the cross machine direction resolution (CDR – commonly referred to as static resolution; Figure 3) and the machine direction resolution (MDR – commonly referred to as dynamic resolution; at speed; Figure 5) per pixel. These two resolutions, when calculated together, determine the true operational pixel resolution for a particular application.

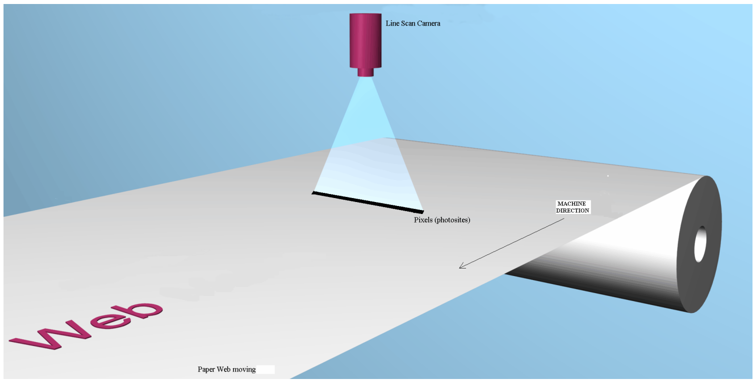

*Figure 5 – Machine Direction pixel resolution on a moving web or "Dynamic Resolution"*

**An example is instructive:**
Your application involves the inspection of a paper web 100 inches (2.54 meters) wide being processed at 1000 feet per minute (304 m/min). The CCD array you decided to use is based on 2048 linear pixels and you are going to place each sensor so that the field of view per sensor is 20 inches (50.8 cm). This array will operate or scan at 20MHz. What are the static and dynamic resolutions? To determine the static (CDR) resolution you take the field of view (FOV) of the sensor and divide it by the number of active pixels used by the CCD array (i.e., 20” FOV ÷ # of pixels (Table 2)).

**TABLE 2**

| FOV | ÷ | P | = | CDR |
|---|---|---|---|---|
| 20 | ÷ | 2048 | = | CDR |
| | | 0.010 inches | = | CDR |
| | | 0.254 mm | = | CDR |

**CDR – Cross Machine Direction Resolution per pixel**

To determine the dynamic resolution (machine direction resolution; MDR) you must take the number of active pixels (P) plus the additional non-active pixels and divide by the data rate (DR) used. This will give you the actual scan rate. The scan rate, which is the time it takes to scan through all pixels, is then multiplied by the web speed (WS[3]) which will give you an initial pixel resolution (IPR) in the machine direction. That IPR is then added to the CDR[4] to give you the actual MDR of the above listed example (Table 3).

**TABLE 3**

| | | | | | | |
|---|---|---|---|---|---|---|
| $\frac{P + 38}{DR}$ | X | WS | + | CDR | = | MDR |
| $\frac{2048 + 38}{20\text{ MHz}}$ | X | WS | + | 0.010 | = | MDR |
| $\frac{2086}{20{,}000{,}000}$ | X | 200 | + | 0.010 | = | MDR |
| 104.3 µs | X | 200 | + | 0.010 | = | MDR |
| | IPR = | 0.021 | + | 0.010 | = | MDR |
| | | | | 0.031 inches | = | MDR |
| | | | | 0.784 mm | = | MDR |

**MDR – Machine Direction Resolution per pixel (at speed)**

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[3] Remember to adjust the web speed from fpm (m/min) to inches per second (mm/sec).

[4] Remember the pixels 13 µm square which means that the CDR static is = to the MDR static and must be added to the IPR for actual MDR resolution at speed.

Please take note that Dynamic resolution (Figure 5) is a function of web speed and scan time and, to improve it, two things must be done. One must either **slow the material down** (an unacceptable choice) or **reduce the time to complete a scan.** Reducing the length of the scan can be accomplished in three ways: use less pixels, use a faster clock, or do both. Figure 6 (below) shows the effect of reducing the number of pixels from 2048 (the competitors) to 1024 (RKB) and simultaneously viewing 10" (254mm) rather than 20" (508mm). Static resolution remains at 10 thousandths of an inch (0.254mm), but **dynamic resolution is greatly improved**. The scan period drops from 102 µs to 51 µs, which changes the amount of web movement from 0.0512" (1.3mm) to 0.026" (0.66mm)[5].

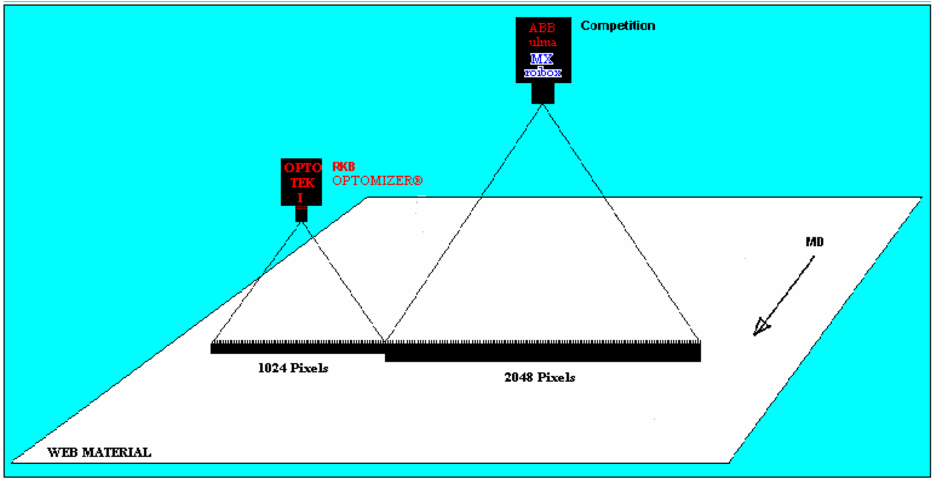

*Figure 6 – Machine Direction pixel resolution on a moving web or "Dynamic Resolution"*

The above calculations have now provided you with both the CDR (figure 3) and MDR (figure 5) resolution of the active pixels contained in the sensor you are using for the above example. Thus, for a paper web traveling at 1000 fpm (304 m/min) with a 2048 pixel camera applied at a FOV of 20 inches (50.8 cm), the pixel coverage area is 0.010 inches (0.254 mm) CD by 0.031 inches (0.784 mm) MD. From the above calculations, we can now calculate the true resolution of each pixel contained within the specified CCD array. By taking the CDR and multiplying it by the MDR, the overall area that each pixel covers for this specified example is 0.21 sq. mm (according to TAPPI Test Method T437; Dirt in paper and paperboard). Another fact born from the calculations above is how much the paper web will move during one full CCD array scan. We know that the scan rate is 104.3 µs, thus the paper web which is traveling at 1000 fpm (304 m/min) moved 0.020 inches (0.508 mm), twice the static resolution (figure 3).

Every CCD camera-based solution, no matter what CCD pixel array you use, has a best case and worst-case resolution scenario. If a defect fault or event covers the full pixel, either in a static environment or dynamic environment, the voltage signal output is at its highest optimum level or full modulation (***best case***). However, in reality one has to deal with machine process speed, various energy levels, and web tension control fluctuations, web wander, shrinkage and other variables generally not present during inspection in a static environment. All these factors can seriously alter your best case resolution scenario. Another "real-world" issue that most suppliers neglect to consider is the relative timing between a defect fault and event during any one particular CCD pixel array scan. Unfortunately, reality being such as it is, many defect faults or events cover only a portion of the full pixel during any one scan and the resultant voltage signal output is reduced from its optimum level or modulation. It is quite feasible that a defect fault or event could fall on a quarter of the pixel coverage providing only a 25% optimum voltage level output or modulation (***worse case***). Refer to Figure 7 for a depiction of the best case and worse case signal responses.

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1024 ÷ 20,000,000 = 51.2µs, 51.2µs x 400"/sec = 0.020"
1024 ÷ 20,000,000 = 51.2µs, 51.2µs x 1m/sec = 0.508mm

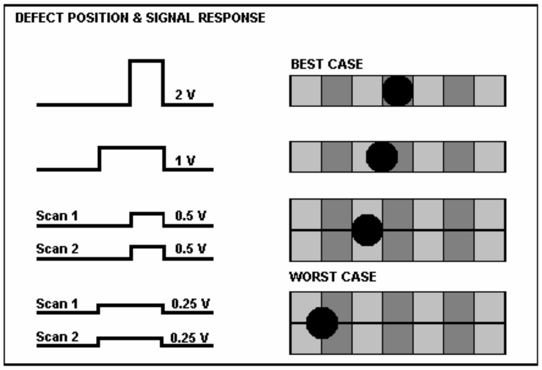

*Figure 7 – Best Case/Worse Case Signal and Defect Resolution Response*

As seen above in figure 7, when a defect fault during a CCD linear array scan lands completely within the pixel, the resultant voltage level output is at full modulation or 100%. However, when the defect fault lands on the crosshairs, so to speak, upon completion of one scan and initiation of another, approximately ¼ of the defect fault is detected resulting in ¼ modulation or 25%. This phenomenon, which can reduce the ability of the detection process, can be avoided if proper and direct care is taken prior to manufacturing a system to take the possibility of decrease modulation into account. Additionally, the reduction in defect modulation dramatically gets worse when machine process speeds are increased. Of course, lighting which is another factor, can play an important roll if you cannot generate enough energy to run the CCD array at optimum scan rates.

Although it is common knowledge that most, if not all, CCD linear array chip sets are rated to work at 20MHz data rate (pixel clock rate). In reality, it takes a very high-energy source to actually achieve this operational rate, if achievable at all. Some CCD chip set suppliers claim to have developed linear arrays, such as a 2048 pixel array, that can operate at 40MHz or higher. This is true and false. If the camera is broken into sections (i.e., dividing 2048 pixels by 4) and parallel processed, then the flow of information is increased from a standard 2048 at 20MHz. However, these types of sensors are very expensive and generally are prohibitive from being used in most applications when costs to implement defect detection are just not warranted. It is believed that all vendors of CCD camera-based video web inspection systems claim the highest possible data rates. RKB does the same thing and it is considered a very viable marketing tool. However, taking this hype out of the picture, reality sets in and increasing the clock speed beyond the capabilities of the camera is not possible. In most on-line CCD camera based systems, the actual data rates being used by vendors such as HMX, ABB, Cognex, etc… is not the suggested data rate by CCD chip set manufacturers. In fact, in many cases, the current installed based on camera based systems are operating with scan rates within the 7 to 12 MHz range. RKB generally operates, depending on the application, between 15 and 18 MHz, which is more than sufficient for most inspection applications.

Point of fact! It has been disclosed to RKB by various users of current CCD camera systems and through head to head, on-line trials with two of the worlds biggest suppliers that their actual operational data rate (scan rate) used is much lower than the rated data rate of the CCD chip sets used and specified the Chip manufacturers. This is due to many factors including, but not limited to sensor placement (distance to web surface), utilization of wide angle lenses, use of extensive software oriented controls and algorithms for actual defect detection (not defect display), types of lighting techniques used and the use of improper CCD linear array chip sets or improper number of sensors. Finally, web speed plays an enormous roll as a detractor for reliable, consistent and accurate detection.

It is a known fact that light or energy reflected off paper has a much higher illuminant level then light transmitted through paper. Thus, any type of line scanning CCD chip set that uses transmitted energy only would be handicapped relative to optimum performance levels. It is also a known fact that, to date, only RKB has provided line-scanning solutions based on a 1024 linear array chip set. Other companies have claimed they can do it, but no one has ever done so. Every system that has been installed since 1989 starting with Combustion Engineering, ABB, ROIBOX, Measurex, Honeywell-Measurex, Cognex and others have all been based on the inherently slower 2048 CCD linear array chip set. Most likely due to its cheap costs and ability to make large profits. Although RKB also provides solutions based on the 2048 chip set, we have provided and have proven systems based on the 1024 chip set and other types of chip sets. It really depends on the application at hand, machine speed, and of course, the financial ability of the customer. Certainly, when possible, one would want to use a faster chip set like the 1024 linear array as the overall resolution and results are much improved over slower scanning systems. Let's look at the top three suppliers of CCD camera-based video web inspection systems. The following tables list operational parameters for RKB, ABB and Cognex (Formally Honeywell-Measurex; HMX). The tables below, numbered 4 and 5, will provide a rough comparison on system resolution and capability.

**Table 4**

**STATIC RESOLTUION CAPABILITY**

| Vendor Name | Pixel Count | Field of View | Static Resolution/pixel |
|---|---|---|---|
| RKB | 1024 | 10 inches (25.4 cm) | 0.010” (0.254mm) |
| ABB | 2048 | 20 inches (50.8 cm) | 0.010” (0.254mm) |
| Cognex (formally HMX) | 2048 | 20 inches (50.8 cm) | 0.010” (0.254mm) |

**Table 5**

**DYNAMIC RESOLUTION CAPABILITY**

| Vendor Name | Pixel Count | Data Rate | Scan rate | Dynamic Resolution/pixel |
|---|---|---|---|---|
| RKB | 1024 | 18 MHz | 56.8 μs | 0.028” (0.7mm) |
| ABB | 2048 | 6 MHz | 341 μs | 0.171” (4.4mm) |
| Cognex (formally HMX | 2048 | 10 MHz | 205 μs | 0.102” (2.6mm) |

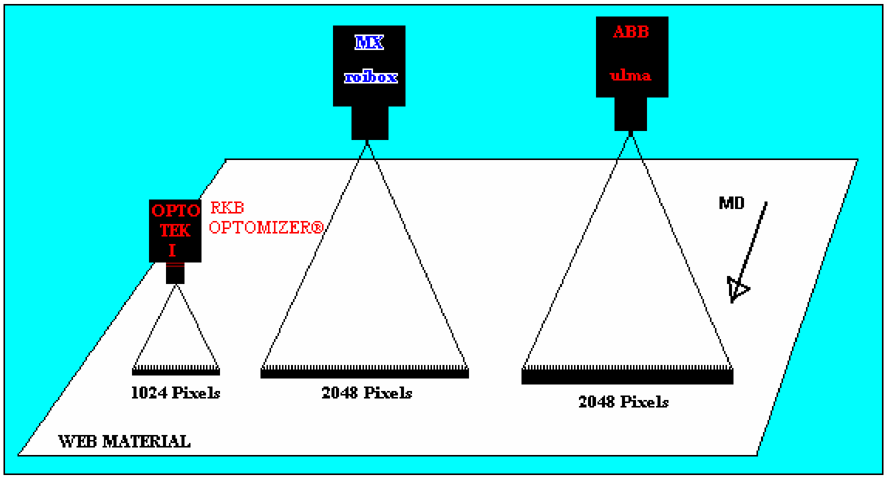

*Figure 8 - Table 4 and 5 Depiction*

Most web-based material manufacturers can calculate static and dynamic resolutions themselves. RKB provides the necessary formulas in its methodology description of its solutions when proposed. All one needs to actually know from a potential vendor is what will be the actual data rate they will use per their recommendations or proposed systems. Then the potential customer can decide if what is being offered will actually do the job or not and if they wish to invest. RKB strongly recommends that you investigate all suppliers no matter how many systems have been supplied to fully understand what it is you’re investing in.

**Calculating Resolution:** Paper manufacturers can calculate static and dynamic resolution themselves. ***Static resolution*** is measured in the cross machine direction and is equal to the number of inches (mm) viewed, divided by the number of pixels used to view that region.

$$\frac{\textbf{Field of view of camera}}{\textbf{Number of pixels in camera}}$$

(i.e., 20 ÷ 2048 pixels = 0.009766" (0.2480564mm)
10 ÷ 1024 pixels = 0.009766" (0.2480564mm))

***Dynamic resolution*** is slightly more difficult, but best case approximation can be made as follows:

1.) Find the period of the scan by dividing:

$$\frac{\textbf{Number of pixels in a camera}}{\textbf{Clock rate used to drive a camera}} = \textbf{period of scan}$$

(i.e., 2048 ÷ 6,000,000 = 341 μs (ABB)
2048 ÷ 10,000,000 = 205 μs (MX)
1024 ÷ 18,000,000 = 56.8 μs (RKB))

2.) Find the web movement by multiplying:

**Period of scan x web speed = web movement**

**Remember to convert web speed to inches per second (mm per second); otherwise the web movement will be in feet (meters) not inches (mm).

(i.e., 341µs x 500"/s = 0.171" or 56.8µs x 500"/s =0.028"
(341µs x 12.7m/s = 4.34mm or 57µs x 12.7m/s=0.071mm))

The amount of web movement is a best case calculation of minimum defect size, or dynamic resolution. As web speed increases the minimum defect size requirement must increase.

As stated earlier in this report, paper machine processing speeds can greatly affect the overall results of CCD linear array resolutions thus affecting the detection capability, assurance and consistency. Through many years of development and supplying inspection solutions, RKB has found that one thing has never, and most likely will never change. The need for speed!!! As markets tighten up and become more competitive, paper manufacturers are required to produce more with less. To accomplish this task, machine-processing speeds are ever increasing with no signs of stabilizing. As a result, inspection solutions have to be modified to accommodate these ever increasing speeds. New systems must conform to inspect for defects at higher rates of speed. It is not enough that you could detect a 0.010” (0.254mm) defect at 1500-fpm (457 m/min), you now have to be able to detect that size of defect at 3000 fpm (914 m/min). An inherent problem with CCD solutions versus phototransistor systems, although both sensing solutions are made of similar material, is machine speed. In the older phototransistor type systems, you wanted faster line speeds which helped generate the defect signal pulse due to AC coupling. Since the CCD linear arrays do the scanning, machine speed has become the enemy of high speed, on-line machine vision inspection, so to speak.

As with all inspection solutions, the resultant output obtained from the electronic processing modules is an electronic signal. In this signal you have what we call noise (generated by the product itself). From that noise, you have discrete voltage spikes that may or may not be defect faults (*Figure 9*). This overall signal is referred to as the signal to noise ratio. In most cases, one would want a signal to noise ratio of 3:1 or better, with 3 representing the defect and 1 representing the noise. However, since reality shows that defects do not necessarily land and cover a full pixel in any given scan, as shown in Figure 7, the resultant voltage levels become lower and more difficult to discern. This phenomenon is especially true with subtle dirt and coating streaks/scratches. Under a static environment, all sensors should produce similar results with similar outputs. However, when machine speed is applied to the equation, the defect may not provide the optimum modulation during detection to provide a reliable output signal. This has been demonstrated in the paper industry time and time again. RKB Commonly hears from papermakers that the units they currently use are so sensitive and see everything that they have to reduce the detection threshold. This was a common statement made when Laser Systems had there hey day. What is actually occurring is that the defect electronic signal is not strong enough nor contains significant characteristic changes for the inspection system to pick out the defect from the random noise. As such, the inspection system is rendered for all intent and purpose, useless.

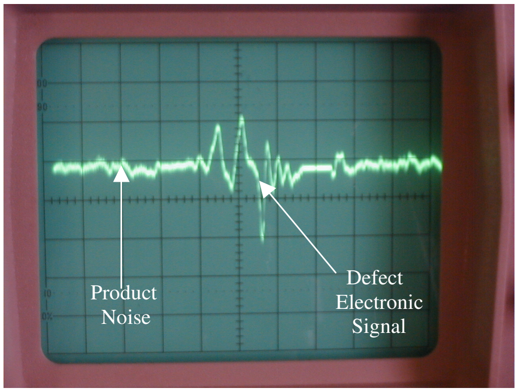

***Figure 9 - Signal to Noise Level of Defect Vs Material***

The fact is that over sensitive systems cannot discriminate between junk noise produced by the web material from an actual defect. Yes, it may be true the systems did detect the defect fault, but they detected a lot of other stuff (i.e., fibers, dust, etc.) that is not considered defective material. In most, if not all cases, the operational staff end up adjusting the unit to eliminate the false detection’s and settle for what the unit can do which is a far cry from what they paid for the unit to do.

For example, let's take a 1/32" (0.8mm) black spot on a white paper. Apply machine speed to the paper web and increase said speed accordingly. As you can see in *Figure 10*, the detection capability of the CCD linear array chip set deteriorates due to the fact that the defect fault or event is no longer falling or covering one full pixel, but only part of a pixel during any given scan. Therefore, the modulation of the defect electronically starts to decrease until it becomes completely immersed within the noise level of the product material itself.

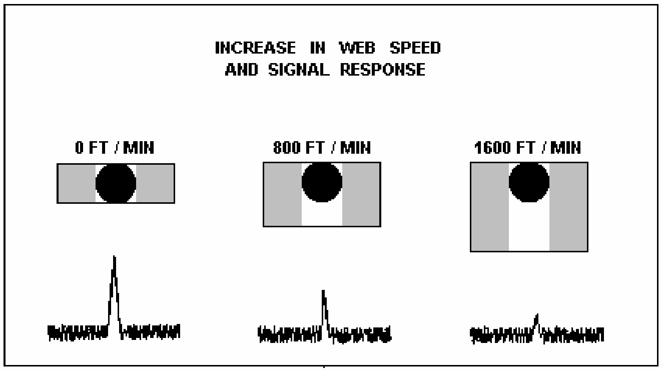

***Figure 10 – Effects of web speed on the defect signal to noise ratio***

Another phenomena that hinders reliable detection with CCDs, unless taken into account, is pixel stretch. Again, as you can see in figure 10 above, as you increase the machine speed, the machine direction resolution per pixel also increases or stretches. This affect causes the total area covered by the pixel to increase. Therefore, if you are looking at a 1/32" (0.8mm) black spot that covers a full pixel in static mode (left view in Figure 10), the same size spot will cover less of the pixel as machine speed increases until the modulation level of the voltage signal decreases to the point of non-detection (right side view in Figure 10). Now, take a white colored streak on white-coated paper and apply the same principal. Not only does the contrast level significantly decrease, but streak detection no longer can be done using line scanning technology as there is no way of being able to bring the subtle defect out of the noise level if your pixel coverage is, lets say 2mm wide by 10 mm line and your fault is only 5% or 10% of that coverage.

Earlier we mentioned that wide angle lenses also affect reliable detection. The main reason why suppliers of inspection systems would use this type of lens is to facilitate the use of as few sensors as possible, keeping costs down while maintaining profit margin. Although some applications would require the use of wide-angle lenses, main stream paper inspection is not one of them. Utilizing wide-angle lenses creates Vignette (*figure 11*). Vignette is defined as "an image that shades off gradually into the surrounding background."

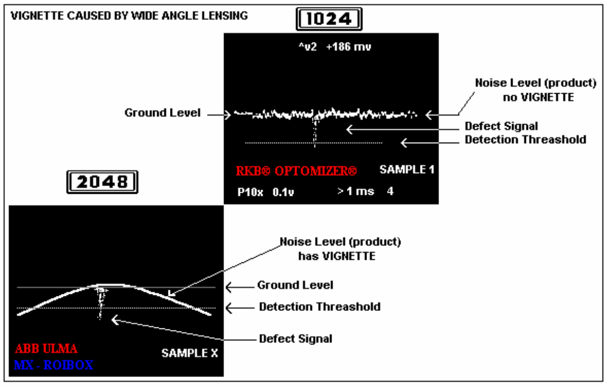

***Figure 11 - Vignette Affect on Electronic Signal resulting from Wide Angle Lensing***

Vignette applied to the electronic output signal of a paper defect fault or event, the defect eventually fades off into the noise level of the product material itself seriously degrading the detection systems capabilities for reliable, accurate and consistent detection. This becomes more apparent towards the outer fields of view of the sensors. It is RKBs' opinion, although commonly used in our industry by others, that wide-angle lenses sacrifice the ability of the detection system to perform for the customer as intended. As seen in figure 11, the top oscilloscope representation shows the RKB CCD solution that is designed without the use of wide angle lenses, thus NO VIGNETTE phenomena affects detection reliability. The bottom picture shows what happens when wide-angle lenses are put in place to reduce the number of sensors required to do the job. The result, serious vignette problems exist.

***Figure 12*** represents three types of black spots, 0.5mm (0.020") diameter, 0.8mm (0.032") diameter and 1.5mm (0.060") diameter. Most users of web inspection equipment who mainly look for dirt are commonly concerned only with defects of 0.8mm (0.032") diameter and upwards.

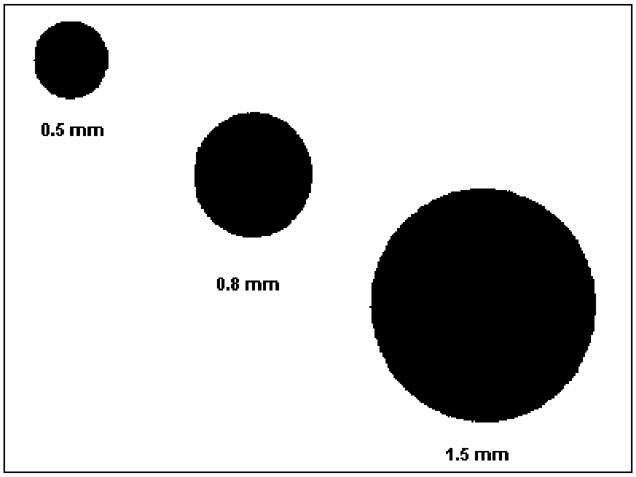

***Figure 12 – Black Spots***

To look at the pixel comparison for the 0.8mm (0.032") ad 1.5mm (0.060") spots, simply apply the spots presented in ***figure 12*** to ***figures 13, 14* and *15,*** below which depicts pixel size comparisons with the 0.5mm (0.020") diameter spot. As you will see, the 1024 CCD pixel arrangement, RKBs standard setup, is far more reliable and accurate than those utilizing a 2048 CCD arrangement.

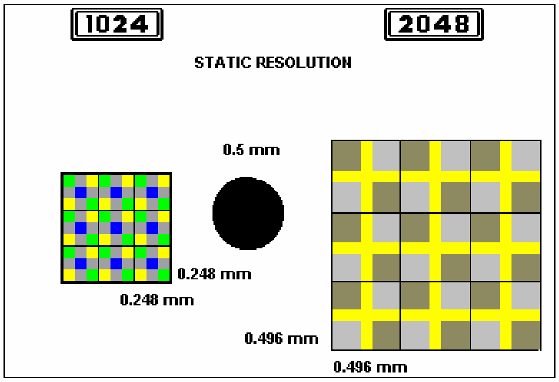

***Figure 13 – Black Spot "stationary"***

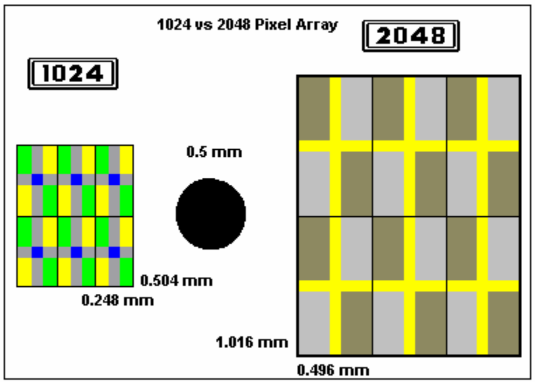

***Figure 14 – Black Spot @ medium speed***

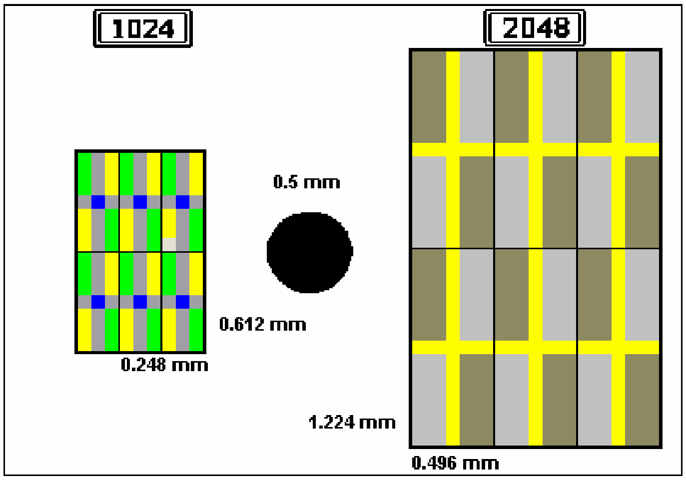

***Figure 15 – Black Spot @ high speed***

What about coating streaks and scratches? It is true the above information mostly talks about CCD resolution as applied to autonomous defect detection and not streaks which are line type defects that generally run true to the machine direction. The reason is that the above information is relative to CCD line scanning solutions. It is RKBs position that line-scanning solutions do not work well, if at all when applied to streak type phenomena. Why, for many reasons, but the most apparent is that streaks are commonly very subtle in nature and do not have significant deviations from the material in which they occur in. Therefore, the signal to noise ratios generally obtained using line-scanning cameras is not defined well enough to generate a significant electronic defect signal from the electronic noise level of the material being inspected. As a result, the threshold detection settings would have to be set very low which can cause false signals to be generated.

Another reason RKB believes line-scanning techniques are not a valid approach for streak detection is due to the sensor make up themselves which are very similar to phototransistor type sensors. Every pixel, no matter what type of line scan chip set format is used, is made up of similar material (silicone) as a phototransistor. Since you are dealing with one TV line cross machine direction, the line scanning array becomes more or less like a point source sensor like phototransistors packed cross direction. The only difference is that under machine speed, the pixel of a line scan array will stretch and the phototransistor sensor will remain constant. What happens during streak detection is that the material with the defect will pass under the sensor (i.e., pixel or phototransistor) and without significant contrast, causing the sensor, in a way, to recalibrate itself to the new material in this case the defect. Thus, to the sensor, there is no defect, just new material. Yes, the sensor may pick up the change at the beginning of the streak and end, but will not signal during the length of the streak. As a result, many times, a line scan camera will misinterpret the defect as a spot and report as such completely missing the actual event. This has been proven time and time again since the introduction of camera systems that use only line scanning techniques.

Another fact to consider is that if all the so called “Brand Name” suppliers use the same sensor array (i.e., 2048 pixel chip set), then how could one system outperform the other if the main “BRAIN” of the unit is the same. The answer is that they cannot and this has been proven by many current installations worldwide, especially those at coated paper making facilities. In short, if the system you implement cannot see or discriminate the defect from the noise, it will never register or classify the defect. To the knowledge of RKB, all suppliers of camera inspection equipment base their systems around the 2048 pixel line scan chip set. As a result, none of these companies have been overly successful in coating streak detection. As a result, these systems become, in effect, useless tools that can only provide hole and gross spot detection. Specifications that most paper makers finally accept. But at what cost? We for one would not want to end up with a hole detector that we could have gotten at 1/10th the price. This is not just RKB opinion, but based on facts presented to us from users in the field and the physical makeup of the sensors themselves.

***Parystec is not discussed above, as they use area scan CCD technology which is one of the most worst approaches to inspection for holes and spots in any process above 700 fpm. This will be explained later. Invest in a solid technology that will provide years of reliable and accurate detection and defect fault informational services. Some technologies sound great on paper, but may prove to be quite expensive and ineffective in the long run.***

## SCRATCH AND STREAK DETECTION METHODOLOGY:

The most commonly implemented systems for monitoring webs for coating scratches and streaks are currently CCD camera-based techniques based on the line scanning format (in particular the 2048 pixel camera). Like many, RKB uses line-scanning technology to identify various fault events such as holes, spots and edge cracks. However, unlike competitive suppliers which use line-scanning technology to try and identify line type events (i.e., scratches and streaks), RKB takes an entirely different approach in its use of CCD camera technology regarding coating scratch and streak detection. ***Without exception***, R.K.B. OPTO-ELECTRONICS, INC., uses what it calls its streak camera based on CCD technology. To understand RKBs' technological methodology, you must first understand how line-scanning methodology is applied.

### Scratch and streak detection applied with a "line scan" technology

Now that we know how line-scanning technology is applied to autonomous faults as described in the section above, we can now look at what requirements are needed to use the same type of sensors for coating streaks and scratches. As stated above, most scratches and streaks are very subtle in nature and are very difficult to discern between defect and material (formation). Since the standard setup with a line scanning system is designed for autonomous occurrences, which are generally very sharp in characteristic as compared to the amount of material being monitored, line type occurrences like scratches and streaks would not produce significant changes in contrast to material for reliable detection. Since scratches and streaks and generally long in the machine direction, line scanning technology would need to be applied so that the pixels are covering more area in the machine direction, commonly referred to as pixel stretch. Many suppliers have stated that if the pixel is extended (stretched) in the machine direction up to 60 mm to 100 mm (2.4" to 3.9"), the formation variation inside the pixel can be averaged out and the streak information multiplied. To accomplish pixel extension (stretch), four things can be done. We can increase the machine speed (not an option), decrease the data rate (a fixed specification), increase the line rate (exposure rate; individually adjusted) or decrease the data rate and increase the line rate together. Since we know the general formulas required determining machine direction resolution as stated above, we can determine the first two choices easily.

First, increasing the web speed. Obviously, certain grades of material have to be made at particular speeds. Therefore, increasing machine speed to adjust for longer machine direction resolution is not a viable option and cannot be counted on. Secondly, we can decrease the data rate applied to the line scan sensor. This option is easily accomplished by slowing down the camera rate (widely used in the inspection industry) by applying a slower data rate clock. Therefore, instead of using 20 MHz (as applied in the above calculation for holes and spots) we use 3 MHz, effectively allowing the camera pixels to integrate more energy over a longer period of time. By doing this, we can adjust the scan rate to scan slower therefore allowing the pixels to cover more area in the machine direction. For example; a coated web is traveling at 2500 fpm with a 2048 pixel line scan camera monitoring the web every 10" FOV cross direction. The data rate is slowed down to 3 MHz, what is the dynamic (machine direction) resolution? By applying the known formula stated above, (P+38) ÷ (DR) x (WS) + (CDR), we can determine that the MDR is 0.35" (8.9 mm) MD. Therefore, the web moves through a pixel 0.35" (8.9 mm) every scan. Obviously not a huge increase in web coverage per pixel, certainly not close to what some suppliers' state they do. Thus this process is not very practical in use to discern any subtle material formation changes required of scratch and streak phenomena. This leaves the last two options, increase the line rate (exposure time) or decrease the data rate while increasing the line rate.

By increasing the line rate (exposure time) we can increase the area the pixel is view in the machine direction while leaving the data rate alone. For example; a 2048 pixel camera with an active 20 MHz data rate applied to a 2500 fpm line will produce a scan rate of 104.3 µs per scan. Thus at 2500 fpm (762 m/min) or 500"/sec (12.7 m/sec) the material being monitored moves 0.05" (1.27 mm) in the machine direction. Since adjusting the line rate (exposure time) of the camera is not dependent on data rate and can be applied separately, we can manually increase the line rate to any time constant we wish. Thus increasing the line rate (exposure time) to 8.0 milliseconds we can extend (stretch) the pixel out over a 4" (101.6 mm) area in the machine direction. This allows the pixel to integrate a greater amount of energy over a longer period of time in hopes of averaging more information by providing a certain picture which when interrupted with either a lack of energy or increase in energy, would set off a detection threshold level predetermined by the supplier. The last option, decreasing the data rate while increasing the line rate is redundant in that no significant benefit can be gained since the line rate can be increased to any time constant in material of web speed or data rate. Thus, the last option has no point and is invaluable to perform.

Now that we know we can increase the image area or exposure time of a pixel, why then does RKB feel that this approach is ineffective and unreliable for coating scratch and streak detection? There is much reason to question this approach as to its authenticity. First and for most, most scratches and streaks are very subtle in nature. So subtle that many suppliers, even those offering line scan technology as a solution, state that coating scratches "represent a rather small change in signal compared to formation". Since RKB agrees with this statement, all suppliers agree that most scratches and streaks are so small that many appear similar to material formation (noise). To reliably bring the defect signal out of the noise, there must be significant modulation. If the line scan sensor is viewing a 10" (25.4 cm) FOV cross direction, each pixel is viewing 0.005" (0.127 mm). If we increase the line rate to 8 milliseconds, we can extend the pixel coverage to 4" (101.6 mm) in the machine direction. Thus the effective pixel coverage is 0.005" (0.127mm) CD by 4" (101.6mm) MD. One would surmise then that if a coating scratch or streak was 0.005" or wider would provide enough contrast difference to the pixel integrator to pull out a difference from normally viewed product to when a contrast difference was present no matter how small.

Then why are so many line scanning system not performing well? One reason we believe is that since many of the scratches and streaks appear like the material formation (as confirmed by many suppliers) there is no significant modulation to discern between fault and formation (noise). Another problem RKB believes affects a line scanning approach is that short term background noise (i.e., material noise), as well as low and high frequency changes cannot be effectively eliminated without eliminating the fault itself, thereby adversely affecting the signal to noise ratio of the desired single generated by the scratch or streak. Another problem RKB believes affects the ability of line scanning technology to work consistently is that autonomous events (i.e., dirt and holes) and other anomalies affect the pixels integration value thereby introducing false signals. Lastly, most line scanning technologies are applied reflectively for scratch and streak detection with their sensors positioned at angles to the web material. Positioning these sensors at angles to the material being monitored introduces other phenomena that can affect overall scratch and streak detection. This phenomenon is a shallowing of the scratch and streak towards to the outer fields of view per sensor. For example, if you place a piece of paper in front of you with a light pencil line drawn down the middle, your eye can pick it up if viewed directly over it. However, if the pencil line is drawn towards the edge of the paper and you are still looking directly over the middle of the paper, the pencil line tends to disappear from focus. This same effect happens with scratches and streaks as viewed by a sensor. Since the sensor is transposing an array of pixels X inches away from the web onto the web, the pixels located center of the field of view have a direct focus, where towards the outer field of view, the pixels are subjected to more of an angle where the reflective light used by the inspection system appears to fill in the scratch or streak therefore, decreasing the contrast difference, potentially, to the point where again, the fault itself appears like the material formation can cannot be reliably recognized. Finally, many scratches are just too small and do not provide enough modulation within the pixel for any recognizable signal to be produced reliable and consistently.

## Scratch and streak detection applied with RKBs' streak sensing technology

As stated above, RKB does not use line-scanning technology for coating scratch and streak detection for many of the reasons as stated above. Instead, RKB envisioned a radical approach that can guarantee reliable and consistent detection of very subtle scratches and streaks. So radical is this invention, the United States Patent Office awarded RKB patent protection under patent number 5,118,195. The invention features a real time system for detecting scratches and streaks which occur substantially parallel to the direction of motion of a continuous or sheet feed web. An energy source such as an incandescent lamp impinges or transmits energy (light) which is then received by RKBs CCD based streak camera (what we call our Opto-Tek II™) technology.

The sensors, standard two-dimensional interlaced cameras (e.g., a television), are mounted relative to the web by conventional means well known in the art. The sensors contain an array of x pixels horizontal by x pixels vertical. It should be noted that cameras can be mounted collinear or staggered or arranged in any other suitable fashion as long as their cumulative fields of view cover the entire width of the web being monitored with each field of view overlapping its adjacent fields. The overall system design enables the use of a 2 inch (5.08 cm) field of view (FOV) per sensor in the transverse web motion (Cross Direction) by a 2.7 inch (6.858 cm) FOV per sensor in the web motion (Machine Direction). The sensors, interlaced into odd and even fields, scan at a data rate of 1/60 of a second, producing a standard picture frame every 1/30 of a second. Horizontally, the sensors contain x number of photo-sites (pixels) providing overall 301,875 or more pixel coverage. Dividing the 2 inches (5.08-cm) FOV by x number of complete raster lines results in an effective 4-mil resolution per line. The resultant data received by the cameras is processed in parallel from each sensor.

Since the sensors are standard types, a full frame (or two fields) takes approximately 0.033 seconds to read out. The outputs are processed along with undesirable control signals and are shuttled to our proprietary line finder processing system. The line finder processes each raster separately over its time constant, approximately 63.5µs (basically each line of pixels is displayed in 63.5µs). As a result of the longer exposure time, the final output reaches an energy level that represents the sum of the energy received by the individual pixels focused on the target web. By using line finder processing power and other proprietary circuitry, short term background noise (i.e., material noise), as well as very low frequency noise is eliminated, thereby enhancing the overall signal-to-noise (defect to material) ratio of the desired signal that is generated by scratches and streaks. Since autonomous events (i.e., holes and dirt) or other high frequency background noise affects only a few pixels, normally less than 1% of a raster line and line type events (i.e., scratches and streaks) affects all (100%) of the pixels along a raster line, autonomous events and undesirable frequency noise are eliminated and have no affect on the signaling process of scratches and streaks.

Thus, the invention is not plagued with false signals and undesirable noise, which normally affect point source sensors such as line scanning technology. Therefore, false signals are not present and are not detected. The resultant signal is a very clean and discernible fault that is indisputably detected. Once identified, the data is transmitted to the Quality Assurance Management System (**QAMS™**).

To determine actual resolution of this innovative, state-of-the-art CCD camera scratch and streak detection process the following formulas are used. These implications are:-

The cross direction resolution (effectively a static resolution) per raster line is determined by dividing the field of view (FOV) by the number of active pixel lines (APL) contained within that FOV. RKB minimum FOV per sensor in any given application is generally 2 inches (50.8 cm). In this application we will be using a 6.30 inches (16.00 cm) field of view per sensor, thus to determine minimum resolution capability, the following formula is used:-

**FOV[6] ÷ APL[7] = CDR[8]**

| FOV | ÷ | APL | = | CDR | |
|---|---|---|---|---|---|
| 6.3 | ÷ | 525.00 | = | CDR | |
| | | **CDR** | **=** | **0.012** | inches CD |
| **Cross Direction Resolution Calculation** | | | | **0.305** | millimeters CD |

**APL = Active Pixel Lines**

The machine direction resolution (effectively a dynamic resolution) per raster line is somewhat more involved in determining. Since we are using a two dimension CCD interlaced camera sensor with an approximate ratio of 4:3, the static resolution in the machine direction can easily be obtained. Since we know our CD resolution per sensor is 6.3 inches (16.00 cm), the MD resolution per TV line is 8.00 inches (20.32 cm). However, the calculation of true dynamic resolution involves machine speed and the appropriate number of fields required to obtain minimum two fields of scratch and streak data. Again, since we know what type of sensor we are using, the picture field rate is pre defined at 1/60 of a second, producing a standard picture frame every 1/30 of a second or 0.033 seconds. Thus the formula to use to determine actual dynamic resolution is a follows:-

**DR[9] x NF[10] x WS[11] x SMD12 = MDR**

Thus the actual dynamic resolution as calculated using the above formula indicates that the resolution achieved by the RKB system using its patented, state-of-the-art CCD area scanning technology provides a resolution capability of 1/60 x 3 x WS x SMD = MDR.

| DR | x | NF | x | WS | + | SMD | = | MDR |
|---|---|---|---|---|---|---|---|---|
| 0.0167 | | 3 | x | 8 | + | 8.38 | = | MDR |
| 0.05 | | | x | 8 | **+** | 8.38 | = | MDR |
| | | | 0.40 | + | 8.38 | = | MDR | |
| | | | **MDR** | **=** | **8.78** | inches MD | | |
| **Machine Direction Resolution Calculation** | | | | | **222.99** | millimeters MD | | |

**DR represents data rate (I.e., 20Mhz, 18Mhz etc)**

Thus for the example listed above you have a web traveling at 40 fpm (12.19 m/min) or 8 inches/sec (20.32 cm/sec). The sensors are positioned with a 6.3 inch (16.0 cm) field of view providing a cross direction resolution per TV line of 0.011 inches (0.278 mm) wide. The actual calculated machine direction resolution per TV line is approximately 8.78 inches (22.30 cm). Overall, each pixel contained within the TV line has an equivalent resolution of 0.011 in (0.278 mm) x 0.016 in (0.425 mm). What does this mean?

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[6] Where FOV represents 'Field of View' per sensor

[7] Where APL represents total number of 'TV Lines' (raster lines) in each sensor

[8] Where CDR represents cross direction resolution per TV (raster) line

[9] Where DR represents sensor data rate in seconds

[10] Where NF represents the required number of fields

[11] Where WS represents maximum web speed in inches/sec

12 Where SMD represents the static machine direction resolution (no web movement)

By utilizing a complete raster line containing x number of pixels per line, RKBs CCD Camera-based Video Web Inspection System can process a full line of pixels over a much longer period of time. As a result, processing them out of the signal to noise level can eliminate noise and other variables that might affect one or two pixels. Additionally, by viewing a wider area of the with hundreds of thousands of pixels, comparisons can be made quickly as to what is noise versus an actual defect fault and thus be processed accordingly.

This is the theory, but does it work? Yes. Let's take the RKB scanning technology for example. The resolution per sensor of a streak camera based on a 2500-fpm (762-m/min) web is 0.004" (0.1mm) CD by 27.79" (70.58 cm) MD. Thus, the longer integration time afforded to RKB provides for adequate time to process false signals from real signals. The end result is that RKB, which has proven its technology in the industry, can detect more reliably, consistently and accurately coating scratches and streaks. Additionally, RKB can successfully detect faults as small as 0.002" (0.05mm) wide at any speed, since the only restriction on RKBs approach is length of defect fault, not size which affects line scanning technologies as speed increases.

Whilst it is by no means theoretically impossible for a line scanning system to detect the required defect events at current line speeds, RKBs approach is more in line with being able to achieve it more consistently. Furthermore, you the user can utilize the system to ***"judge roll quality by comparing the streak specification for the grade being run to the streak count provided by the system. This comparison must be on a roll by roll basis based upon the trim pattern such that individual rolls can be shipped or rejected"***. RKB approach can better suit these requirements for reporting streak density increases to analyze each roll better than that of its competition considering the level of detection RKB is capable of seeing versus other system solutions.