

Post-Production/ Image Manipulation

4K+Systems Theory Basic for Motion Picture Imaging

Dr. Hans Kiening

A while ago, digital cameras and cell phones were the biggest thing in consumer electronics, but the most popular phrase today seems to be “HD.” One would think that the “H” in HD stands for “hype.” Although professionals have a clear definition of HD (1920 × 1080 pixels, at least 24 full frames per second, preferably 4:4:4 color resolution), at electronics stores, the “HD-Ready” sticker on hardware offers considerably less performance (1280 × 1024 pixels, 4:2:1, strong compression, etc.). On display are large monitors showing images that are usually interpolated from standard definition images (720 × 576 pixels or less). The catchphrase “HD for the living room” means (on a different quality level) – comparable to the discussion of 2k versus 4k in professional post-production – expectations, and sometimes just basic information, could not be more contradictory. Yet an increasing number of major film projects are already being successfully completed in 4k. So, it is high time for a technically based appraisal of what is really meant by 2k and 4k. This section strives to make a start.

Part 1: Resolution and Sharpness

To determine resolution, a raster is normally used, employing increasingly fine bars and gaps. A common example in real images would be a picket fence displayed to perspective. In the image of the fence, shown in Figure e6.1, it is evident that the gaps between the boards become increasingly difficult to discriminate as the distance becomes greater. This effect is the basic problem of every optical image. In the foreground of the image, where the boards and gaps haven’t yet been squeezed together by the perspective, a large difference in brightness is recognized. The more the boards and gaps are squeezed together in the distance, the less difference is seen in the brightness.



Figure e6.1 Real-world example for a resolution test pattern.
All images courtesy of Dr. Hans Kiening.

To better understand this effect, the brightness values are shown along the yellow arrow into an x/y diagram (Figure e6.2). The brightness difference seen in the y -axis is called *contrast*. The curve itself functions like a harmonic oscillation; because the brightness does not change over time but spatially from left to right, the x -axis is called *spatial frequency*.

The distance can be measured from board to board (orange arrow) on an exposed image such as a 35mm. It describes exactly one period in the brightness diagram (Figure e6.2). If such a period in the film image continues, for example, over 0.1mm, then there is a spatial frequency of 10 line pairs/mm (10 lp/mm, 10 cycles/mm, or 10 periods/mm). Visually expressed, a line pair always consists of a bar and a “gap.” It can be clearly seen in Figure e6.1 that the finer the reproduced structure, the more the contrast will be smeared on that point in the image. The limit of the resolution has been reached when one can no longer clearly differentiate between the structures. This means the resolution limit (red circle indicated in Figure e6.2) lies at the spatial frequency where there is just enough contrast left to clearly differentiate between board and gap.

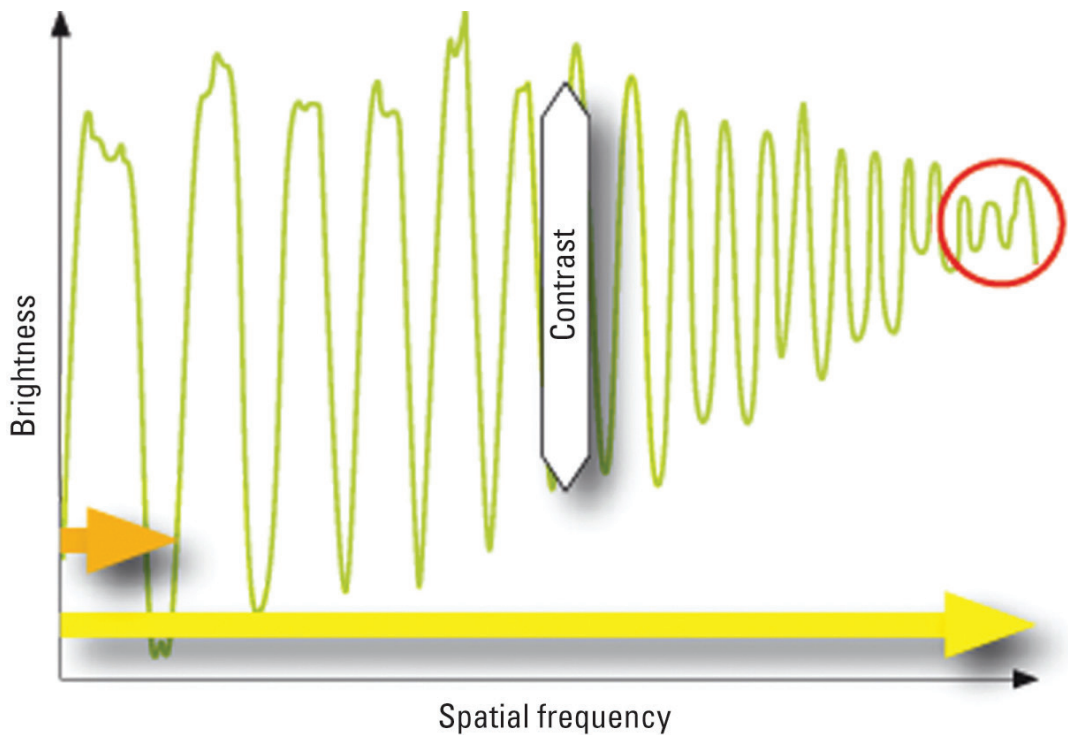


Figure e6.2 Brightness along the picket fence in Figure e6.1.

Constructing the Test

Using picket fences as an example (Figure e6.1), the resolution can be described only in one direction. Internationally and scientifically, a system of standardized test images and line pair rasters to determine and analyze resolution has been agreed on. Horizontal and vertical rasters are thereby distributed over the image surface.

To carry out such a test with a film camera, the setup displayed in Figure e6.3 was used. The transparent test pattern was exposed with 25fps and developed. Figure e6.5 shows the view through a microscope at the image center (orange border in Figure e6.4).

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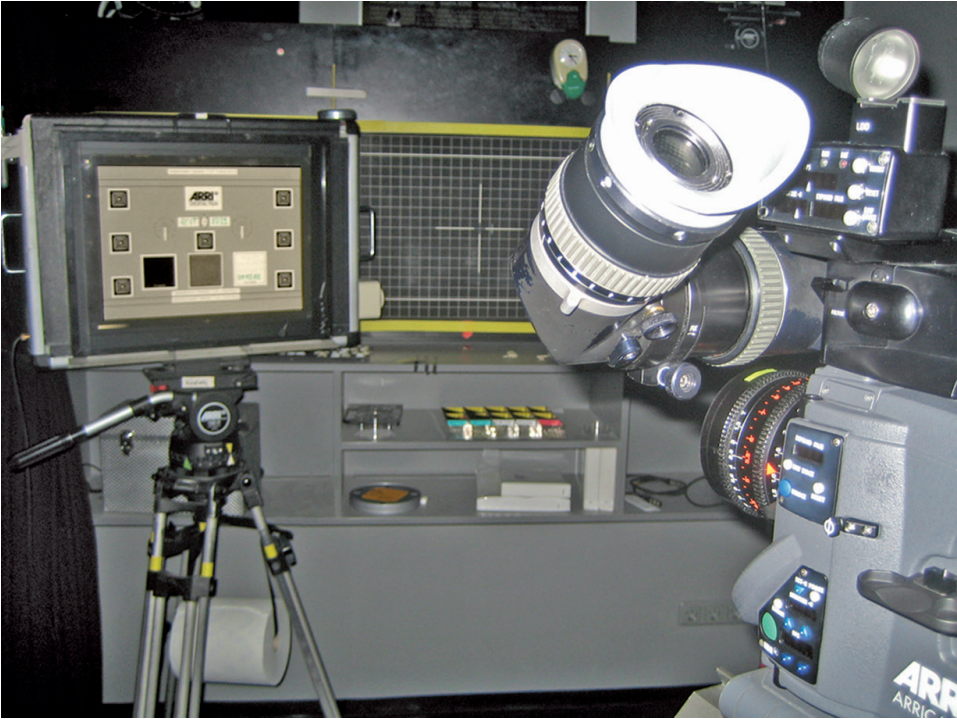


Figure e6.3 Setup for resolution.

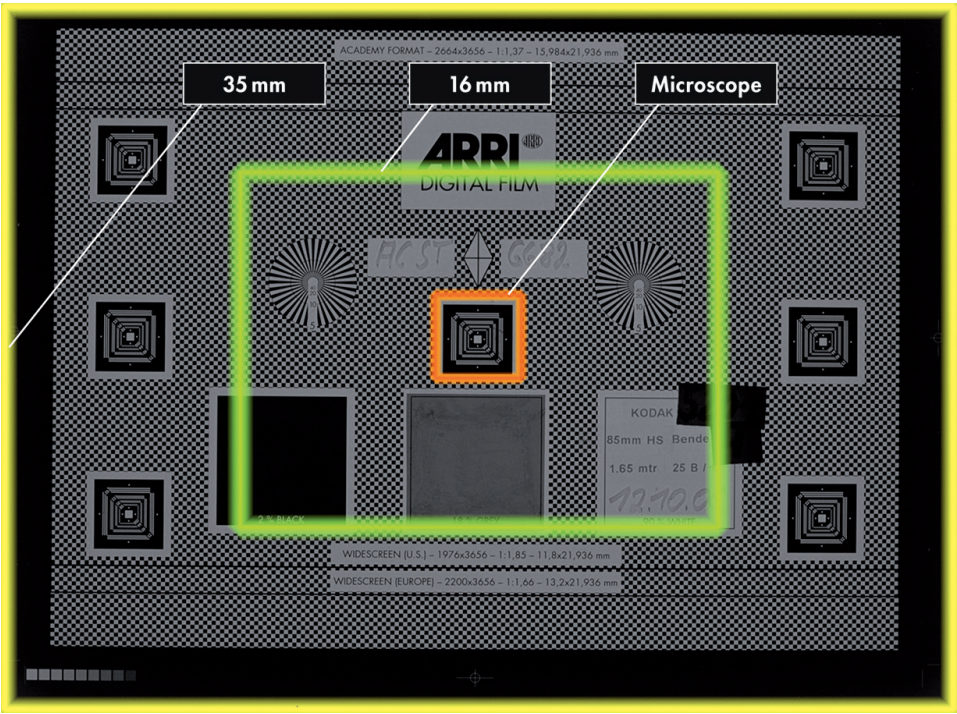


Figure e6.4 Framing.

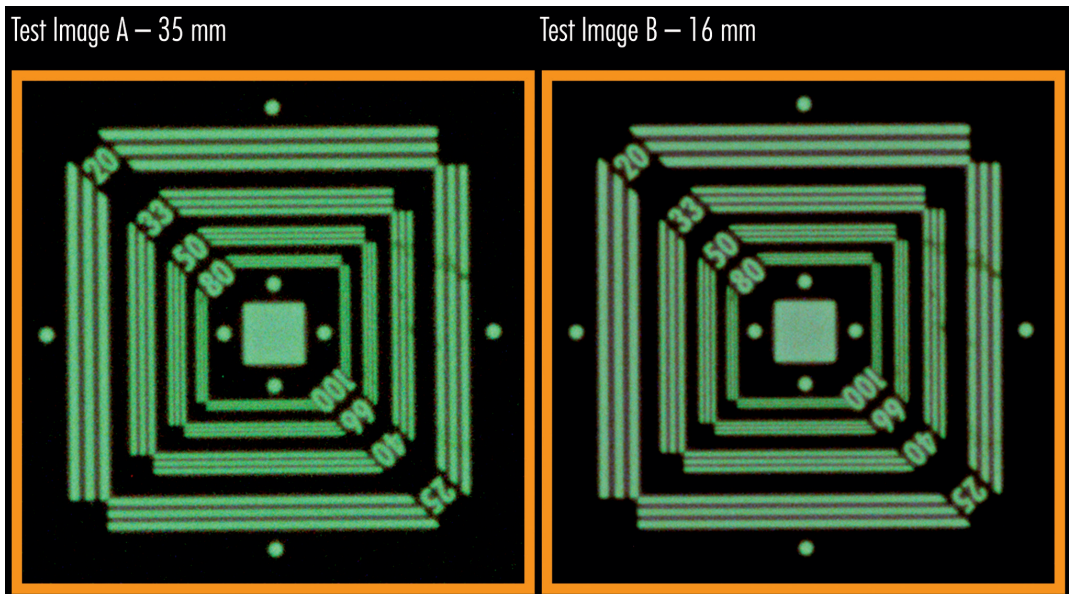


Figure e6.5 View through the microscope at the negative (center).

Resolution Limit 35mm

Camera: ARRICAM ST

Film: Eastman EXR 50D Color Negative Film 5245 EI 50

Lens: HS 85mm F2.8

Distance: 1.65m

It is apparent that the finest spatial frequency that can still be differentiated lies between 80 and 100 lp/mm. For these calculations, a limit of 80 lp/mm can be assumed. The smallest discernible difference was determined by the following:

$$1\text{mm}/80 \text{ lp} = 0.012\text{mm}/\text{lp}$$

Lines and gaps are equally wide, ergo:

$$0.012\text{mm}/2 = 0.006\text{mm} \text{ for the smallest detail}$$

Resolution Limit 16mm

Camera: 416

Film: Eastman EXR 50D Color Negative Film 5245 EI 50

Lens: HS 85mm F2.8

Distance: 1.65m

If a 35mm camera is substituted for a 16mm camera with all other parameters remaining the same (distance, lens), an image will result that is only half the size of the 35mm test image but resolves exactly the same details in the negative.

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Results

This test is admittedly an ideal case, but the ideal is the goal when testing the limits of image storage in film. In the test, the smallest resolvable detail is 0.006mm large on the film, whether 35mm or 16mm. Thus, across the full film width there are $24.576\text{mm}/0.006 = 4,096$ details or points for 35mm film and $12.35\text{mm}/0.006 = 2,048$ points for 16mm film. Because this happens in the analog world, these are referred to as points rather than pixels. These statements depend on the following: (1) looking at the center of the image; (2) the film sensitivity is not over 250 ASA; (3) exposure and development are correct; (4) focus is correct; (5) lens and film don't move against one another during exposure; and (6) speed < 50fps.

Digital

The same preconditions would also exist for digital cameras (if there were a true 4k resolution camera on the market today); only the negative processing would be omitted. Thus, in principle, this test is also suitable for evaluating digital cameras. In that case, however, the test rasters should flow not only horizontally and vertically, but also diagonally and, ideally, circularly. The pixel alignment on the digital camera sensor (Bayer pattern) is rectangular in rows and columns. This allows good reproduction of details, which lie in exactly the same direction, but not of diagonal structures, or other details that deviate from the vertical or horizontal. This plays no role in film, because the sensor elements – film grain – are distributed randomly and react equally well or badly in all directions.

Sharpness

Are resolution and sharpness the same? By looking at the images shown in Figure e6.6, one can quickly determine which image is sharper. Although the image on the left comprises twice as many pixels, the image on the right, whose contrast at coarse details is increased with a filter, looks at first glance to be distinctly sharper. The resolution limit describes how much information makes up each image, but not how a person evaluates this information. Fine details such as the picket fence in the distance are irrelevant to a person's perception of sharpness – a statement that can be easily misunderstood. The human eye, in fact, is able to resolve extremely fine details. This ability is also valid for objects at a greater distance. The decisive physiological point, however, is that fine details do not contribute to the subjective perception of sharpness. Therefore, it's important to clearly separate the two terms, resolution and sharpness.



Figure e6.6 Resolution = sharpness?

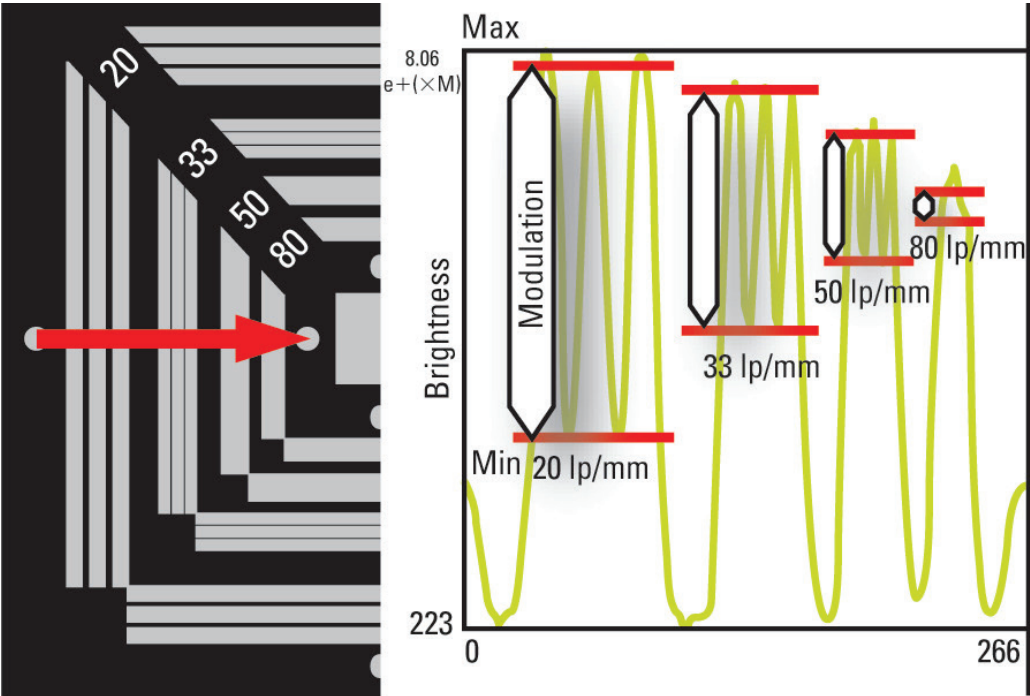
The coarse, contour-defining details of an image are most important in determining the perception of sharpness. The sharpness of an image is evaluated when the coarse details are shown in high contrast. A plausible reason can be found in the evolution theory: “A monkey who jumped around in the tops of trees, but who had no conception of distance and strength of a branch, was a dead monkey, and for this reason couldn't have been one of our ancestors,” said the paleontologist and zoologist George Gaylord Simpson (2008). It wasn't the small, fine branches that were important to survival, but rather the branch that was strong enough to support the monkey.

Modulation Transfer Function

The term *modulation transfer function* (MTF) describes the relationship between resolution and sharpness and is the basis for a scientific confirmation of the phenomenon described earlier. The modulation component in MTF means approximately the same as contrast. Evaluate the contrast (modulation) not only where the resolution reaches its limit, but over as many spatial frequencies as possible and connect these points with a curve, to arrive at the so-called MTF (Figure e6.7).

In Figure e6.7, the x-axis illustrates the already established spatial frequency expressed in line pairs per millimeter on the y-axis, instead of the brightness seen in modulation. A modulation of 1 (or 100%) is the ratio of the brightness of a completely white image to the brightness of a completely black image. The higher the spatial frequency (i.e., the finer the structures in the image), the lower the transferred modulation. The curve seen here shows the MTF of the film image seen in Figure e6.5 (35mm). The film's resolution limit of 80 lp/mm (detail size 0.006mm) has a modulation of approximately 20%.

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$$\text{Modulation} = \frac{[I_{\text{Max}} - I_{\text{Min}}]}{[I_{\text{Max}} + I_{\text{Min}}]}$$

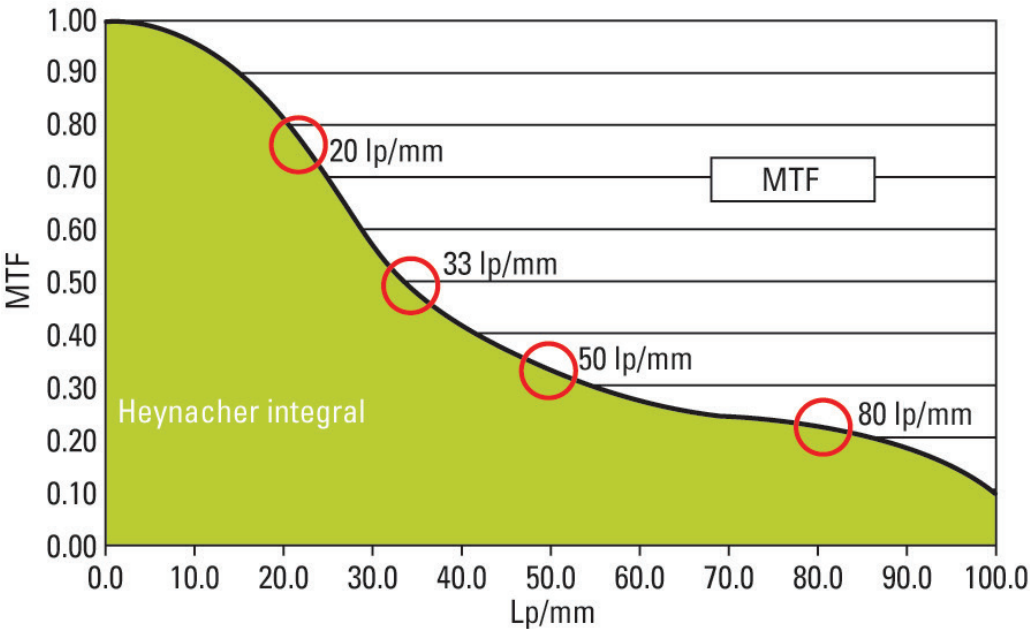


Figure e6.7 Modulation transfer function and the Heynacher integral.

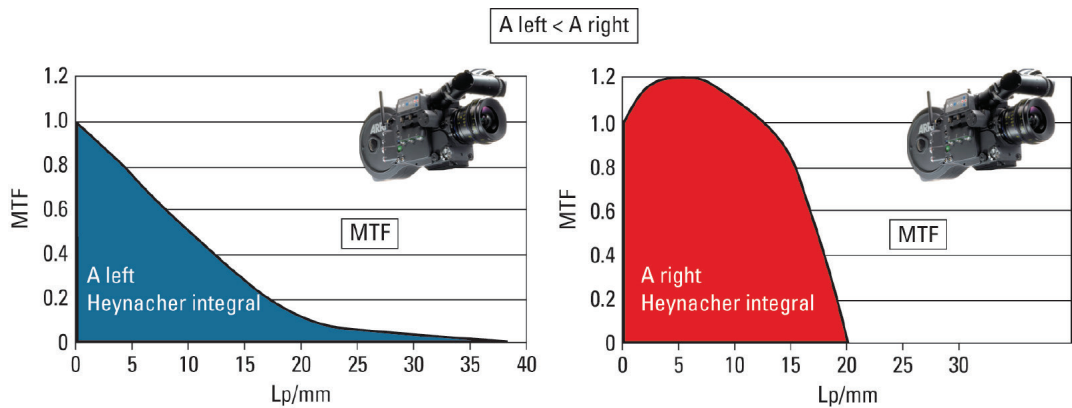


Figure e6.8 MTF and Heynacher integral for Figure e6.7

In the 1970s, Erich Heynacher from Zeiss provided the decisive proof that humans attach more value to coarse, contour-defining details than to fine details when evaluating an image. He found that the area below the MTF curve corresponds to the impression of sharpness perceived by the human eye (the so-called Heynacher integral; Heynacher, 1963). Expressed simply, the larger the area, the higher the perception of sharpness. It is easy to see that the coarse spatial frequencies make up the largest area of the MTF: The farther right into the image's finer details, the smaller the area of the MTF. Looking at the camera example in Figure e6.6, it is obvious that the red MTF curve shown in Figure e6.8 frames a larger area than the blue MTF curve, even if it shows twice the resolution.

For Experts

An explanation of the difference between sine-shaped (MTF) and rectangular (CTF) brightness distribution in such test patterns will not be offered here. However, all relevant MTF curves have been measured according to ISO standards for the fast Fourier transform (FFT of slanted edges).

Part 1 Summary

Sharpness does not depend only on resolution. The modulation at lower spatial frequencies is essential. In other words, contrast in coarse details is significantly more important for the impression of sharpness than contrast at the resolution limit. The resolution that delivers sufficient modulation (20%) in 16mm and 35mm film is reached at a detail size of 0.006mm, which corresponds to a spatial frequency of 80 lp/mm (not the resolution limit < 10%).

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Part 2: Into the Digital Realm

How large is the storage capacity of the film negative? How many pixels does one need to transfer this spatial information as completely as possible into the digital realm, and what are the prerequisites for a 4k chain of production? These are some of the questions addressed in this section.

The analyses here are deliberately limited to the criteria of resolution, sharpness, and local information content. These, of course, are not the only parameters that determine image quality, but the notion of 4k is usually associated with them.

Film as a Carrier of Information

Film material always possesses the same performance data: the smallest reproducible detail (20% modulation) on a camera film negative (up to EI 200) is about 0.006mm, as determined by the analysis done earlier in this section. This can also be considered the size of film's pixels, a concept that is well known from electronic image processing. It does not matter if the film is 16mm, 35mm, or 65mm – the crystalline structure of the emulsion is independent of the film format. Also, the transmission capability of the imaging lens is generally high enough to transfer this spatial frequency (0.006mm = 80 lp/mm) almost equally well for all film formats.

The film format becomes relevant, however, when it comes to how many small details are to be stored on its surface – that is the question of the total available storage capacity. In Table 6.1, the number of pixels is indicated for the image's width and height. Based on the smallest reproducible detail of 0.006mm, Table 6.1 gives an overview of the storage capacity of different film formats.

Table e6.1 Number of Film Pixels per Height and Width

Format	Width × Height (SMPTE/ISO Camera Gate)	Pixels
Super 16mm	12.35mm × 7.42mm	2058 × 1237 pixels
Super 35mm	24.92mm × 18.67mm	4153 × 3112 pixels
65mm	52.48mm × 23.01mm	8746 × 3835 pixels

Scanning

These analog image pixels must now be transferred to the digital realm. Using a Super 35mm image as an example, the situation is as follows:

The maximum information depth is achieved with a line grid of 80 lp/mm. The largest spatial frequency in the film image is therefore $1/0.012\text{mm}$ (line 0.006mm + gap 0.006mm). According to the scanning theorem of Nyquist and Shannon, the digital grid then has to be at least twice as fine, that is, $0.012\text{mm}/2 = 0.006\text{mm}$. Converted to the width of the Super 35mm negative, this adds up to $24.92\text{mm}/0.006\text{mm} = 4153$ pixels for digitization.

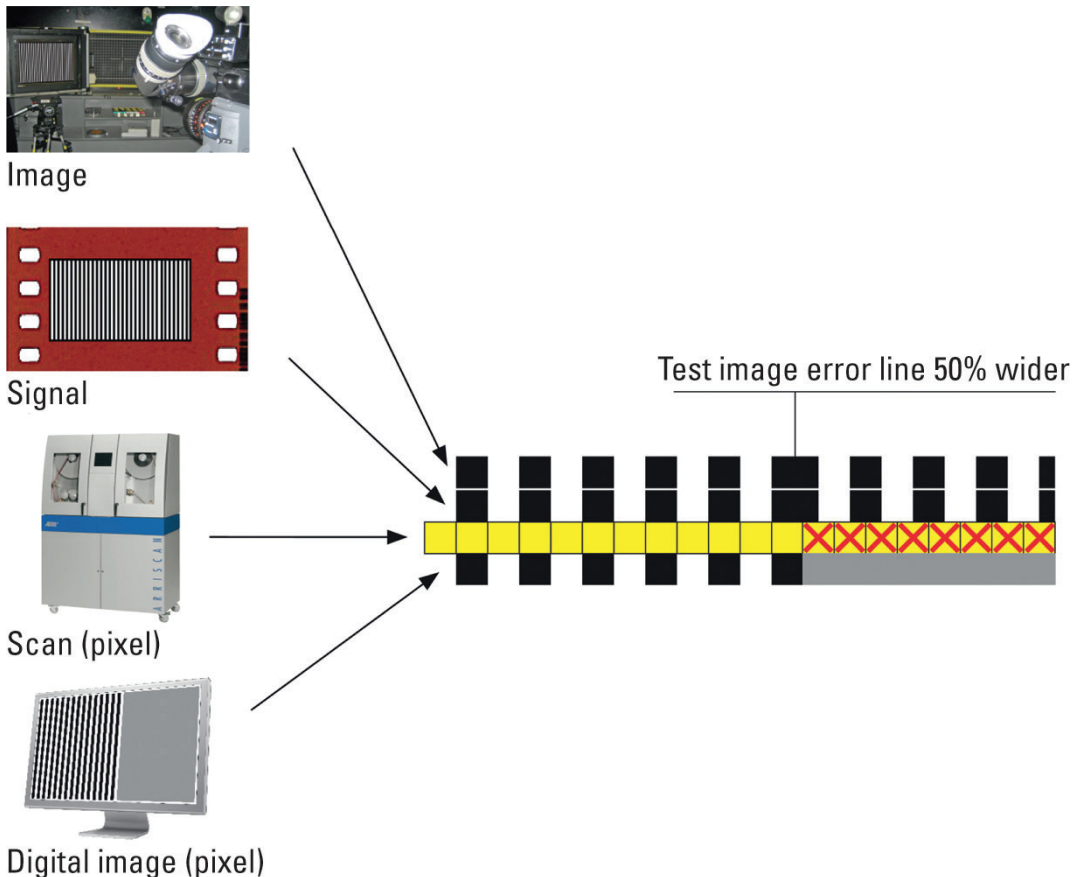


Figure e6.9 Principle of aliasing.

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Aliasing

Stick with the line grid as a test image and assume a small error has crept in. One of the lines is 50% wider than all of the others. While the film negative reproduces the test grid unperturbedly and thereby true to the original, the regular digital grid delivers a uniform gray area, starting at the faulty line – simply because the pixels, which are marked with an “x,” consist of half a black line and half a white gap, and so the digital grid perceives a simple mix – which is gray.

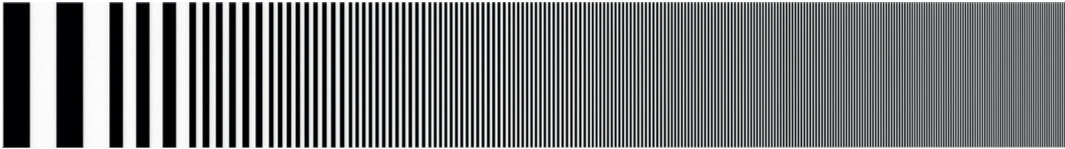


Figure e6.10 Frequency sweep.

So, if the sample to be transferred consists of spatial frequencies that become increasingly high – as in Figure e6.10 – the digital image suddenly shows lines and gaps in the wrong intervals and sizes. This is a physical effect whose manifestations are also known as acoustics in the printing industry. There, the terms *beating waves* and *moiré* are in use. In digitization technology, the umbrella term for this is *aliasing*. Aliasing appears whenever there are regular structures in the images that are of similar size and aligned in the same way as the scanning grid. Its different manifestations are shown in Figure e6.11. The advantage of the film pixels, the grains, is that they are statistically distributed and not aligned to a regular grid and they are different from frame to frame.



Figure e6.11 Aliasing.

Figure e6.11 shows an area of incipient destructive interference and an area of pseudo-modulation. This describes the contrast for details, which lie beyond the threshold frequency and which, in the digital image, are indicated in the wrong place (out of phase) and have the wrong size. This phenomenon does not only apply to test grids – even the jackets of Academy Award winners may fall victim to aliasing (Figures e6.12 and e6.13). *Note:* You can see from these figures that aliasing is a nasty artifact for still pictures. It becomes significantly worse for motion pictures because it changes dynamically from frame to frame.



Figure e6.12 Digital still camera with 2 megapixels.



Figure e6.13 Digital still camera with 1 megapixel.

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Impact on the MTF

It is very obvious that the aliasing effect also has an impact on the MTF. Pseudo-modulation manifests itself as a renewed rise (hump) in the modulation beyond the scanning limit. Pseudo, because the resulting spatial frequencies (lines and gaps) have nothing to do with reality: Instead of becoming finer, as they do in the scene, they actually become wider again in the output image (Figures e6.14 and e6.15).

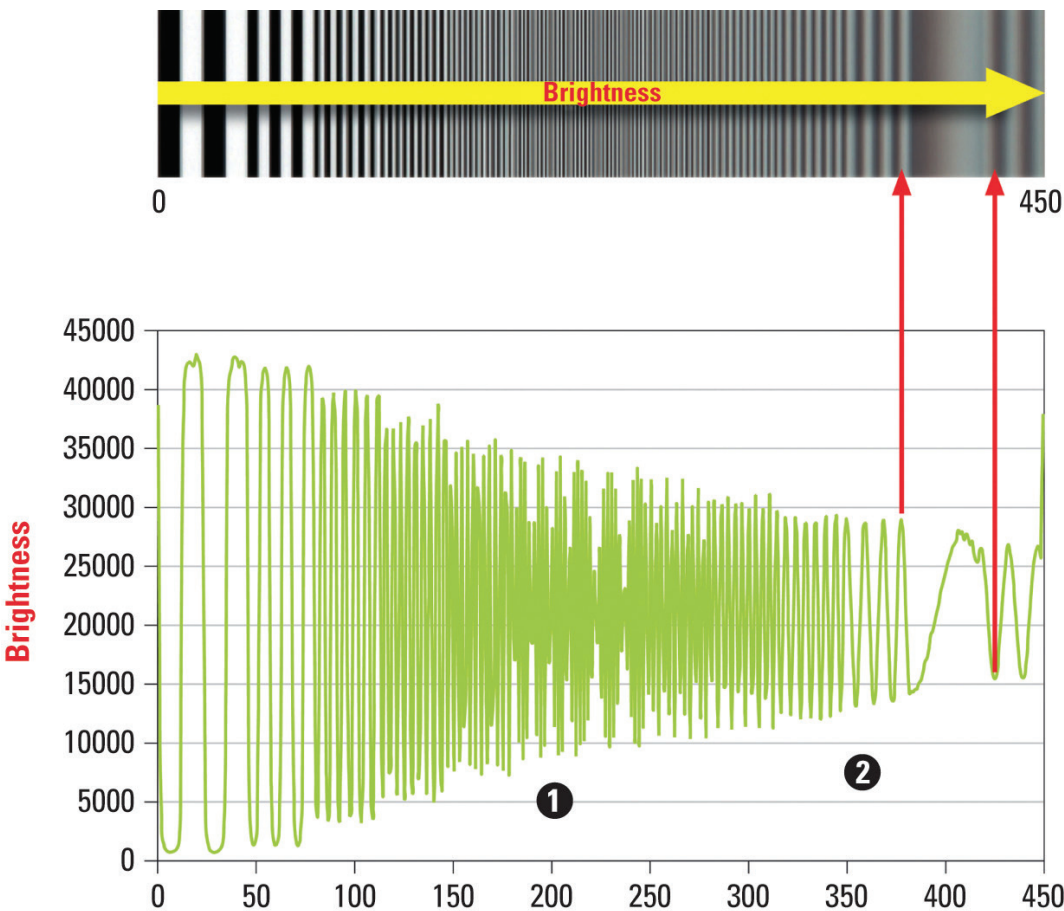


Figure e6.14 Luminance along the frequency sweep.

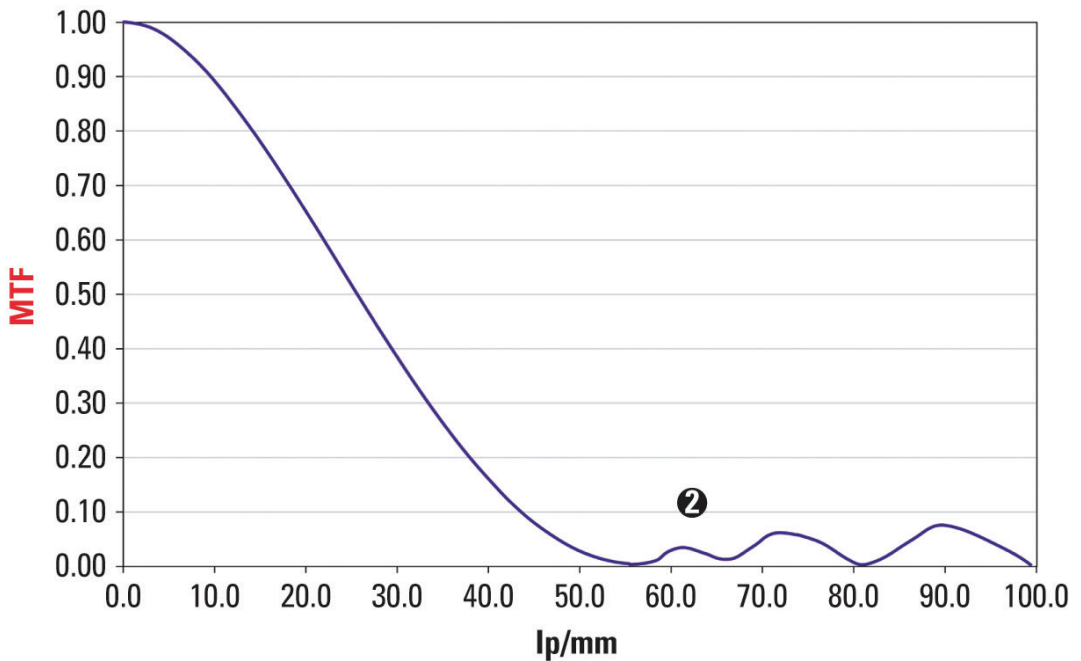


Figure e6.15 Resulting MTF.

Avoiding Alias

The only method for avoiding aliasing is to physically prevent high spatial frequencies from reaching the scanning raster; that is, by defocusing or through a so-called optical low pass, which in principle does the same thing in a more controlled fashion. Unfortunately, this not only suppresses high spatial frequencies; it also affects the contrast of coarse detail, which is important for sharpness perception.

Another alternative is to use a higher scanning rate with more pixels, but this also has its disadvantages. Because the area of a sensor cannot become unlimitedly large, the single sensor elements have to become smaller to increase the resolution. However, the smaller the area of a sensor element becomes, the less sensitive it will be. Accordingly, the acquired signal must be amplified again, which leads to higher noise and, again, to limited picture quality. The best solution often lies somewhere in between. A combination of a 3k sensor area (large pixels, little noise) and the use of mechanical microscanning to increase resolution (doubling it to 6k) is the best solution to the problem.

Table e6.2 Required Scanning Pixels

Format	Width	Pixels	Scanning Resolution/ Digital Acquisition	Final Image Size
Super 16mm	12.35mm	2058 pixels	3k	2k
Super 35mm	24.92mm	4153 pixels	6k	4k

The currently common maximum resolution in post-production is 4k. The gained 6k data is calculated down with the help of a filter. In the process, the MTF is changed thus:

1. The response at half of the 4k scanning frequency itself is zero.
2. Spatial frequencies beyond the scanning frequency are suppressed.
3. The modulation at low spatial frequencies is increased.

Whereas measures (1) and (2) help to avoid aliasing artifacts in an image, measure (3) serves to increase the surface ratio under the MTF. As discussed earlier, this improves the visual impression of sharpness. To transfer the maximum information found in the film negative into the digital realm without aliasing and with as little noise as possible, it is necessary to scan the width of the Super 35mm negative at 6k. This conclusion can be scaled to all other formats.

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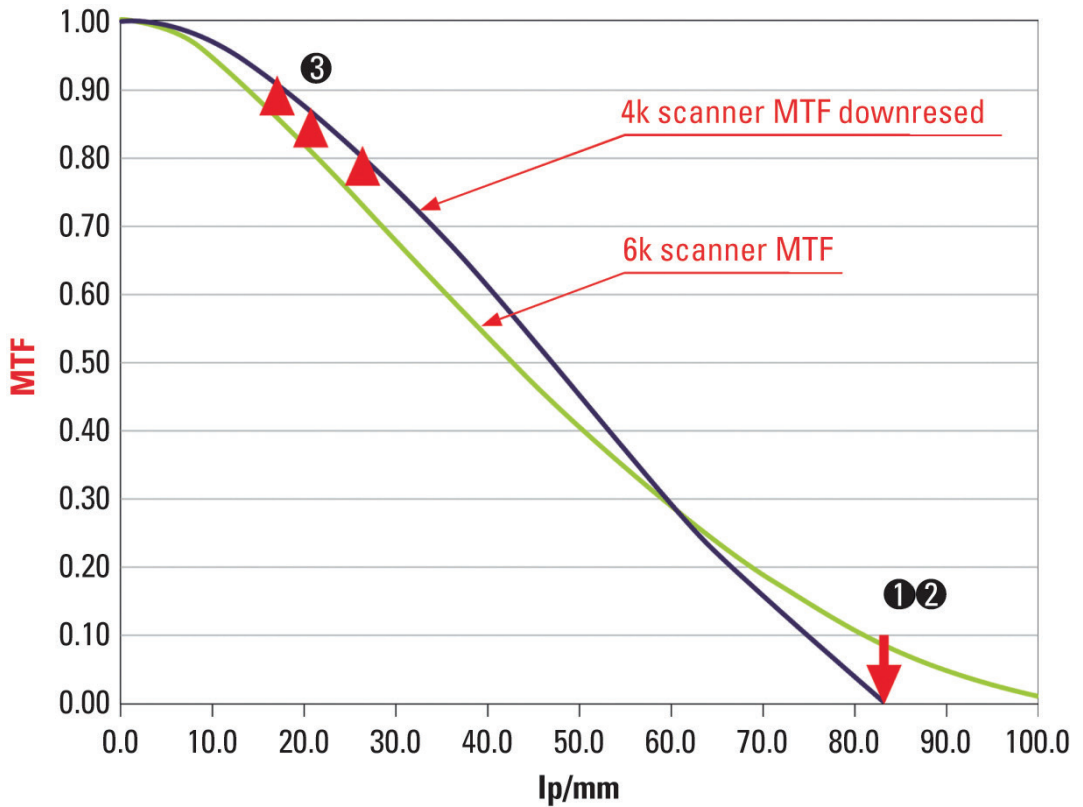


Figure e6.16 Scanner MTF.

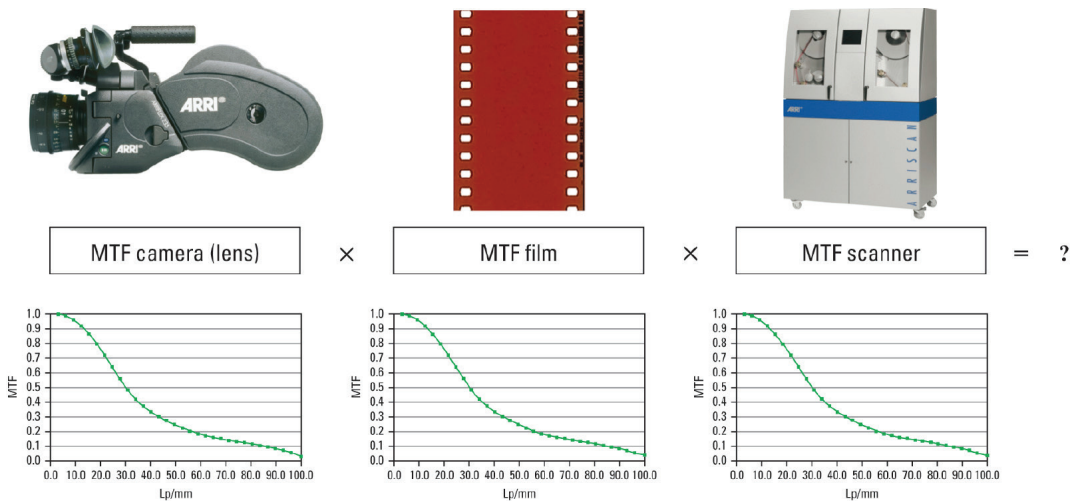


Figure e6.17 Theory of MTF cascading.

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The Theory of MTF Cascading

What losses actually occur over the course of the digital, analog, or hybrid post-production chain?

The MTF values of the individual chain elements can be multiplied to give the system MTF. With the help of two or more MTF curves, one can quickly compare – above all – without any subjectively influenced evaluation. Also, once the MTF of the individual links of the production chain is determined, the expected result can be easily computed at every location within the chain, through simple multiplication of the MTF curves.

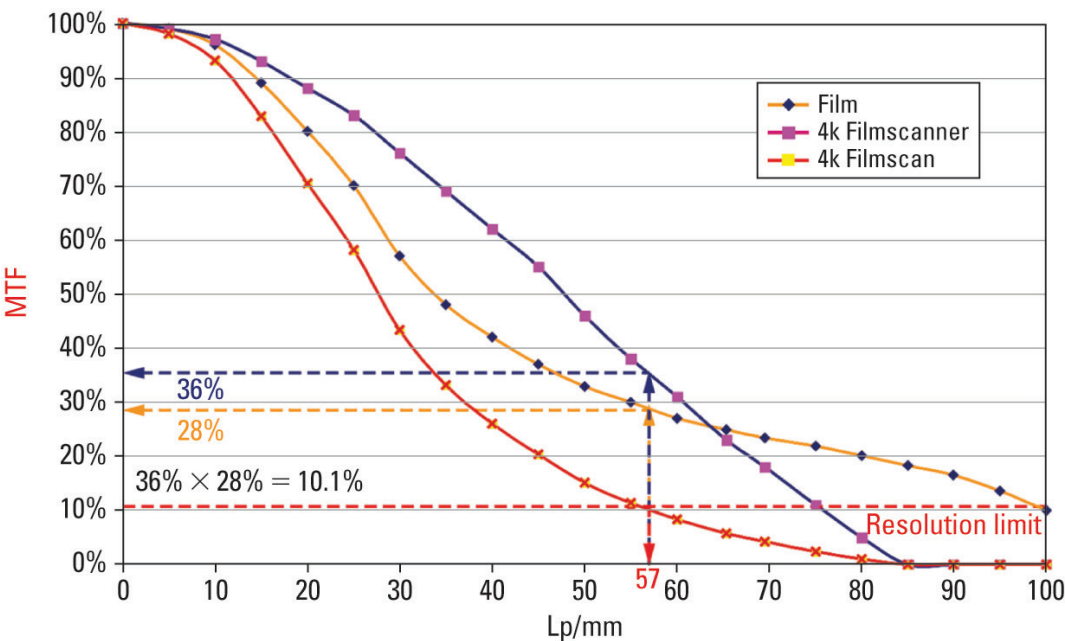


Figure e6.18 Resulting MTF in a 4k scan.

MTF Camera (Lens) × MTF Film × MTF Scanner ×?

An absolutely permissible method for a first estimate is the use of manufacturers' MTF data for multiplication. However, it must be remarked that there usually are very optimistic numbers behind this data, and calculating them in this way shows the best-case scenario. Actual measured values are used for the calculations here. Instead of using the MTF of the raw stock and multiplying it by the MTF of the camera lens, the resulting MTF of the exposed image is directly measured and multiplied by the MTF of a 4k scanner.

What Does the Result Show?

The MTF of a 35mm negative scanned with 4k contains only little more than 56 lp/mm (the equivalent of 3k with the image width of Super 35mm) usable modulation. The resolution limit is defined by the spatial frequency, which is still transferred with 10% modulation. This result computes from the multiplication of the modulation of the scanner and of the film material for 57 lp/mm:

$$\begin{aligned} & \text{MTF}_{4k_scanner} (57 \text{ lp/mm}) \times \text{MTF}_{exposed_film} (57 \text{ lp/mm}) \\ &= \text{MTF}_{in_4k_scan} (57 \text{ lp/mm}) 36\% \times 28\% \\ &= 10.08\% \end{aligned}$$

The same goes for a digital camera with a 4k chip. There, a low-pass filter (actually a deliberate defocusing) must take care of pushing down modulation at half of the sampling frequency (80 lp/mm) to 0, because otherwise aliasing artifacts would occur.

Ultimately, neither a 4k scan nor a (three-chip) 4k camera sensor can really transfer resolution up to 4k.

This is a not an easily digestible paradigm. It basically means that 4k data only contains 4k information if it was created pixel by pixel on a computer – without creating an optical image beforehand. However, this cannot be the solution, because then, in the future, there would be animated movies only – a scenario in which actors and their affairs could only be created on the computer. This would be a tragic loss, and not just for supermarket tabloid newspapers!

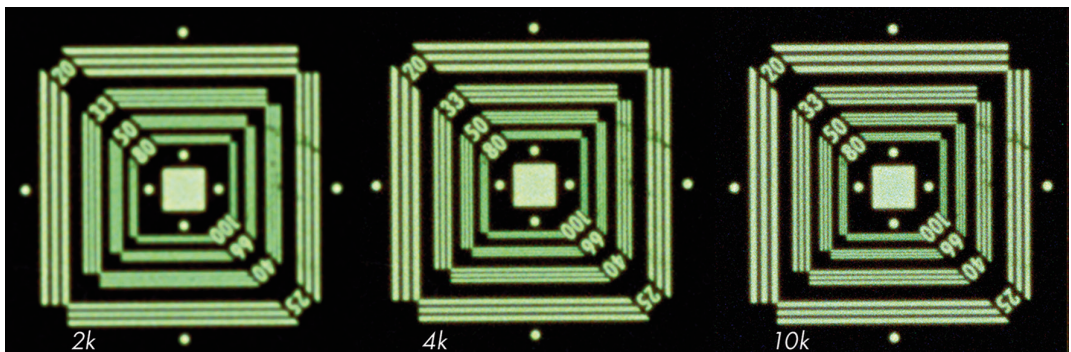


Figure e6.19 From left, 2k, 4k, and 10k scans of the same 35mm camera negative.

Part 2 Summary

In the foreseeable future, 4k projectors will be available, but their full quality will come into its own only when the input data provides this resolution without loss. At the moment, a correctly exposed and 6k/4k scanned 35mm film negative is the only practically existing acquisition medium for moving pictures that comes close to this requirement. By viewing from a different angle, one could say that the 4k projection technology will make it possible to see the quality of 35mm negatives without incurring losses through analog processing laboratory technology. The limiting factor in the digital intermediate (DI) workflow is not the (ideal exposed) 35mm film but the 4k digitization. As you can see in Figure e6.19, a gain in sharpness is still possible when switching to higher resolutions. Now imagine how much more image quality could be achieved with 65mm (factor 2.6 more information than 35mm)!

These statements are all based on the status quo in film technology – for an outlook on the potential of tomorrow's film characteristics, read Tadaaki Tani's article (Tani, 2007). The bottom line is that 35mm film stores enough information reserves for digitization with 4k+.

Part 3: Does 4k Look Better Than 2k?

The two most frequently asked questions regarding this subject are “How much quality is lost in the analog and the DI chain?” and “Is 2k resolution high enough for the digital intermediate workflow?”

The Analog Process

“An analog copy is always worse than the original.” This is an often-repeated assertion. But it is true only to a certain extent in the classic post-production process; there are, in fact, quality-determining parameters that, if controlled carefully enough, can ensure that the level of quality is maintained: When photometric requirements are upheld throughout the chain of image capture, creating the intermediates, and printing, the desired brightness and color information can be preserved for all intents and purposes.

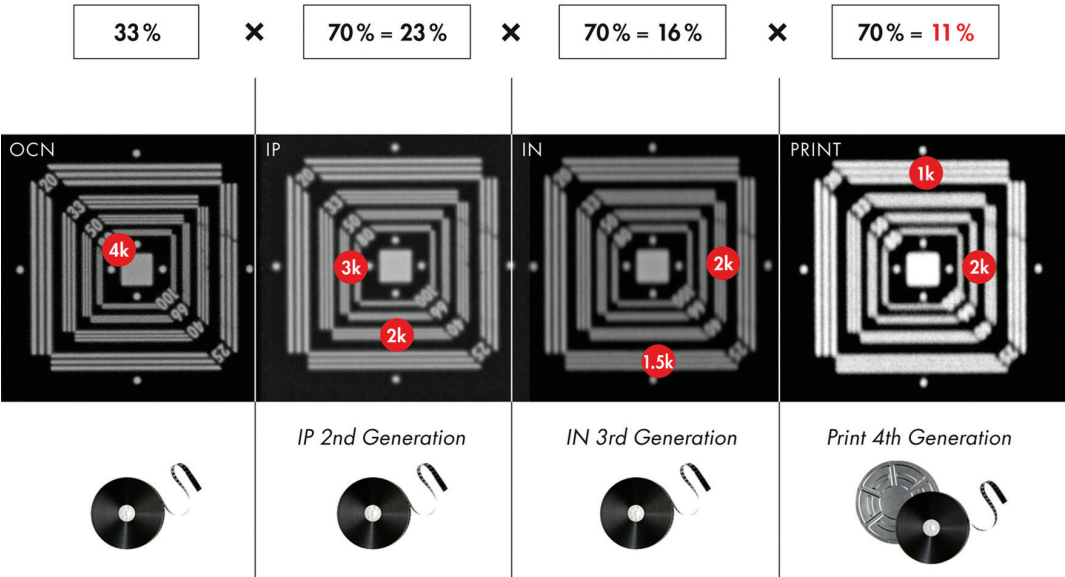


Figure e6.20 10k scans (green), photochemical lab from camera negative to print.

Table e6.3 MTF Losses in Photochemical Lab

MTF at 50 lp/mm	
Exposed Film Image Kodak 5205 (camera + film)	33%
Kodak 5242 Intermediate (copy to IR)	70%
Kodak 5242 Intermediate (copy to IN)	70%
Kodak Print Film 2393	70%
$33\% \times 70\% = 23\% \times 70\% = 16\% \times 70\% = 11\%$	

Clear loss of quality, however, indeed occurs where structures – that is, spatial image information – are transferred. In other words, resolution and sharpness are reduced. This occurs as a result of the rules of multiplication. Table 6.3 shows how 50 lp/mm with a native 33% modulation in the original is transferred throughout the process.

This, however, is an idealized formula, because it assumes that the modulation of the film material and the contact printing show no loss of quality. This is not the case in reality, which can be seen in the differences between the horizontal and vertical resolutions.

Is 2k Enough for the DI Workflow?

Although the word *digital* suggests a digital reproduction with zero loss of quality, the DI process is bound by the same rules that apply to the analog process, because analog components (i.e., optical path of scanner and recorder) are incorporated. To make this clearer, again perform the simple multiplication of the MTF resolution limit in 4k (= 80 lp/mm). The MTF data illustrates the best filming and DI components that can be currently achieved.

As the multiplication proves, inherent to the 4k DI chain, modulation cannot occur at 80 lp/mm, even though the digitally exposed internegative shows considerably more image information than can be preserved throughout the traditional analog chain. An *internegative*, or intermediate negative, is a film stock used to duplicate an original camera negative. Conventionally, it is generated with film printers alternatively exposed from the digitized data on a film recorder. Then it is called a *digital intermediate*.

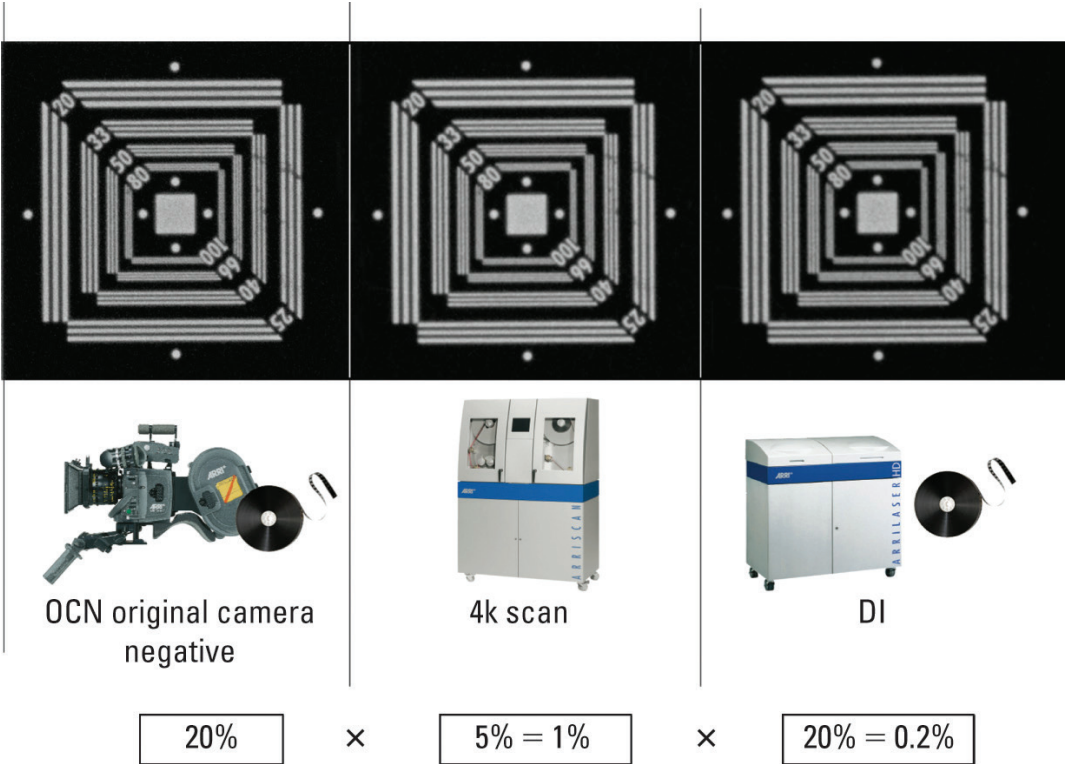


Figure e6.21 10k scans (green), photochemical lab from camera negative to print.

Table e6.4 DI MTF Losses in 4k DI Workflow

MTF at 80 lp/mm	
Exposed Film Image 5205 (ARRICAM, VP, OCN)	20%
Film Scanner MTF at 4k (ARRISCAN)*	5%
Recorded Internegative Fuji RDI (Film + ARRILASER)	20%
$20\% \times 5\% = 1\% \times 20\% = 0.2\%$	
*Per definition to avoid alias.	

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Why, then, is a 4k digital process still a good idea, even though it cannot reproduce full 4k image information? The answer is simple, according to the Heynacher integral (the area beneath the MTF curve): The perception of sharpness depends on the modulation of coarse local frequencies. When these are transferred with a higher modulation, the image is perceived as sharp. Figure e6.22 shows the results of 2k and 4k scans.

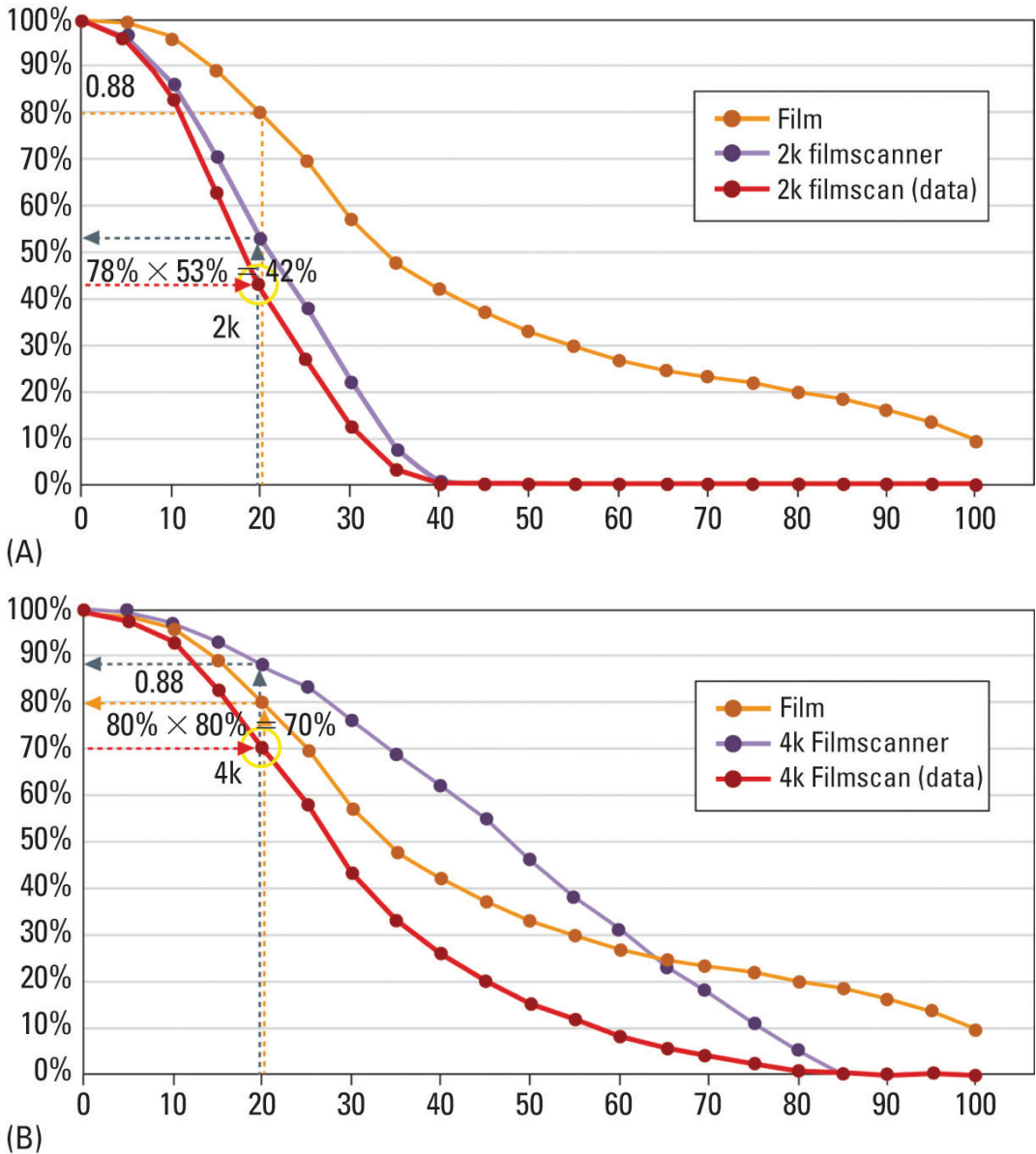


Figure e6.22 (A) 2k scan. (B) 4k scan.

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Because a 4k scanner offers not only more resolution, but also more modulation in lower local frequencies, the resulting 4k images will be perceived as being sharper. When this data is recorded out in 4k on Fuji RDI, for example, it produces the results shown in Figure e6.23.

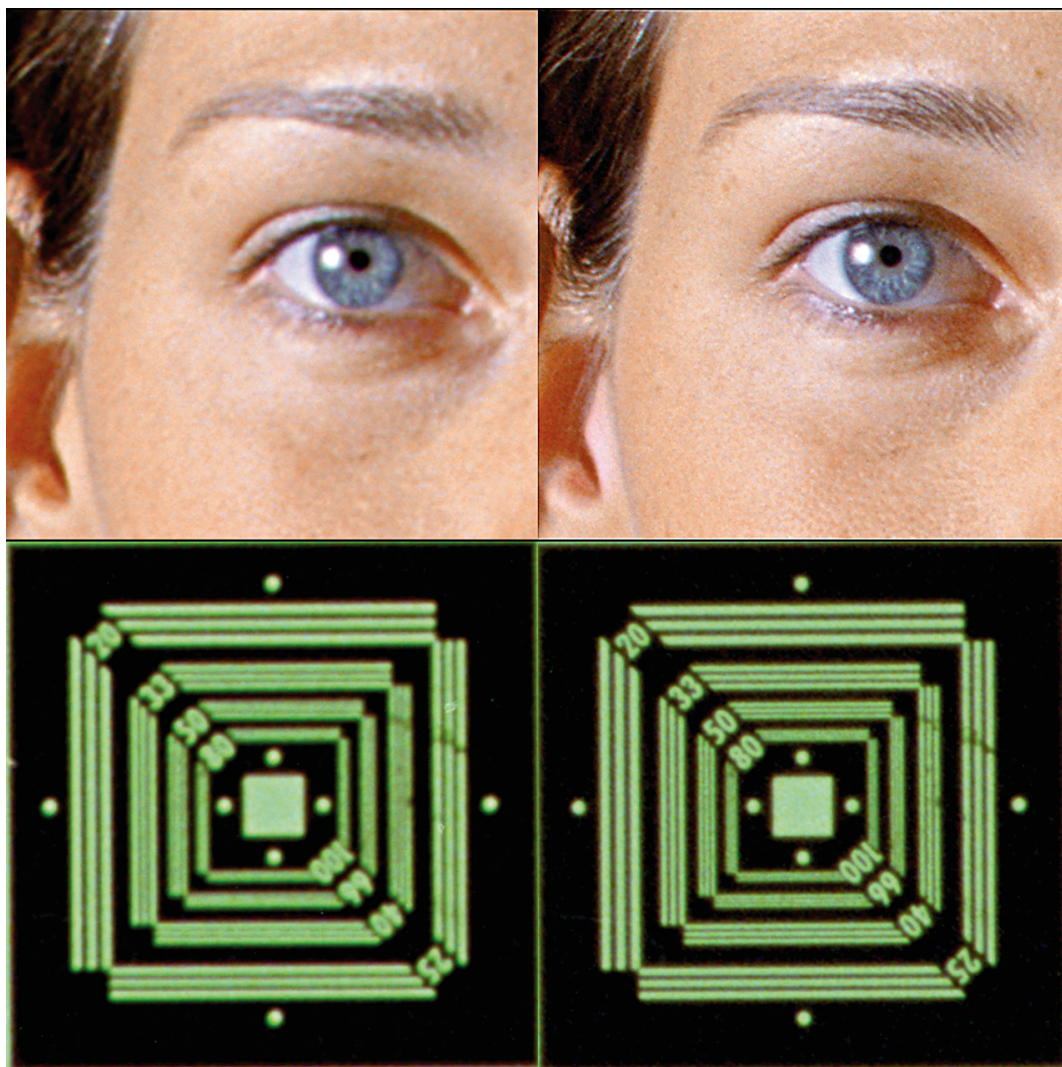


Figure e6.23 Cutout of a 2k (*left*) and a 4k (*right*) digital internegative.

Part 3 Summary

A 4k workflow is advantageous for DI and film archiving. The MTF characteristics seen in 4k scanning will transfer coarse detail (which determines the perception of sharpness) with much more contrast than 2k scanning. It is thereby irrelevant whether or not the resolution limit of the source material is resolved. It is very important for the available frequency spectrum to be transferred with as little loss as possible.

Part 4: Visual Perception Limitations for Large Screens

The section discusses the most important step in the production chain – the human eye. Again, the focus is resolution, sharpness, and alias. More specifically, the focus is now on general perception at the limits of human visual systems, when viewing large images on the screen. This limitation shows how much effort one should put into digitization of detail.

A very common rumor still circulates that alleges that one could simply forget about all the effort of 4k, because nobody can see it on the screen anyway. The next sections take a closer look to see if this is really true!

Basic Parameters

Three simple concepts can be used to describe what is important for a natural and sharp image, listed here in descending order of importance:

1. Image information is not compromised with alias artifacts.
2. Low spatial frequencies show high modulation.
3. High spatial frequencies are still visible.

This implicitly means that an alias-affected image is much more annoying than one with pure resolution.

Further, it would be completely wrong to conclude that one could generate a naturally sharp image by using low resolution and just push it with a filter. Alias-free images and high sharpness can be reached only if oversampling and the right filters for down-scaling to the final format have been used.

Resolution of the Human Eye

The fovea of the human eye (the part of the retina that is responsible for sharp central vision) includes about 140,000 sensor cells per square millimeter. This means that, if two objects are projected with a separation distance of more than 4m on the fovea, a human with normal visual acuity (20/20) can resolve them. On the object side, this corresponds to 0.2mm in a distance of 1m (or 1 minute of arc).

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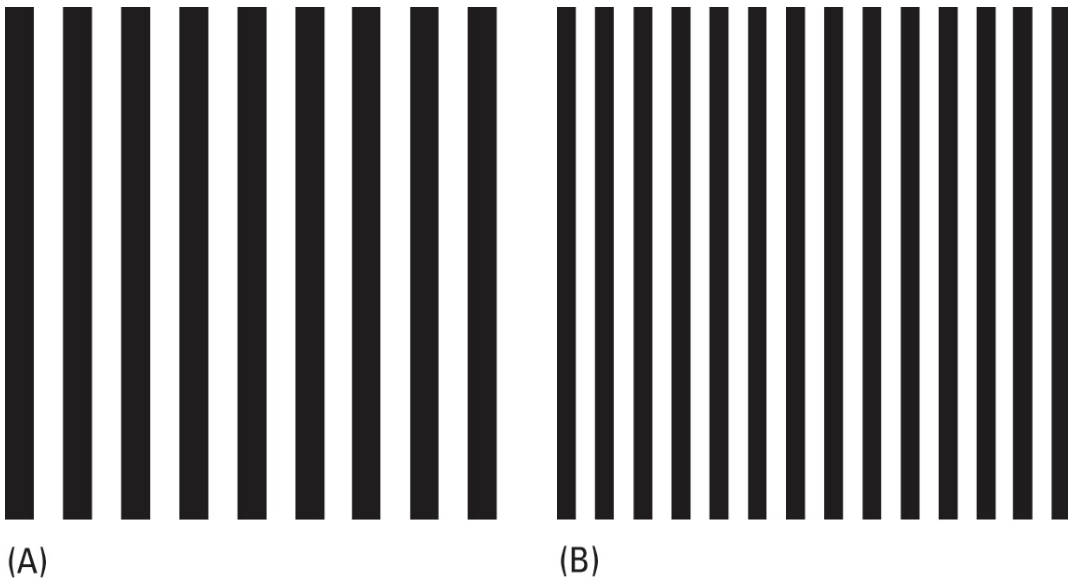


Figure e6.24 (A) 3mm (to be viewed at a 10m distance). (B) 2mm.

In practice, of course, this depends on whether the viewer is concentrating only on the center of the viewing field, whether the object is moving very slowly or not at all, and whether the object has good contrast to the background.

As discussed previously, the actual resolution limit will not be used for further discussion, but rather the detail size that can be clearly seen. Allowing for some amount of tolerance, this would be around 0.3mm at a 1m distance (= 1.03 minutes of arc). In a certain range, one can assume a linear relation between distance and the detail size:

0.3mm in 1m distance » 3mm in 10m distance

This hypothesis can be easily proved. Pin the test pattern displayed in Figures e6.24A and B on a well-lit wall and walk away 10m. You should be able to clearly differentiate between the lines and gaps in Figure e6.24A (3mm); in Figure e6.24B (2mm), however, the difference is barely seen. Of course, this requires an ideal visual acuity of 20/20. Nevertheless, if you cannot resolve the pattern in Figure e6.24A, you might consider paying a visit to an ophthalmologist!

Large-Screen Projection

This experiment can be transferred for the conditions in a theater. Figure e6.25 shows the outline of a cinema with approximately 400 seats and a screen width of 12m. The center row of the audience is at 10m. An observer in this row would look at the screen with a viewing angle of 60 degrees. Assuming that the projection in this theater is digital, the observer could easily differentiate $12,000\text{mm}/3\text{mm} = 4000$ pixels.

The resolution limit is not reached below a distance of 14m. In other words, under these conditions, more than 50% of the audience would see image detail up to the highest spatial frequency of the projector.

Large theaters generally have screens with widths of 25m or more. Figure e6.26 shows the number of pixels per image width that would be needed if the resolution limit of the eye were the critical parameter for dimensioning a digital projection.

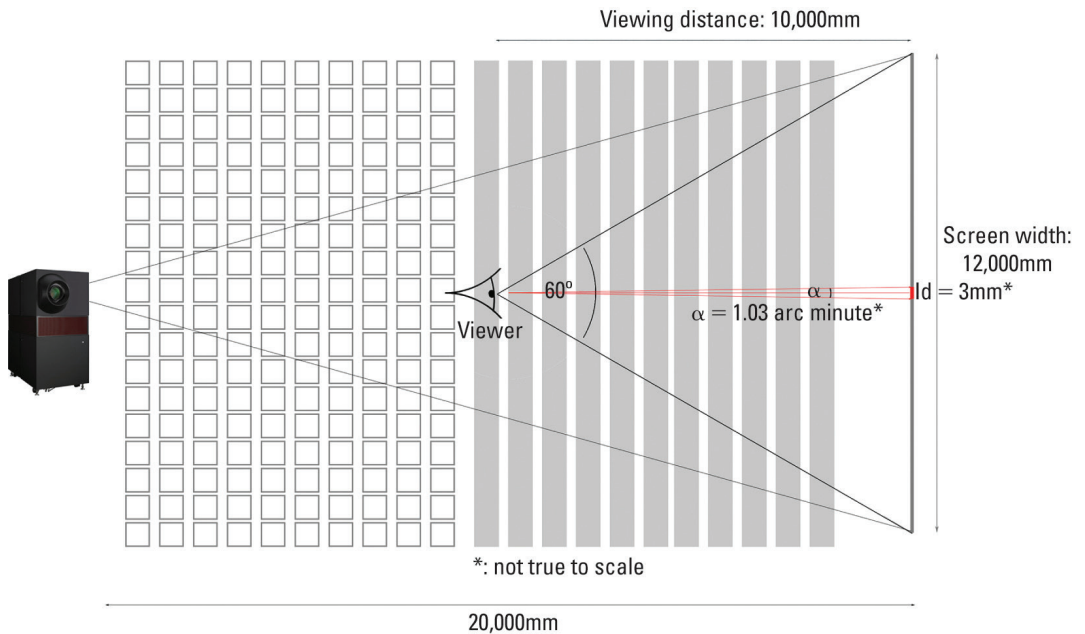


Figure e6.25 Resolution limit in the theater.

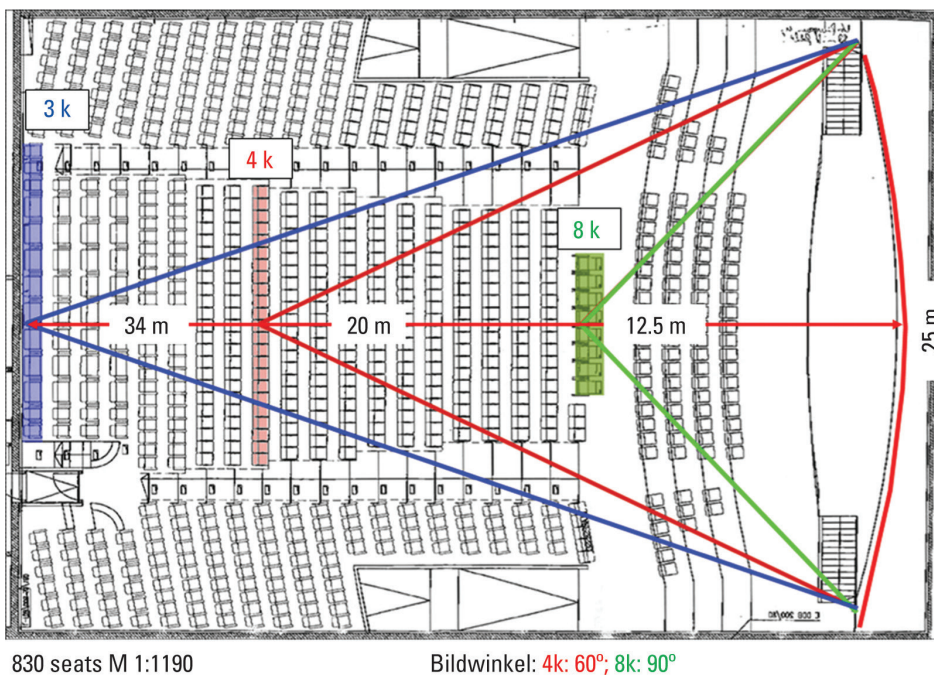


Figure e6.26 Resolution limit for large screens.

Chapter 6

Part 4 Summary

It can be concluded that the rumor is simply not true! A large portion of the audience would be able to see the 4k resolution of the projector. At the same time, the higher resolution inevitably raises the modulation of lower spatial frequencies, which in turn benefits everyone in the theater.

Conclusion

The discussions in this section have shown that a scientific approach is necessary to get a clear view of the real problem instead of merely counting megapixels. This section has addressed only the static image quality factors: sharpness and resolution. As mentioned at the start of this section, there are many more parameters to consider; therefore, an article about the transfer of photometry (sensitivity, contrast, characteristic curve) from scene to screen is being written.

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