While five years ago digital cameras and cell phones were the biggest thing in consumer electronics, the most popular phrase nowadays seems to be "HD." One could think that the "H" in HD stands for "Hype." Although professionals have a clear definition for HD (1920 × 1080 pixels, at least 24 full frames per second, preferably 4:4:4 color resolution), at electronics stores we see the "HD-Ready" sticker on hardware which offers considerably less performance (1280 × 1024 pixels, 4:2:1, strong compression, etc.). On display is a large monitor showing images that are usually interpolated standard definition (720 × 576 pixel sor less). What the catchword HD means for the living room is – on a different quality level – comparable to the discussion of 2k vs. 4k in professional postproduction – expectations, and sometimes just basic information couldn't be more contradictory. Yet an increasing number of major film projects are already being successfully completed in 4k. So, it's high time for a technically-based appraisal of what we really mean by 2k and 4k. This article strives to make a start.

Part I: resolution & sharpness

The first part will start with the terms resolution and sharpness, focusing on the subjective perception of the viewer. This introduction will be based on real image examples from 16mm and 35mm films which, despite the complexity of the subject, should be possible to present without too much reliance upon mathematics.

Part II: into the digital realm

Part two will describe the information content of 16mm, 35mm, and 65mm film images and how they can best be transferred into the digital world.

Part III: production chain

The third part will illustrate how do the various operational steps in the analogue or hybrid production chain (digital intermediate) influence this content?

Part IV: visual perception limitations for large screens

Is 4K worth the effort ? Is it possible for the average guy in the theatre to see details in that size ? Part IV tries to answer this question and shows where are the limitations of our vision system.

Seeing is believing – of course we can't actually show these images on paper. To escape the limitations posed by the print environment, these sample images in their original resolution can be downloaded from our FTP server at:

ftp2.arri.de
login: 4film
Password: ARRI

Part I resolution and sharpness

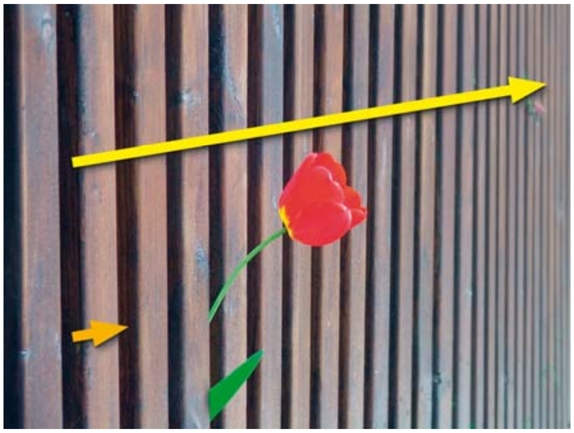
…that's what it's about when we talk about 4k – at least superficially. Yet these aren't the only image parameters, not even the most important – but they're certainly the ones most discussed, and for a good reason: here you can immediately interpret the results optically, without extensive instrumentation or special expertise – even though it's easy to be fooled by your own eyes …

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.

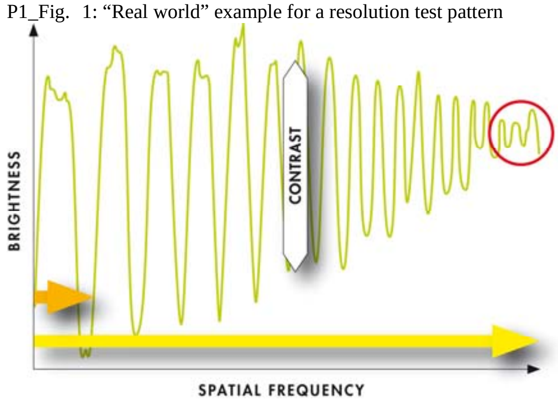
In the image of the fence, we can see that the gaps between the boards become increasingly difficult to discriminate as the distance becomes greater. This effect is the basic problem of every optical image. In the foreground of the image, where the boards and gaps haven't yet been squeezed together by the perspective, we can recognize a large difference in brightness. The more the boards and gaps are squeezed together in the distance, the less difference we see in the brightness.

To understand this effect better, we will enter the brightness values along the yellow arrow into an x/y diagram. The brightness difference seen in the y-axis is called contrast. The curve itself functions like a harmonic oscillation. Because the brightness changes not over time but spatially, from left to right, we call the x-axis spatial frequency.

We can measure the distance from board to board (orange arrow) on an exposed image, 35mm negative, for example. This distance describes exactly one period in the brightness diagram. If such a period in the film image continues, for example, over 0.1mm, then we have a spatial frequency of 10 line pairs per millimetre. (10 Lp/mm, 10 Cycles/mm or 10 periods per mm). Visually expressed, a line pair always consists of a bar and a "gap." It's easy to see in the image: the finer the reproduced structure, the more the contrast will be "slurred" on that point in the image. We have reached the limit of the resolution when we can no longer clearly differentiate between the structures, that means that the resolution limit (red circle) lies at the spatial frequency where there is just enough contrast left to clearly differentiate between board and gap.



P1_Fig. 1: "Real world" example for a resolution test pattern



P1_Fig. 2: Brightness along the yellow arrow in P1_Fig. 1

Constructing the Test

Using picket fences as our example, we can only describe the resolution in one direction. Now there are some experts out there who think that we only need to add some Venetian blinds to the image and the world of the image analyst looks better already. Internationally and scientifically, we have agreed upon a system of standardized test images and line pair rasters to determine and analyze resolution. Horizontal and vertical rasters are thereby distributed over the image surface.

To carry out such a test with a film camera, we used a setup as displayed in P1_P3_Fig. 4.

The transparent test pattern was exposed with 25fps and developed. In P1_P3_Fig. 5 you can see the view through a microscope at the image center (orange border in P1_P3_Fig. 3)

Resolution Limit 35mm

Camera:	ARRICAM ST
Film:	Kodak 5245 50 ASA
Lens:	HS 85mm F2.8
Distance:	1.65 meter

If you download the image **35_micro.tif** and look at it on your monitor with a zoom factor of 100% you can see that the finest spatial frequency that still can be differentiated lies between 80 and 100 Lp/mm. We'll assume for our calculations a limit of 80 Lp/mm – here's how we arrived at the smallest discernible difference.

1mm / 80 Lp = 0.012mm per Line Pair

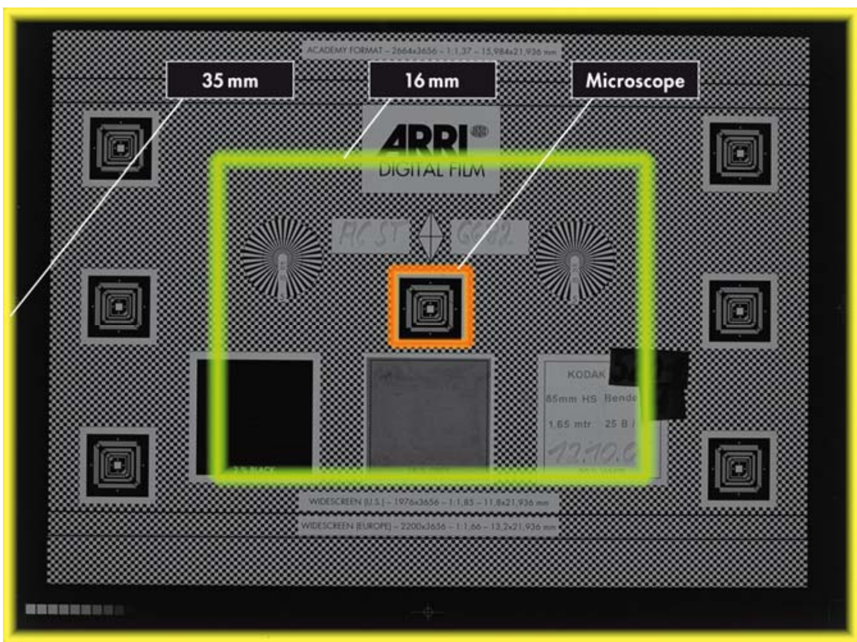
Lines and Gaps are equally wide, ergo:

0.012mm / 2 = 0.006mm for the smallest detail

Resolution Limit 16mm

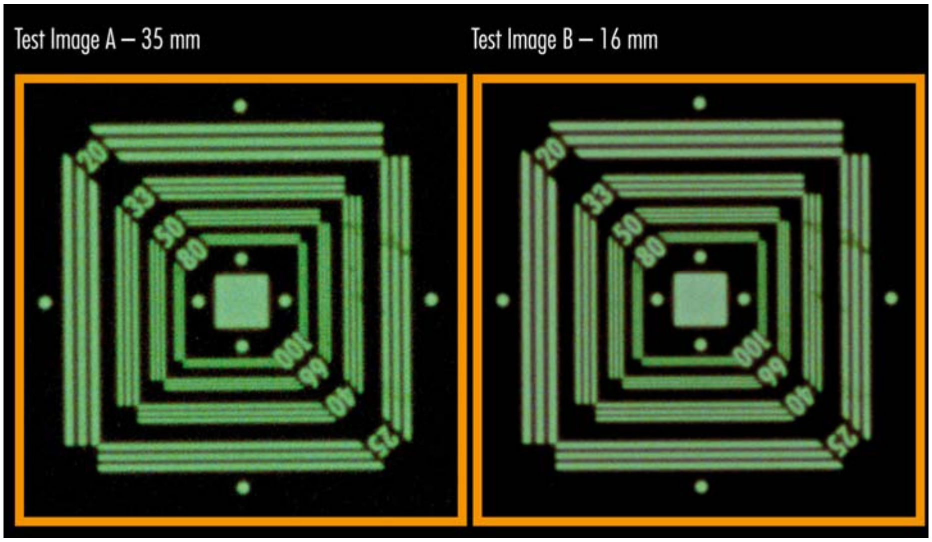
Camera: 416
Film: Kodak 5245 50 ASA
Lens: HS 85mm F2.8
Distance: 1.65 meter

If you substitute the 35mm camera for a 16mm camera but leave all other parameters the same (distance, lens), an image will result (image **16_micro.tif**) that is only half the size of the 35mm test image, but resolves exactly the same details in the negative.



P1_Fig. 3: Area captured with 35 and 16mm negative (yellow/green border) and cutout viewed in the microsope (orange border)

P1_Fig. 4: Setup for camera resolution test with transparent test pattern



P1_Fig. 5: Microsope view on 35mm negative (left) and 16mm (right)

Results

This test is admittedly an ideal case, but the ideal is the goal when testing the limits of image storage in film. In our test, the smallest resolvable detail is 0.006mm large on the film, whether 35mm or 16mm. Across the full film width there are then 24.576mm / 0.006 = 4096 details or points for 35mm film and 12.35mm / 0.006 = 2048 points for 16mm film. I purposely refer to these as points and not pixels because we're still operating in the analogue world.

These statements depend upon the following:

a) we're looking at the center of the image
b) the film sensitivity is not over 250 ASA
c) exposure and development are correct
d) focus is correct
e) lens and film don't move against one another during exposure
f) speed < 50fps

Digital

Of course the exact 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, though, 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 the exact same direction, but not of diagonal structures, or other details which 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

P1_Fig. 6: Resolution = Sharpness?

Is resolution and sharpness the same? Look at both images and quickly decide which is sharper.

Although the image on the left is comprised of twice as many pixels, the image on the right, whose contrast at course 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 our perception of sharpness – a statement which can easily be misunderstood, the human eye, in fact, is well able to resolve extremely fine details. This ability is also valid for objects at a greater distance. The decisive physiological point, though, is the fact that fine details don't contribute to the subjective perception of sharpness. Therefore, it's important to clearly separate the two terms resolution and sharpness.

The coarse, contour-defining details of an image are most important in determining perception of sharpness. The sharpness of an image is evaluated when the course details are shown in high contrast.

A plausible reason can be found in 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," says the palaeontologist and zoologist George Gaylord Simpson (http://de.wikipedia.org/wiki/George_Gaylord_Simpson). It wasn't the small, fine branches that were important to survival, but rather the branch that was strong enough to support our ancestor.

MTF

Modulation Transfer Function – a monstrous word from the field of optics which describes the relationship between resolution and sharpness, and which is the basis for a scientific confirmation of the phenomenon described above. The modulation component in MTF means approximately the same as contrast.

If we 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, we arrive at the so-called Modulation Transfer Function (MTF). Fig7

On the x-axis we see the already-established spatial frequency expressed in Lp/mm, on the y-axis, instead of brightness we see 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 – in other words 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 P1_Fig. 5 (35mm). The film's resolution limit of 80 Lp/mm (detail size 0.006mm) has a modulation of approx. 20%.

In the 1970's, 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). Expressed simply: the larger the area, the higher the perception of sharpness.

It’s easy to see that the coarse spatial frequencies comprise the largest area of the MTF. The further right we move into the image’s finer details, the smaller the area of the MTF.

If we utilize our camera example from P1_Fig. 6 again and look at the corresponding MTF Curve it is quite obvious that the red MTF curve frames a larger area than the blue MTF curve, even if this one shows twice the resolution.

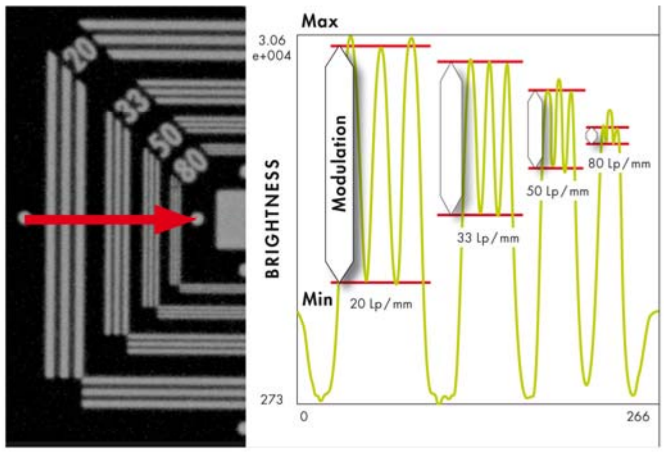
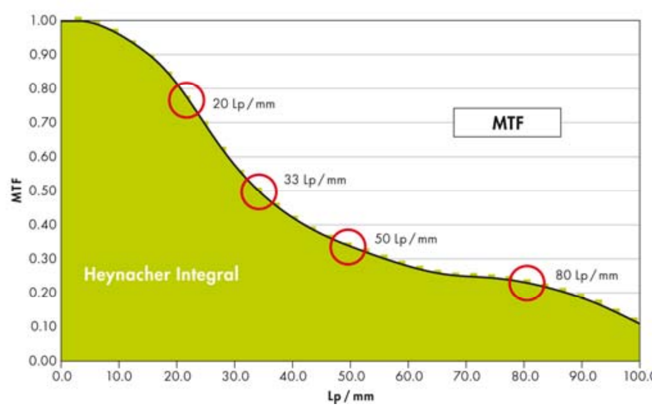
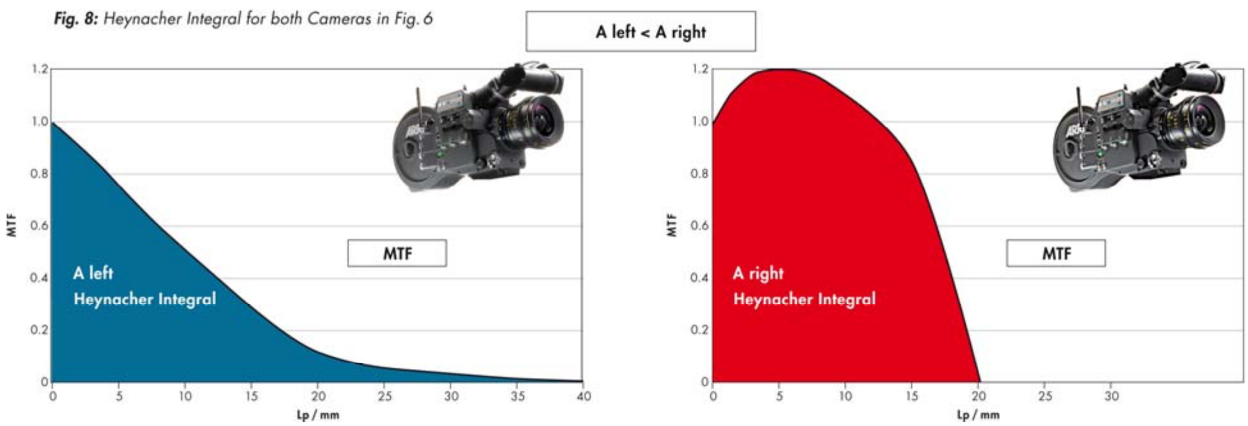


Fig. 7: Modulation Transfer Function (MTF) and the Heynacher Intergral

$$\text{Modulation} = \frac{(I_{Max} - I_{Min})}{(I_{Max} + I_{Min})}$$





P1_Fig. 8: Heynacher Integral for both Cameras in P1_Fig. 6

For Experts

For simplicity's sake, we will forgo an explanation of the difference between sine-shaped (MTF) and rectangular (CTF) brightness distribution in such test patterns. However, all relevant MTF curves have been measured according to ISO standards (FFT of slanted edges).

summary Part I

1. Sharpness does not only depend on resolution. The modulation at lower spatial frequencies is essential. In other words: Contrast in course details is significantly more important for the impression of sharpness than contrast at the resolution limit.

2. The resolution that delivers sufficient modulation (20%) at 16 mm and 35 mm film is reached at a detail size of 0.006 mm, which corresponds to a spatial frequency of 80 lp/mm (not the resolution limit < 10%!).

Part II 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 that this part of the article hopes to answer.

Our analyses 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.

16 mm, 35 mm, 65 mm – Film as a Carrier of Information

No matter how it is cut – film material always possesses the same performance data: the smallest reproducible detail (20% modulation) on a camera film negative (up to 200 ASA) is about 0.006 mm – as was determined in our analysis from part 1. We can think of this as the size of film's "pixels", a concept that is well known from electronic image processing. And it does not matter if it is 16 mm, 35 mm, or 65 mm film: 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 (0.006 mm = 80 lp/mm) almost equally well for all film formats.

The film format becomes relevant, however, when it comes to how many such very small details are to be stored on its surface – that is the question of the total available storage capacity. In the table below the number of "pixels" are indicated for the image's width and height.

Based on the smallest reproducible detail of 0.006 mm the table gives an overview of the storage capacity of different film formats.

Format	Width × Height (SMPTE/ISO Cameragate)	Pixels
S 16 mm	12.35 mm × 7.42 mm	2058 × 1237 pixels

S 35 mm	24.92 mm × 18.67 mm	4153 × 3112 pixels
65 mm	52.48 mm × 23.01 mm	8746 × 3835 pixels

Scanning

These – up to now still „analog“ – image pixels must now be transferred to the digital realm. Taking a Super 35 mm image as an example, the situation is as follows:

The maximum information depth is achieved with a line grid 80 lp/mm. The largest spatial frequency in the film image is therefore 1 / 0.012 mm (line 0.006 mm + gap 0.006 mm). 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 mm / 2 = 0.006 mm.

Converted to the width of the Super 35 mm negative this adds up to 24.92 mm / 0.006 mm = 4153 pixels for digitalization.

All is well – if there wasn’t the “*at least*”, which was accentuated in the sentence before.

Aliasing

Let us stick with our line grid as a test image, and let us assume a small error has crept in. One of the lines is 50% wider than all others.

While the film negative reproduces the test grid unperturbedly and thereby true to original, the regular digital grid delivers a uniform grey 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, so the digital grid percieves a simple mix – which is grey.

So if the sample to be transferred consists of spatial frequencies that become increasingly higher – as in P2_Fig. 2 – all of a sudden the digital image shows lines and gaps in wrong intervals and sizes.

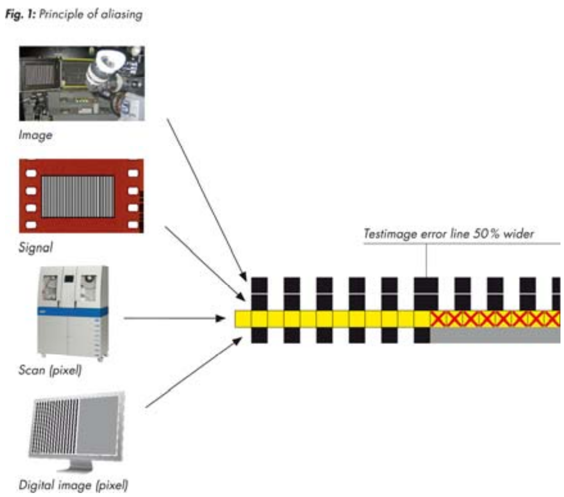
This is a physical effect whose manifestations are also known in acoustics and the printing industry. There, the terms beating waves and moire are in use. In digitization technology, the umbrella term for this is aliasing. Aliasing appears whenever there are regular structures in the images which are of similar size and aligned in the same way as the scanning grid. Its different manifestations are shown in P2_Fig. 3. The advantage of the “film pixel”, the grain, is that they are statistically distributed and not aligned to a regular grid and it is different from frame to frame.

(1) Incipient destructive interference

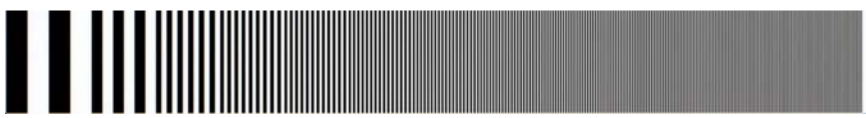
(2) Pseudo modulation
This describes the contrast for details which lie beyond the threshold frequency, and which, in the digital image, are indicated in the wrong place (out of phase) and having the wrong size.This, by the way, is a phenomenon that does not only apply to test grids: even academy award winners respectively their jackets may fall victim to aliasing.

To prevent speculations about the origin of these examples, this be said: Neither a blue nor a red digital camera were used.

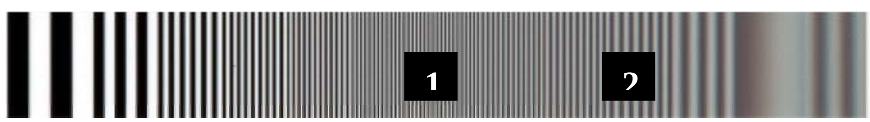
N. B.: Alias is a nasty artefact for still pictures as you can see, it becomes significantly worse for motion picture because it changes dynamically from frame to frame.



P2_Fig. 1: Principle of aliasing



P2_Fig. 2: 6k scan of a frequency sweep



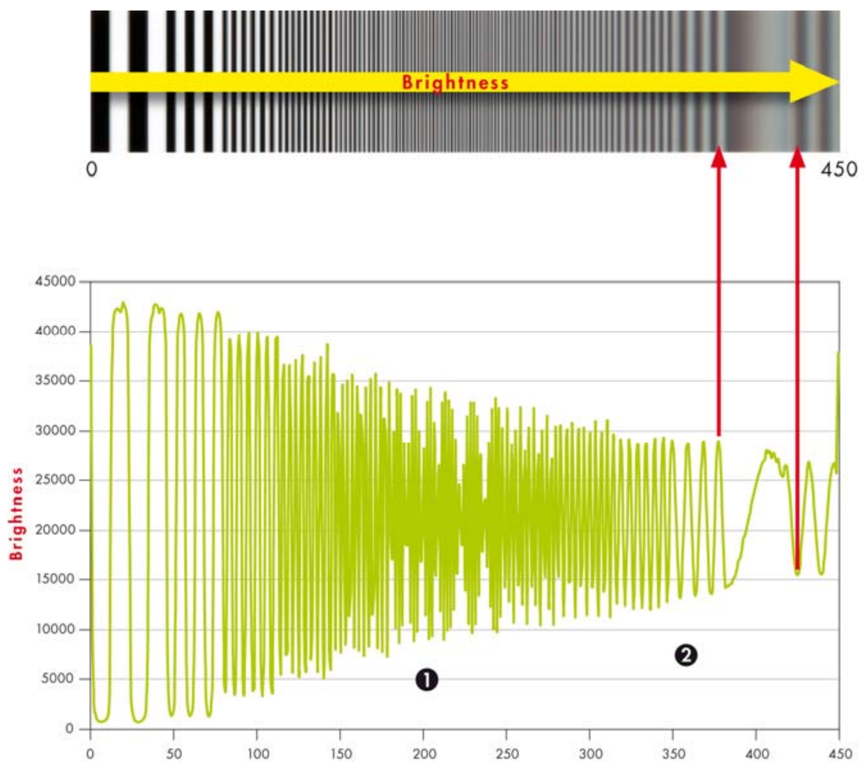
P2_Fig. 3: 3k scan with severe aliasing

P2_Fig. 4: Digital still camera with 2 mio pixel
Digital still camera with 1 mio pixel

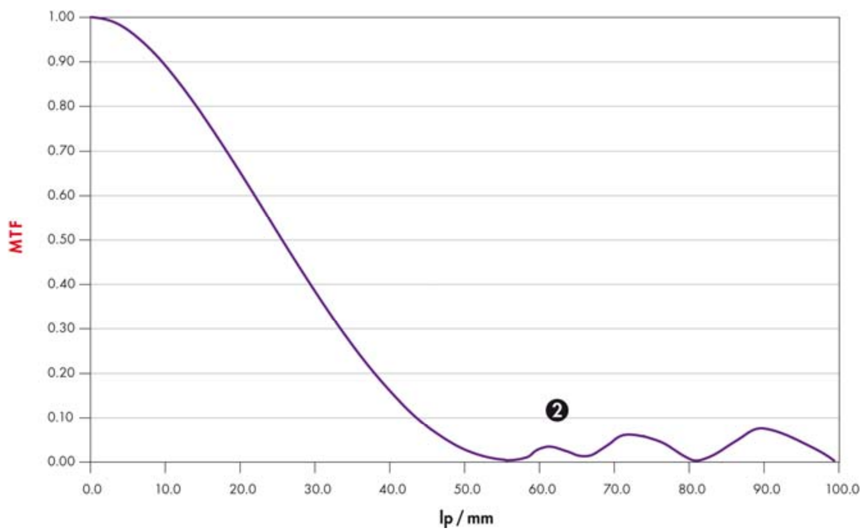
Impact on the MTF

It is very obvious that the aliasing effect also has an impact on the MTF (for modulation transfer function, see part 1). Pseudo modulation manifests itself as a renewed rise (hump) in the modulation beyond the scanning limit (2).

"Pseudo" because the resulting spatial frequencies (lines and gaps) do not have anything to do with reality: instead of becoming finer, as they do in the scene, they actually become wider again in the output image.



P2_Fig. 5: Luminance along yellow arrow



P2_Fig. 6: MTF

Avoiding Alias

The only method to avoid aliasing is to physically prevent high spatial frequencies from reaching the scanning raster, i.e. by defocussing or through a so-called optical low pass, which in principle does the same in a more controlled fashion. Unfortunately, this not only suppresses high spatial frequencies. At the same time, the contrast of coarse detail, which are important for sharpness perception, are also affected.

A different alternative would be to use a higher scanning rate with more pixels. But this would bring disadvantages, as well. Since 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, too. Accordingly, the aquired signal must be amplified again, which leads to higher noise and again to limited picture quality.

As is so often the case, the best solution lies somewhere in between. The intensive R & D work put into developing the ARRISCAN has led to the current state of the art in alias suppression. A combination of a 3k sensor area (large pixels, little noise) and the use of micro-scanning to increase resolution (doubling it to 6k) is the best solution to the problem.

Format	Width	Pixels	Scanning resolution/ Digital acquisition	Final image size
S 16 mm	12.35 mm	2058 pixels	3k	2k
S 35 mm	24.92 mm	4153 pixels	6k	4k

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

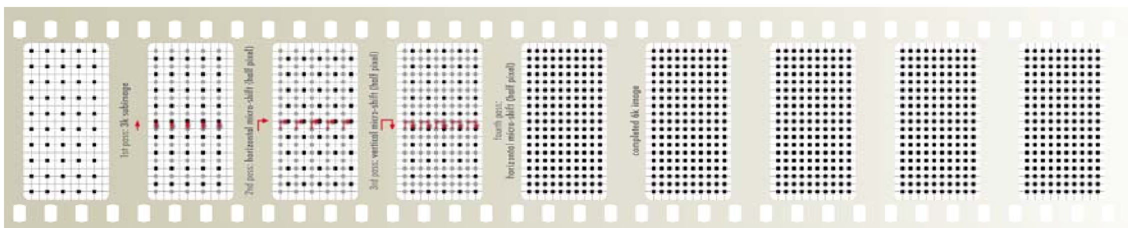
(1) the response at half of the 4k scanning frequency itself is zero,

(2) spatial frequencies beyond the scanning frequency are suppressed and

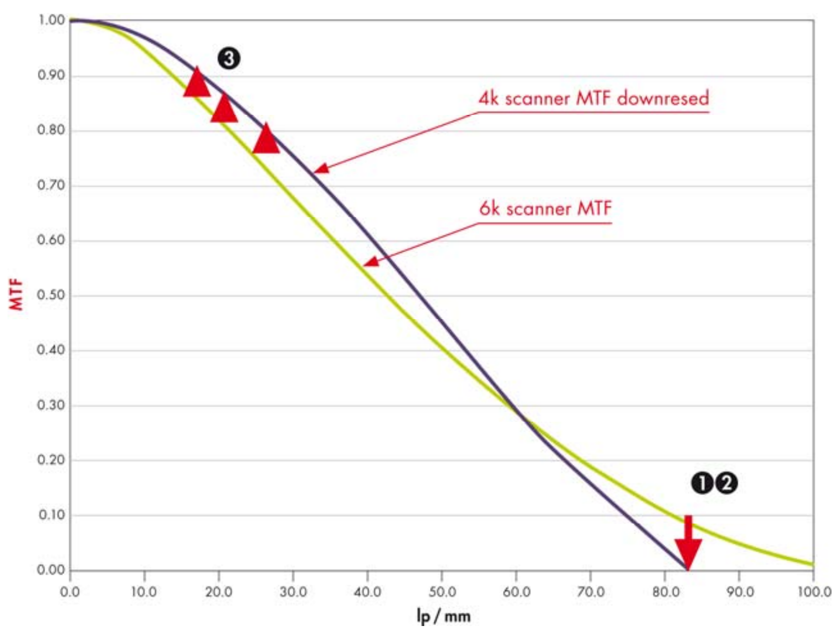
(3) the modulation in low spatial frequencies is increased.

While measures (1) and (2) help to avoid aliasing artefacts in the image, measure (3) serves to increase the surface ratio under the MTF. As already seen in part 1, this improves the visual impression of sharpness.

To transfer the maximum information to be found in the film negative into the digital realm without aliasing and with as little noise as possible, one needs to scan the width of the Super 35 mm negative with 6k. This conclusion can be scaled to all other formats.

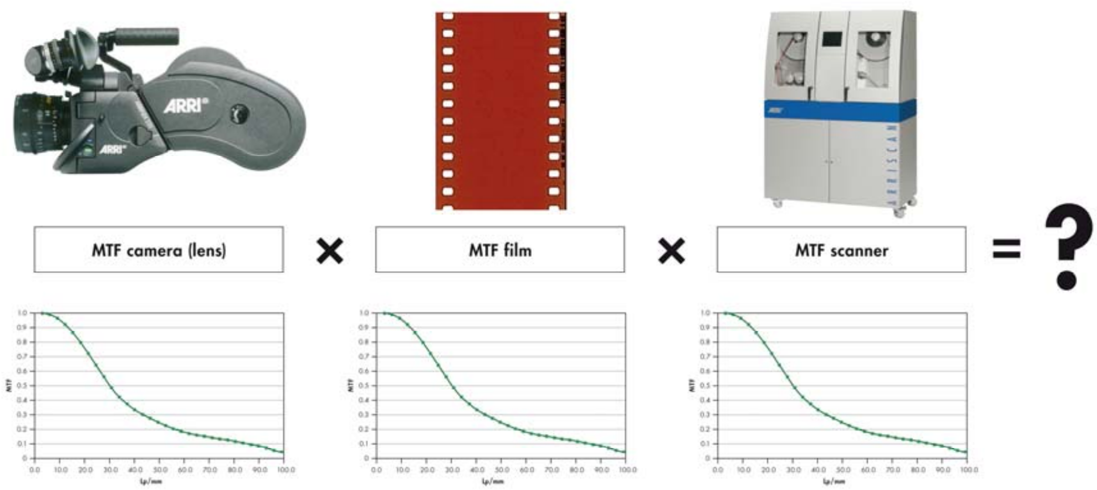


P2_Fig. 7: Microscan

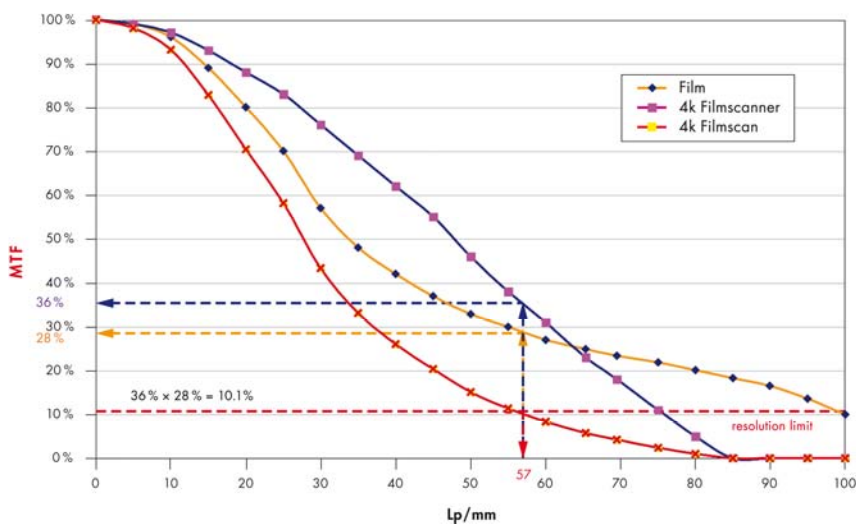


P2_Fig. 8: 6k / 4k scanner MTF

The Theory of MTF Cascading



P2_Fig. 9: Theory of MTF cascading



P2_Fig. 10: resulting MTF in a 4k scan

What losses actually occur over the course of the digital, analog or hybrid postproduction chain?

There is a bit of theory needed for this – but do not fear, it will not be that bad. I hope I have aroused your interest for MTF – a downright useful tool to objectively describe image sharpness and resolution. With the help of two or more MTF curves one can quickly do a comparison – above all without any subjectively influenced evaluation. Even more: once we know the MTF of the individual links of the production chain we can very easily compute the expected result at every location within the chain, through simple multiplication of the MTF curves.

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 in this way shows the best-case scenario.

For our calculations we use actually measured values. What this means is that we do not use the MTF of the raw stock and multiply it by the MTF of the camera lens. Instead, we directly measure the resulting MTF of the exposed image and multiply it by the MTF of a 4k (ARRI-)scan.

What Does the Result Show Us?

The MTF of a 35 mm negative scanned with 4k contains only little more than 56 lp/mm (the equivalent of 3k with the image width of Super 35 mm) 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:

MTF_4k_scanner (57 lp/mm) × MTF_exposed_film (57 lp/mm) = MTF_in_4k_scan (57 lp/mm)

36% × 28% = 10.08%

By the way – the same goes for a digital camera with a 4k chip: There, a low pass filter (actually a deliberate defocussing) must take care of pushing down modulation at half of the sampling frequency (80 lp/mm) to 0, because otherwise aliasing artefacts would show up..

Ultimately : neither a 4k scan nor a (3-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 they were created pixel by pixel on a computer – without creating an optical image beforehand.

Of course, this cannot be the solution, since we would then in the future have to make do with animation movies only. A scenario where actors and their affairs could only be created on the computer. A tragic loss, not just for the yellow press!

summary part II

P2_Fig. 11: a true 4k production chain

4k projectors will be available in the foreseeable future, but their full quality will only come to its own when the data they are fed will provide this resolution without loss. At the moment, a correctly exposed and 6k/4k scanned 35 mm film negative is the only practically existing acquisition media for moving pictures that comes close to this requirement. Viewing things from a different angle one could say that the 4k projection technology will make it possible to see the quality of 35 mm negatives without incurring losses through analog processing lab technology. The limiting factor in the Di workflow is not the (ideal exposed) 35 mm film but the 4k digitization. As you can see in P2_Fig. 9 a gain in sharpness is still possible when you switch to higher resolutions. Now imagine how much more image quality could be achieved with 65 mm (factor 2.6 more information than 35 mm)!

All this statements are based on the status quo in film technology – for an outlook on the potential of tomorrow's film characteristics I can recommend an very interesting article of **Tadaaki Tani** Journal of Imaging Science and Technology® 51(2): 110 -116, 2007.

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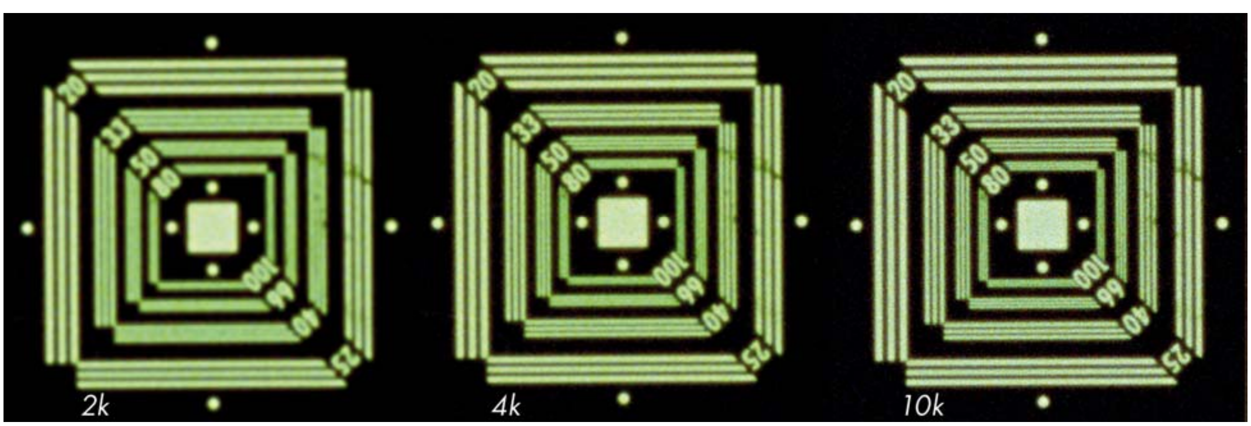
AgX Photography: Present and Future Tadaaki Tani
Frontier Core-Technology Laboratories, Fuji Photo Film Co., Ltd. 577 Ushijima, Kaisei-machi, Ashigarakami-gun, Kanagawa-ken 258-8577, Japan
E-mail: tadaaki_tani@fujifilm.co.jp
Bottomline : 35 mm film stores enough information reserves for a digitization with 4k+.



P2_Fig. 12: 2k, 4k and 10k scan of the same 35 mm camera negativ

Part III the production chain, does 4k Look Better Than 2k ?

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

The Analog Process

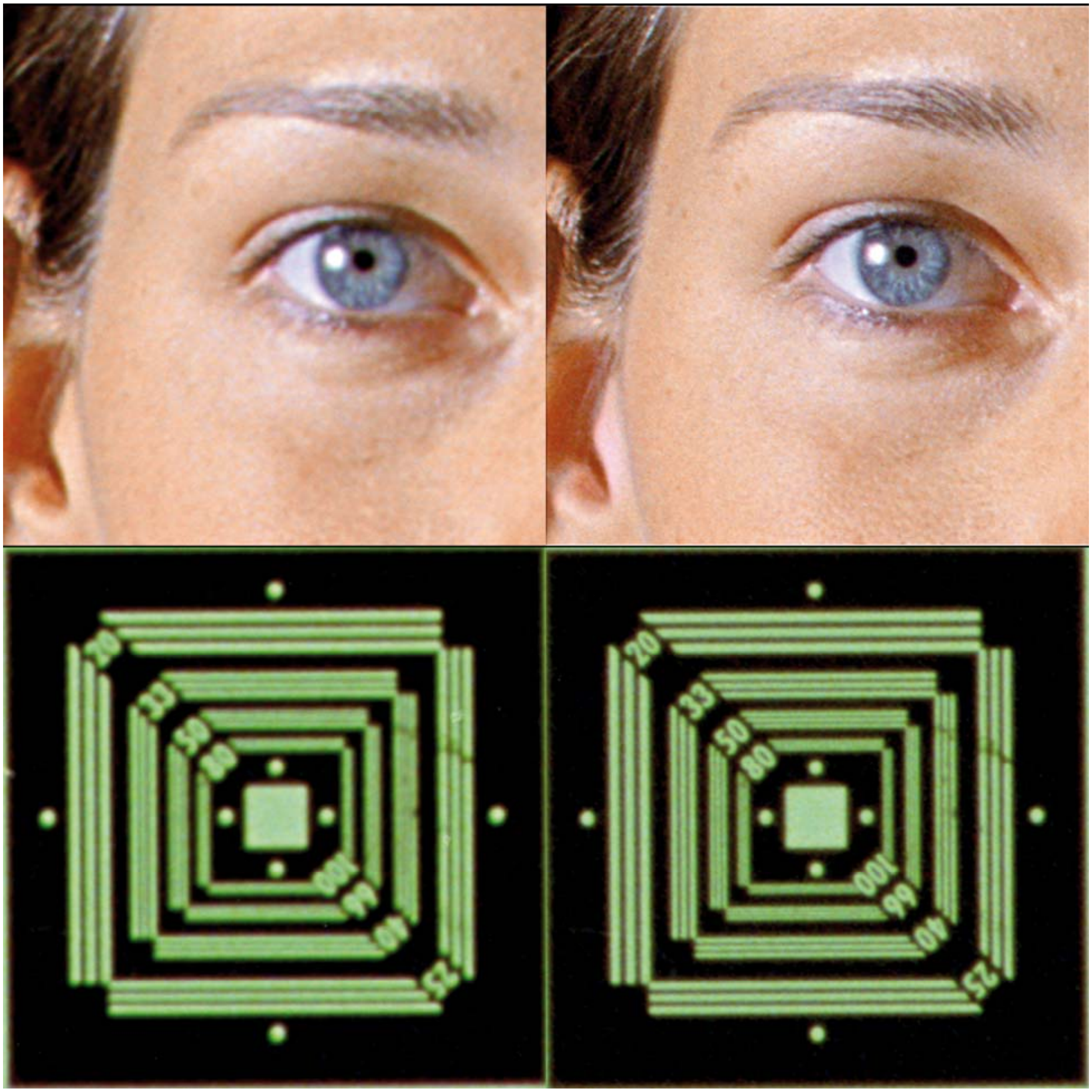
"An analog copy is always worse than the original." This is an often-repeated assertation. But it is true only to a certain extent in the classical postproduction process; there are in fact quality-determining parameters that, if controlled carefully enough, can ensure that the level of quality is maintained: 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.

Clear loss of quality , however, indeed occur where structures, i.e., "spatial image information", are transferred. In other words, resolution and sharpness are reduced. This occurs as a result of the rules of multiplication (see page 22). This illustration shows how 50 lp/mm with a native 33% modulation in the original is transferred throughout the process.

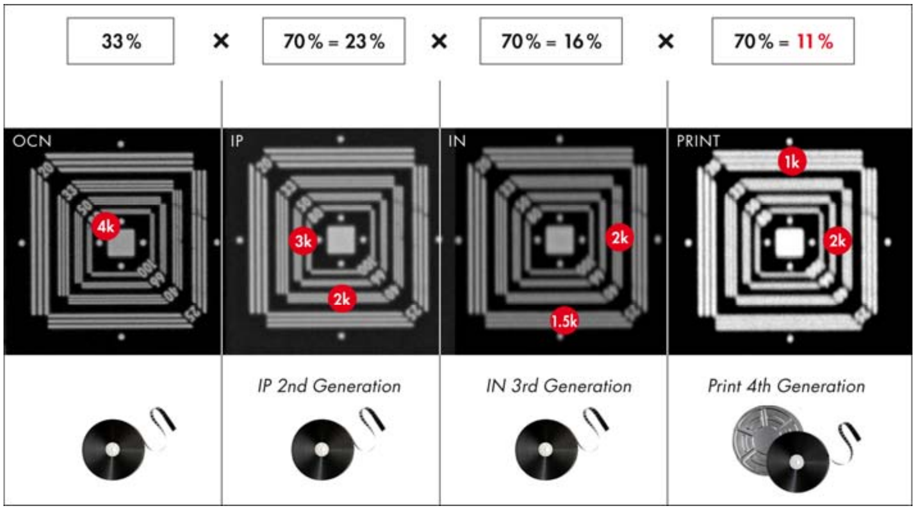
	MTF at 50 lp/mm
Exposed Film Image Kodak 5205 (Camera + Film)	33%
Kodak 5242 Intermediate (Copy to IR)	70%
Kodak 5242 Intermediate (Copy to IN)	70%
Kodak Print Film 2393	70%

33% x 70% = 23% x 70% = 16% x 70% = 11%

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



P3_Fig.1: 2k and 4k cutout of a 2k DI and a 4k DI

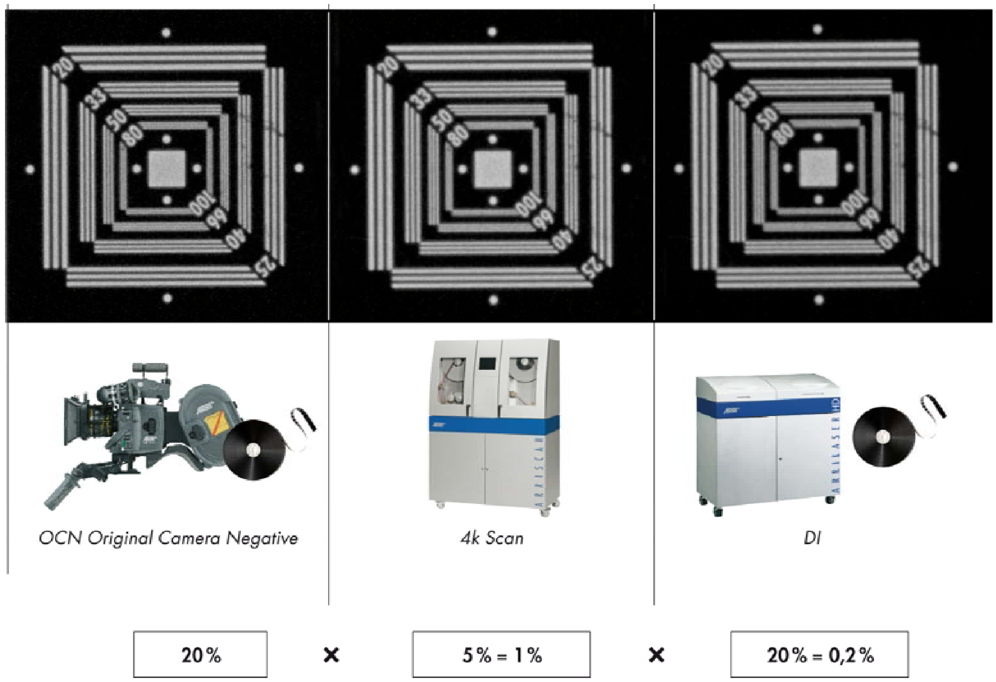


P3_Fig. 2: 10k scans of the imagecenter (green)

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 which apply to the analog process because analog components (i.e. optical path of scanner and recorder) are incorporated.

To make this clearer, let us again perform the simple multiplication of the MTF resolution limit in 4k (= 80 lp/mm). The MTF data illustrate the best filming and DI components which can be currently achieved.



P3_Fig. 3: DI Production chain

	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% x 5% = 1% x 20% = 0.2%

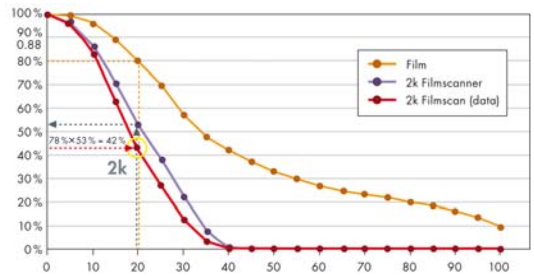
Per definition to avoid Alias

As the multiplication proofs, inherent to the 4k DI chain, there cannot be modulation at 80 lp/mm. Even though the digitally exposed internegative shows considerably more image information than can be preserved throughout the traditional analog chain.

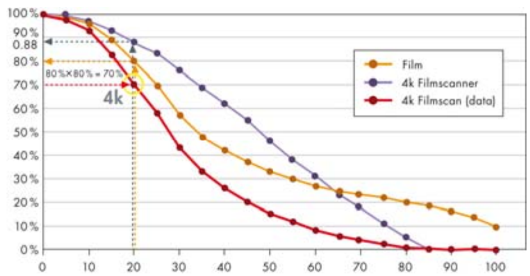
Why, then, is a 4k digital process still a good idea, even though it cannot reproduce full 4k image information? The answer is simple: according to the Heynacher Integral (the area beneath the MTF curve), the perception of sharpness depends on the modulation of course local frequencies .When these are transferred with a higher modulation, the image is perceived as sharp. Illustration P3_Fig.1 shows the results of a 2k and 4k scan.

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 on the ARRILASER in 4k on Fuji RDI, for example, we achieve the results seen in Illustration P3_Fig. 2 left.



P3_Fig. 4: MTF of a 2k Filmscan



P3_Fig. 5: MTF of a 4k Filmscan

summary Part III

A 4k workflow is advantageous for DI and film archiving: The MTF characteristics seen in 4k scanning will transfer course detail (which determine the perception of sharpness) with much more contrast than 2k scanning.

It is thereby irrelevant if the resolution limit of the source material is resolved or not. The most important thing is that the available frequency spectrum is transferred with as little loss as possible.

Part IV Visual Perception Limitations for Large Screens

The last part comes back to the most important step in the production chain – the human eye. Again we are focussing on resolution, sharpness and alias.

More specifically than in the first part now we are not looking at general perception but at the limits of our visual systems when it comes to viewing large images on the screen.

In the end it is exactly this limitation that shows how much effort one should put in to digitalization of detail.

A very common rumour still circulates, which alleges that one could simply forget about all the effort of 4K because nobody can see it on the screen anyway.

Let´s take a closer look to see if this is really true !

Basic parameters

From the last parts we can extract three simple theses to describe what is important for an natural and sharp looking image, listed here in a descending order of importance:

1.image information is not compromised with alias artefacts

2.low spatial frequencies are showing high modulation

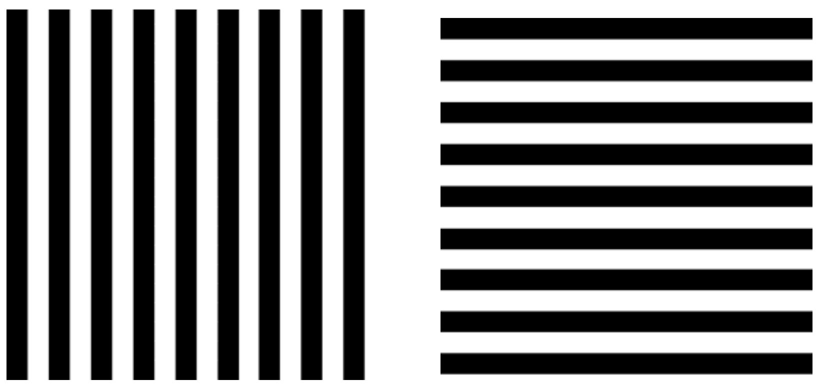
3.high spatial frequencies are still visible

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

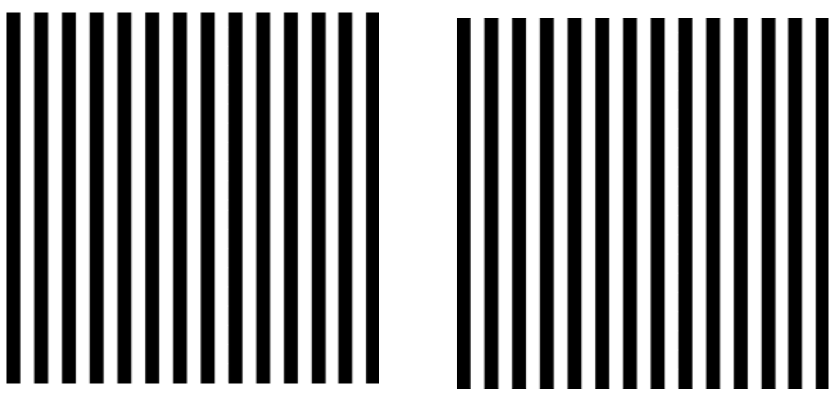
Just to stretch it out one more time – it would be a complete wrong conclusion to think one could generate a natural sharp image by using low resolution and just push it with a filter. Alias free images and high sharpness can only be reached if oversampling and the right filters for downscaling to the final format have been used.

(see page 15)

6K for 35 mm , 3K for 16mm .



P4_Fig. 1: 3mm



P4_Fig. 2: 2mm

Resolution of the human eye

The fovea of the human eye (the part of the retina that is responsible for our sharp central vision) includes about 140000 “sensor-cells” per square millimeter . This means if two objects are projected with a separation distance of more than 4 microns on the fovea a human with an normal visual acuity (20/20) can resolve them. On the object side this would correspond to 0.2 mm in a distance of 1 m (or 1 minute of arc).

In pratice of course, this depends upon the following:

- you are concentrating only on the center of the viewing field
- the object moving very slowly or not at all
- The object has good contrast to the background

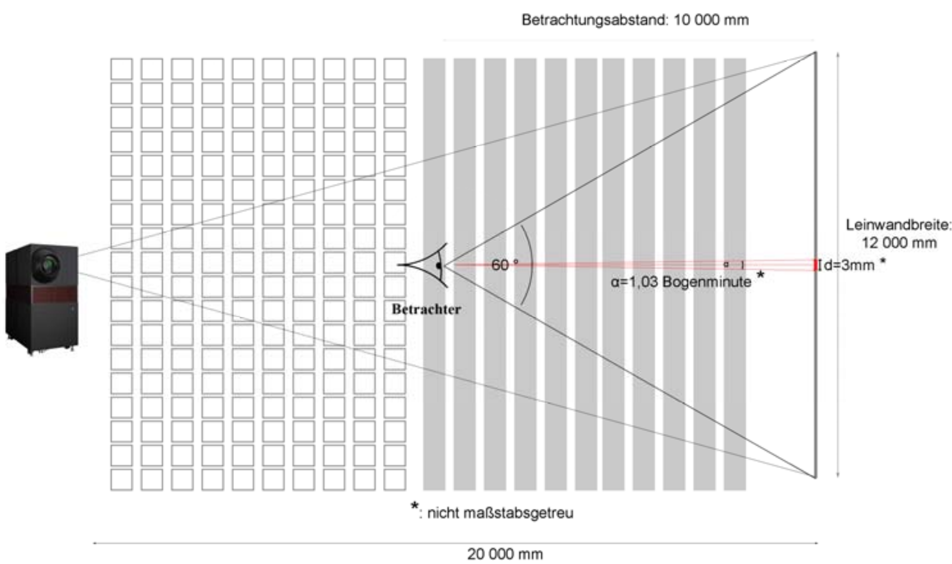
As in the previous sections, we will not use the actual resolution limit for the further discussion but rather the detail size that can be clearly seen. Allowing for some amount of tolerance, this would be around 0.3 mm at 1 m distance(= 1.03 minutes of arc).

In a certain range one can assume a linear relation between distance and the detail size.

0.3 mm in 1m distance $\approx$ 3 mm in 10m distance.

This hypothesis can easily be proved. Pin the test pattern displayed on page xxx on a well lit wall and walk away 10 m. You should be able to clearly differentiate between lines and gaps in P4_fig_1 (3 mm). In fig(2 mm) you should barely see a difference. Of course this requires a ideal visual acuity of 20/20 (US). Nevertheless, if you can't resolve the pattern in fig 1 you might consider paying a visit to an ophthalmologist! .

Large screen projection

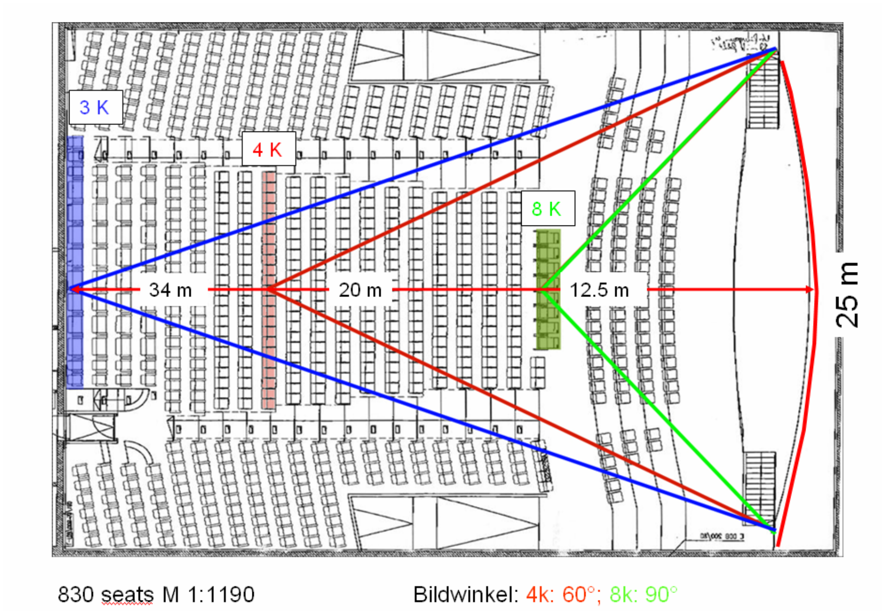


P4_Fig.3 resolution limit in the theatre

This experiment can be transferred for the conditions in a theatre. Displayed in Fig xxx you see the outline of a cinema with approximately 400 seats and a screen width of 12 m. The centre row of the audience is at 10 m. An observer in this row would look at the screen with a viewing angle of 60°.

Assuming that the projection in this theatre is digital the observer could easily differentiate 12000 mm / 3 mm = 4000 Pixel.

The resolution limit is not reached below a distance of 14 m. 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.



P4_Fig.3 resolution limit for large screens

In large theaters you can find screens with a width of 25 m and more. Fig xxx shows how many Pixels per image width one would need if the resolution limit of the eye were the critical parameter for dimensioning a digital projection.

Summary Part IV

The conclusion is that the rumour is simply not true ! A large portion of the audience could very well 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

Perhaps it is possible to explain these issues with less paper, however I hope readers will believe that a scientific approach is necessary to get a clear view to the real problem instead of merely counting megapixels.

This article has dealt only with the static image quality factors sharpness & resolution. As was mentioned in the introduction, there are many more parameters to consider, therefore a new article about the transfer of photometry (sensitivity, contrast, characteristic curve) from scene to screen is in preparation.