Film Grain, Resolution and Fundamental Film Particles

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1 - Introduction

The purpose of this complex essay is to demonstrate the following:

- **Fundamental film particles (silver particles) are distinct from film grain**
- **Silver particles are an order-of-magnitude smaller than film grain**
- **Film grain is a perceived property, not based on fundamental film particles**
- **Resolution of film is related to the size and distribution of fundamental particles in the emulsion**
- **Film grain interferes with the ability of the "fundamental particles" to resolve image detail**
- **Focusing film grain is an inadequate method of resolving the detail in an image**

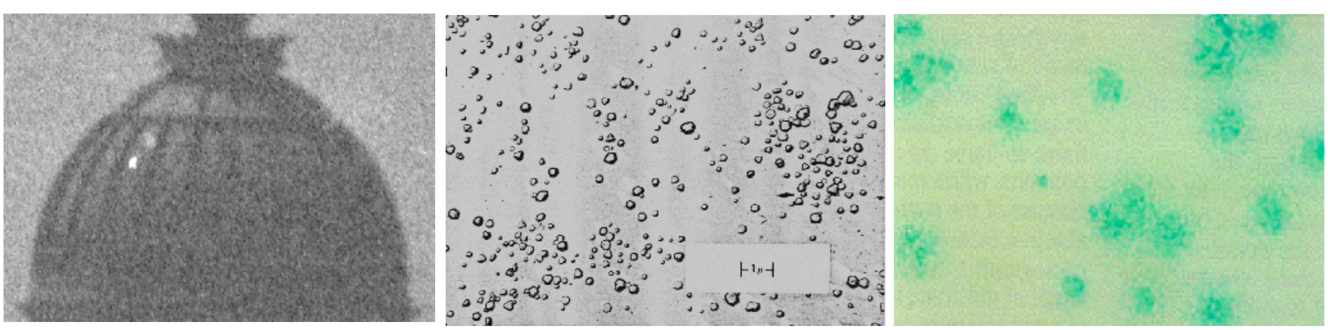

Figure 1a (left) shows a 0.5 mm wide section of a large format B&W negative scanned at 4800 ppi using a standard flatbed scanner. **Figure 1b** (center) from Mees & James (1967) Fig.2-5 shows a micrograph of actual (undeveloped) silver-halide crystal particles (before T-Grain in 1982); most silver particles are much smaller than one micron; average films range from 0.6 um to 0.8 um. **Figure 1c** (right) from Kodak H-1 Fig 19b is a very rare Kodak micrograph showing cyan dye clouds in one layer, within color transparency film, at the thin edge of the film; size range is 1.5 um to about 10 um.

The term “film grain” is often incorrectly used to describe the “fundamental” particles in a chemical-based photographic image. Fundamental image particles are the smallest particles that form an image: **(a)** silver particles or **(b)** color dye clouds. It can be seen in Figure 1a that detail is defined by the dark line of the dome rib against the gray panel; the film grain detracts from smoothness of the rib. In Figure 24 (p24), a wet and dry scan comparison of the sme image, the effect is greater in the dry scan where the film grain is more pronounced.

Film grain is a repeating noise pattern that is an order of magnitude larger than the fundamental image particles. Film resolution is directly related to the size and distribution of silver particles in an emulsion. The noise pattern tends to obscure detail rather than define detail. The pattern is superimposed over the image, not the source of the image.

A common mistake is to think that film grain is the image-forming element. Many Kodak and Fuji publications, including much of the popular photographic literature (magazines), commonly make the mistake of referring to fundamental film particles as film grain. This further propagates the imprecise usage of the term.

In the table below it can be seen that the size of film grain is often larger than the ability of film to resolve detail of a specific size: 10-30 microns (um) vs. 8 um. This strongly suggests that (a) film grain and (b) the ability to resolving detail are different properties.

Table 1: Film Property vs Scale

Size Domain	I-------------------SCALE--------------------I			Tool for	What is
Property	**Microns**	**lp/mm**	**ppi**	**Evaluating Property**	**Measured?**
Fundamental Particles	0.2-2.0	5000-500	254,000-127,000	Microscopy	Silver Particles
Film Resolution*	8*	80*	4064*	MTF Curve	Resolving Power
Film Grain	10-30	50-10	2540-1690	Image Enlargement	Film Grain
RMS Granularity	48**	10**	528**	Microdensitometer	Noise at 1.0D
Graininess	NA	NA	NA	Print Grain Index	Random Film Noise
Human Visual Acuity	85***	6***	300***	Human Vision	Details

* Applicable to Fuji Velvia RVP capable of 80 lp/mm native resolution.
** Diameter of area used in the RMS Granularity measurement; no units, a measure of image noise.
*** Based on human not being able to resolve greater than 300 ppi.

Film grain is a – perceived – visual phenomenon resulting from the visual accumulation of smaller particles through the thickness of the emulsion layer; see Film Grain, Section 3. The Kodak H1 publication says about film grain:

> “Although the viewer sees a granular *pattern*, the eye is not necessarily seeing the individual silver particles, which range from about 0.002 mm down to about a tenth of that size.”

Experienced workers explain that different techniques such as **(a)** magnification (through a microscope or loupe), **(b)** enlargement (photographic print) and **(c)** scanning, yield different results for film grain size. These findings, in themselves, are highly suggestive that film grain is a perceived property that depends on the conditions of examination.

Working with Film Grain

In an era of 4800-6400 ppi flatbeds, one of the remaining claims to superiority of the drum scanner is its ability to “tune” the capture system to the physical image structure of specific films using two parameters: aperture and pitch. Many activities of the drum scan operator are geared towards eliminating film grain while maintaining resolution. The resulting drum-scanned image is prized when it looks like a digital image free of film grain.

On the other hand, when creating a print with film using an enlarger (analog technique), operators often use a **grain-magnifying tool** to assure the sharp focus of film. Figure 2 shows a Micro-Sight 12x grain focusing tool. From this action, some operators have assumed that creating sharp “film grain” is the key to achieving image sharpness. However, film grain is not actually sharp because it is made up of numerous smaller particles that are an order-of-magnitude smaller than the film grain, composited through the thickness of the emulsion.

Figure 2

The problems of (1) locating a well-focused region of a small piece of film in a 35 mm film frame (24 x 36 mm), (2) evaluating its degree of focus and then (3) focusing that region of the film, explains why **"focusing the grain"** has become a common default for determining image sharpness. Focusing on the perceived film grain is a misapplication of imaging resources, because film grain has indistinct edges. It is image noise not "grain."

Achieving fine detail with crisp contrast differences should be the goal of the imaging process, be it on a flatbed or drum scanner. Based on the generic information in an MTF Curve, focus is a function maximizing contrast between lights and darks.

Good focus is achieved by finding the highest degree of contrast difference between light and dark, in a bit of blurry detail, while avoiding the use of film grain. In the original scene, the detail could have been black and white before they were transformed to lower-contrast grays by the lens and then diffused by the silver particles or dye clouds in the film.

2 - Fundamental Film Particles – Silver-Halide Crystals

The fundamental image particles in chemical-based images are:

- **Silver particles in B&W images**
- **Color dye clouds in color film images (clouds develop around silver particle centers)**

Silver-halide particles (in undeveloped film) average about 0.2 - 2.0 microns (one micron equals one millionth of a meter or, a thousandth of a millimeter). Color dye clouds range from 1.0 um to 10 um.

- **Silver-halide crystals are 0.2- 2.0 um**
- **Color dye clouds are 1.0 to 6-10 um**

Human vision is orders-of-magnitude less acute than the size of the silver particles. Even corrected, human vision ranges from 75-100 microns, with an average of 84 um, or 300 dpi. Using a common 10x loupe, humans can image 7.5 to 10 um, which is still too coarse to see individual silver particles, even at a thin edge of an image.

The fundamental image particles (silver), when rescaled into dimensions commonly used for the wavelengths of visible light, range from 200 to 2000 nm (nanometers).

- **1" = 25.4 mm (millimeters)**
- **1" = 25,400 um (microns)**
- **1" = 25,400,000 nm (nanometers)**
- **1000 microns (um) = 1 mm**
- **1000000 microns = 1 meter**
- **1000 nm = 1 micron (um)**
- **1000000 nm = 1 mm**
- **1000000000 nanometers (nm) = 1 meter**

The size domain of visible light is 400-750nm; blue light ranges from 380-450 nm; green light ranges 450-550 nm; and red light ranges 550-750 nm. Ultra-violet light ranges 205-380 nm, while infrared radiation ranges 750-5000 nm. Note that the smallest silver particles (0.2-0.8 microns) are not visible unless clumped into larger agglomerates, because most are smaller than the wavelengths of light.

The light microscope has a theoretical maximum resolution of 1000**x** when using an oil immersion objective and condenser. With a 100x oil immersion lens and a 1.25 NA oil immersion Abbe-type condenser, a microscope can resolve particles at 250nm, or 0.25 um. They can be used to see fundamental film particles; see details on p 18. A microscope cannot be used to see film grain because the closer one gets, the more indistinct the apparent edges of the perceived particles become because film grain is noise not particles.

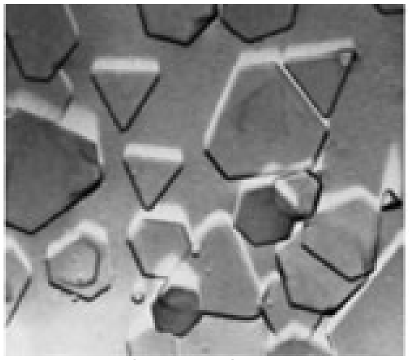

Figure 3: KODAK T-GRAIN emulsion crystals 1982-present, H-1

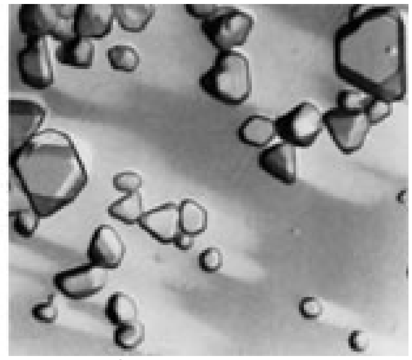

Figure 4: Conventional silver-halide crystals, 1860-1982, H-1

Quoted directly from the Kodak Motion Picture Publication **H-1** (1999):

"Incorporating T-GRAIN Emulsions into films improves film speed without sacrificing fine grain. The uniquely shaped grains align better than conventional silver crystals, absorbing and transmitting light more effectively. In recent years, [first in Kodacolor VR, 1982] a new type of emulsion KODAK T-GRAIN® was incorporated into some Kodak films. The amount of exposure, which determines the densities of various areas, also affects the graininess of all films. Other factors that affect graininess are different developers and different amounts of development time of black-and-white films. Because the development processes of color films are rigidly fixed, the effect of development [on them] is rarely a factor in their graininess (however, forced processing does cause an increase in graininess). Because many color films are made with emulsion layers of varying graininess levels, increasing the exposure (up to a point) places more of the density in the finer-grained layers, which actually reduces the overall graininess of the observed images."

Table 2: Feature Size versus Digital Resolution

Size	Digital Resolution	Imaging Device
0.1 um	254,000 ppi	SEM/XRD
0.2 um	127,000 ppi	SEM/XRD
0.5 um	50,800 ppi	SEM/XRD
0.8 um	31,750 ppi	SEM/XRD
1.0 um	25,400 ppi	Light Microscope
2.0 um	12,700 ppi	Light Microscope
3.0 um	8,467 ppi	Light Microscope
4.0 um	6,350 ppi	Light Microscope
5.0 um	5,080 ppi	Light Microscope & Scanners
5.3 um	4,800 ppi	Drum or Flatbed Scanners
5.5 um	4,618 ppi	Drum or Flatbed Scanners
6.0 um	4,233 ppi	Drum or Flatbed Scanners
6.34 um	4,000 ppi	Drum or Flatbed Scanners
7.0 um	3,629 ppi	Drum or Flatbed Scanners
8.0 um	3,175 ppi	Drum or Flatbed Scanners
8.5 um	3,000 ppi	Drum or Flatbed Scanners
9.0 um	2,822 ppi	Drum or Flatbed Scanners
10.0 um	2,540 ppi	Drum or Flatbed Scanners
10.5 um	2,400 ppi	Drum or Flatbed Scanners
12.0 um	2,117 ppi	Drum or Flatbed Scanners
13.0 um	1,954 ppi	Drum or Flatbed Scanners
15.0 um	1,693 ppi	Drum or Flatbed Scanners
20.0 um	1,270 ppi	Drum or Flatbed Scanners
21.2 um	1,200 ppi	Drum or Flatbed Scanners
25.0 um	1,016 ppi	Drum or Flatbed Scanners
50.0 um	508 ppi	Drum or Flatbed Scanners
60.0 um	423 ppi	Young Human Eyes
75.0 um	340 ppi	Above Average Human Eyes
85.0 um	300 ppi	Average Human Eyes
100 um	254 ppi	Most Human Eyes
1000 um	25.4 ppi	One Millimeter
1000000 um	NA	One Meter

In ***The Theory of the Photographic Process,*** eds: C.E.K. Mees and J.T. James (1967, 3rd), Chapter 2 by C.R. Berry and R.P. Loveland, pp 38-40 they list the average silver-halide particle sizes for film emulsions such as: high-resolution film, motion picture film, portrait film and high-speed film. The size range is from 0.30 to 1.71 um (microns), about the size of those listed in the Kodak **H-1** publication, 0.2 to 2.0 um.

THE SILVER HALIDE GRAINS

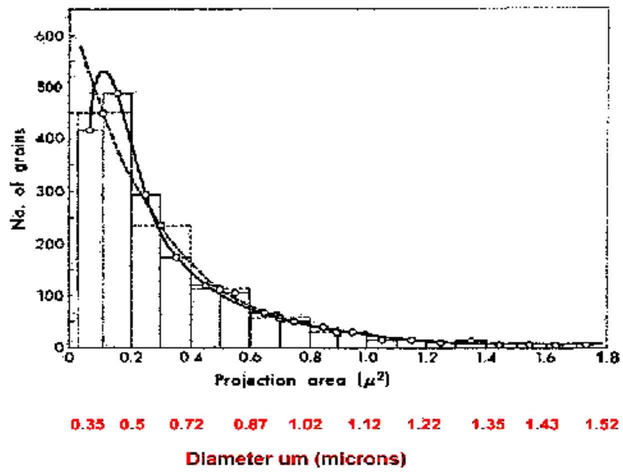

FIG. 2.7. *Histogram, size-frequency curve, and the effect of the width of the size classes.*

TABLE 2.1

Particle-Size Constants for Typical Photographic Materials

Plate or Film	Diameter microns um	$N \times 10^9$
High-resolution film	0.048	—
Motion-picture-positive film	.30	577.5
Positive-type film	.63	117.85
Fine-grain roll film	.79	52.35
Portrait film	.88	25.66
High-speed roll film	1.09	22.61
X-ray film	1.71	6.32

Figure 5: Figure labeled 2.7 was taken from Mees and James (1967) p 39.

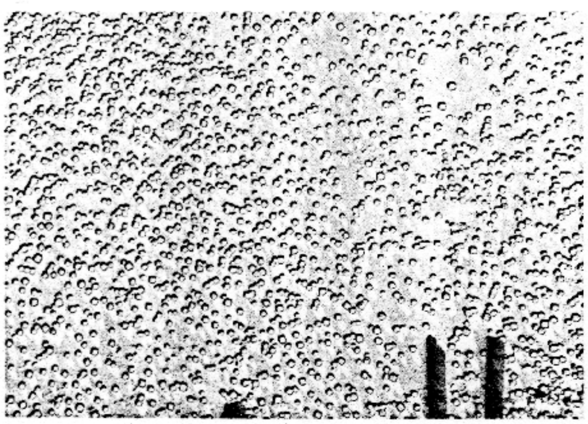

FIG. 2.4. *Preshadowed carbon replicas of small silver bromide crystals of a uniform size precipitated by the double-jet method of Demers. Shadowing angle = 18 degrees. Space between c̶ ̶ters of bars = 1 μ.*

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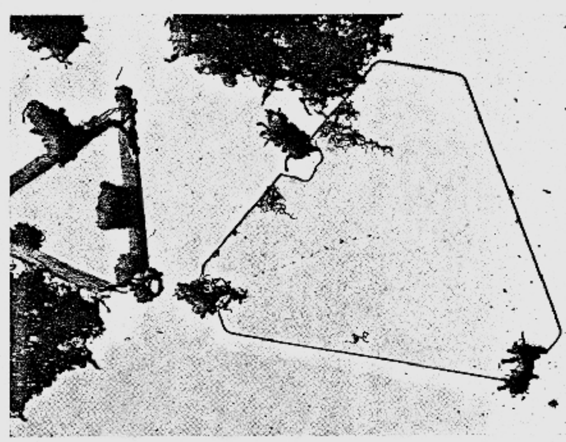


Fig. 1. Electron micrograph (×25,000) showing development centres and the etching out of silver bromide to provide the material for the developed silver. *Photo: R. B. Flint, Research Laboratories, Kodak Ltd.*

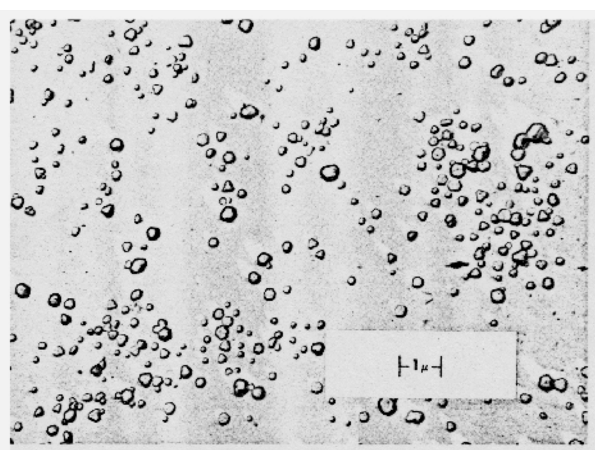


Fig. 2.5 Motion Picture type film emulsion. Size range from 0.2 to 0.6 microns. Bar is 1 micron.

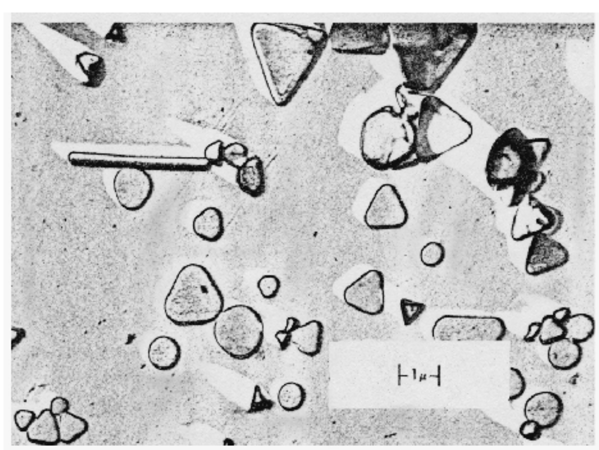


Fig. 2.6 High-Speed negative type emulsion. Grain size from 0.4 to 1.5 microns. Bar is 1 micron.

Figures 6-9: Images labeled "Figures 2.4, 2.5 and 2.6" are from Mees & James (1967) pp 35-39, all have 1um markers. The image labeled "Figure 1" is from Baines (1976) *The Science of Photography*, p112.

Dye Clouds are the Fundamental Image Elements in Color Film

Color films have dye clouds (1.0 - 10 microns [um] across) that start from silver particle, or clumps, core(s). The dye clouds develop around the silver particle's or clumps of particles: see below. Color films have lower resolution than B&W films, because the fundamental particle size is larger than in B&W film.

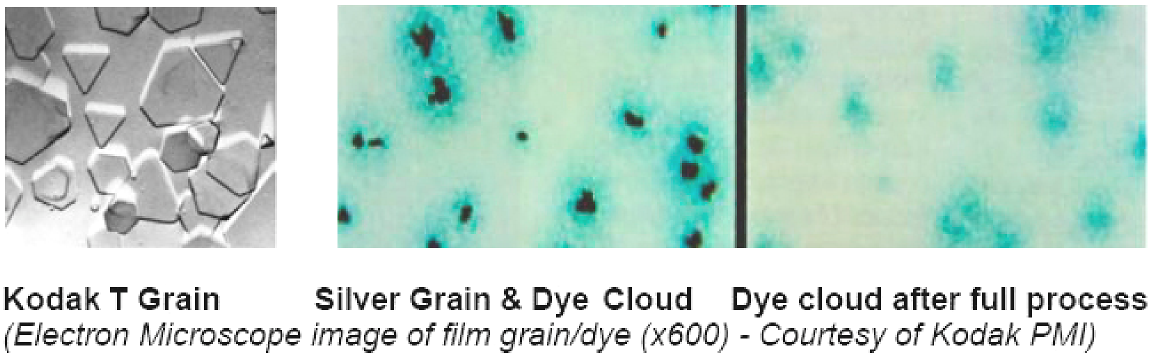


Figure 10: From Kodak Publication H-1: The image on the left in a representation of the mix silver particle sizes found in B&W films, before T-Grain. The center image shows cyan dye clouds with silver particle clump(s) centers. On the right, the dye clouds are shown after full development, including a competing dye coupler, which reduces dye cloud size. In actual film, the dye clouds overlap within layers. In modern color films there are up to 9 layers of dye clouds; three sub-layers in each of the 3 colors of dye.

The Kodak **H-1** Publication shows discretely developed dye clouds to be about 1.0 um to 6-10 um (microns) across. This assumes that the core silver particle is either a clump of particles about 0.4 to 2.0 um across, or an individual silver particle about 0.4 - 0.8 um in width. The images above were made from edges of areas of very faint color, and are probably from a slow speed film. In areas of greater density individual dye clouds cannot be distinguished, however there is the modulation of tone called "film grain." Each color layer group can have three different light response speeds: (1) a fine grain "slow" layer, (2) a moderate grain "normal" speed layer and (3) a coarse grain "fast" layer.

3 - Film Grain

Film grain is the product of the human eye and brain working in combination when viewing very large numbers fundamental image particles, seen through the full thickness of the emulsion layer, often composed of numerous sub-layers. Film grain is "perceived" as "fuzzy" particles just beyond the ability of our human eyes to resolve, rather than an actual physical "particle." Film Grain is a real visual phenomenon created by the interaction of the human eye and brain with the noise in film. Film grain influences the sharpness of a film by acting as a regular noise pattern (unwanted image information) that diminishes the ability to resolve image detail at the size domain of the "perceived" film grain.

Seeing film grain requires the brain to cluster noise into the appearance of clumps. Some magnification will help see grain in an image that appears to have a smooth tone, see Fig 11. However, applying greater magnification does not resolve grain because it is indistinct.

Figure 11 (top half): Film grain from Kodak H-1, p28

From: Kodak, Professional Black-and-White Films (F-1) 1984, p 28.

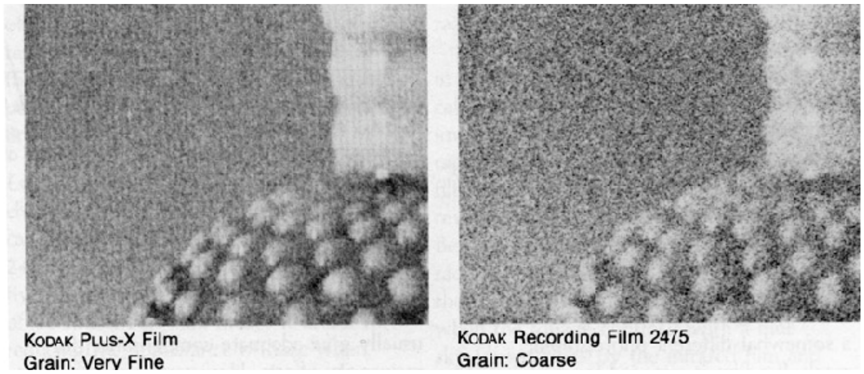


Figure 11 (bottom half): Film grain from Kodak H-1, p28

Dye Clouds in Color Film

Dye clouds are the source of film grain in color films. Dye clouds range in size from 1.0 um to 6 um, and up to 10 microns across when in small clumps. There are up to 9 layers of dye clouds in modern color film (see Fig.12), thus the perception film grain is made through the thickness of the 9 dye layers of the image emulsion. Color films have lower resolution than B&W films, because the smallest image components are larger than in B&W film.

Transparency films are said to be grainless because there are no silver particles in the final emulsion, and the dye clouds have indistinct edges. While silver particle are present in color film before and during the many stages of the development process, they are bleached out near the end of processing. The complexity of the silver-to-dye transition during development and filamentation of dye cloud, through the multiple emulsion layers, means that only rare "single dye cloud" will ever be observed. Mostly, single dye clouds will be found at edges, and in thin image areas of a pure color that is equivalent to a dye (CMY), such as in the Kodak (**H-1**, Fig 13a-d) images below.

Film Grain in a color film is the accumulation of tens, to hundreds, of dye clouds in each of the nine dye layers found in modern color film. Fuji film data sheets from 1986 show 6 layers in Fujichrome professional 400 D (RHP); and 7 layers in Fujichrome professional (sheet film) 50D RFP, 64T RTP and 100D RDP.

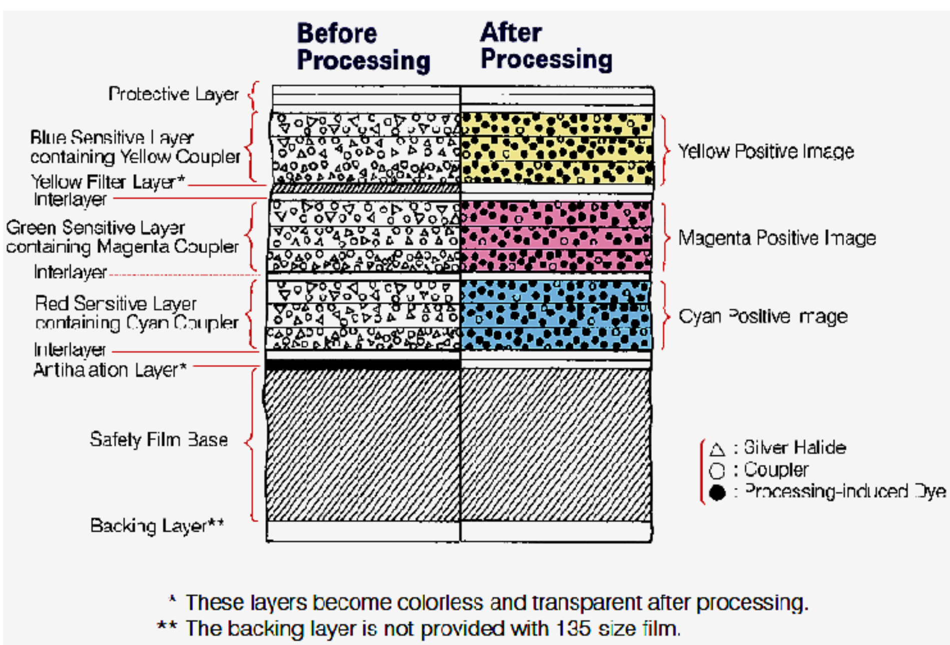


Figure 12: Nine layers of CMY color dyes found in Fuji Provia 400 (2007) <http://www.pictureline.com/images/pdf/PROVIA400FAF3-066E_1.pdf>. Similar color Fuji films from 1980-90 had 6, 7 and 8 layers.

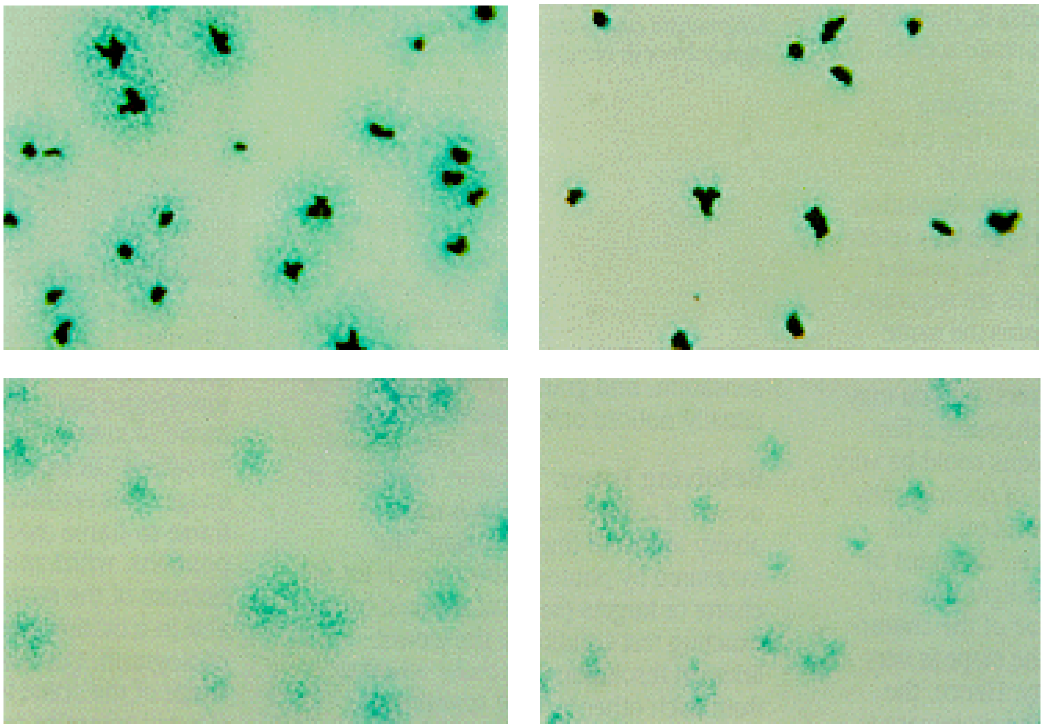


Figure 13a-d: Images from Kodak H-1 (1998) Fig. 19, p25. Photomicrographs at 1200x of a cyan dye layer made very thin to show structure. From upper left to lower right: (a) the film after color development showing clumps of metallic silver grains (0.4 to 1.0 um) surrounded by dye clouds (1-10 um); (b) the same film developed with a completing coupler that reduces the size of the dye clouds, reducing the grain size; (c) the same film developed without a competing dye coupler, after bleaching; and (d) developed with a competing dye coupler after silver bleaching; dye cloud size is as small as 1.0 um.

Film Grain in Black-and-White Film

B&W film is composed of numerous silver particles which are an order of magnitude (ten times) smaller than the size domain of film grain size. Silver particles range in size from 0.2 um to 2.0 um, with an average size of 0.6 um, while film grain appears to ranges in size from 6 um to 30 um. Film grain is so indistinct it is difficult to measure; a range of 8-12 um is thought to be average by many workers.

Film grain size is not measured using RMS Granularity, which is a **unitless** evaluation of unevenness of a uniform tone. RMS Granularity has no units.

From Kodak's **Kodak Professional Black-and White Films,** Pub. F-5 (1984) on p 28:

> **"Graininess: The densities in black-and-white negatives are composed of microscopic grains of black metallic silver. By their random placement in the gelatin of the emulsion, there is a statical clumping of the grains that form the familiar granular pattern that becomes visible when a negative is enlarged enough. "**

Same, and on p 32:

> **"While commonly called the emulsion, the light-sensitive layer of a film is actually a suspension of silver halide crystals in gelatin. The size and distribution of the crystals, the types of halides of which the crystal are made, their number, how they have been sensitized during manufacture, and the thickness of the emulsion layer, along with many controlling steps in the emulsion and film manufacture, determine such film characteristics as speed, contrast, characteristic curve shape, graininess, resolving power, and optical sensitivity."**

In Kodak publication on motion picture film Publication **H-1** (1999) p 25:

> **"One might expect a photographic image made up of cyan, magenta, and yellow dye clouds to appear more grainy than the corresponding silver image. In fact, close to its resolution limit** [6 lp/mm, 300 ppi], **the eye sees only brightness differences and does not distinguish color in very small detail. When color films are projected, the "dye-cloud clusters" form groups similar to "silver-grain clusters" in black-and-white films. At high magnifications, these clusters cause the appearance of graininess in the projected screen image."**

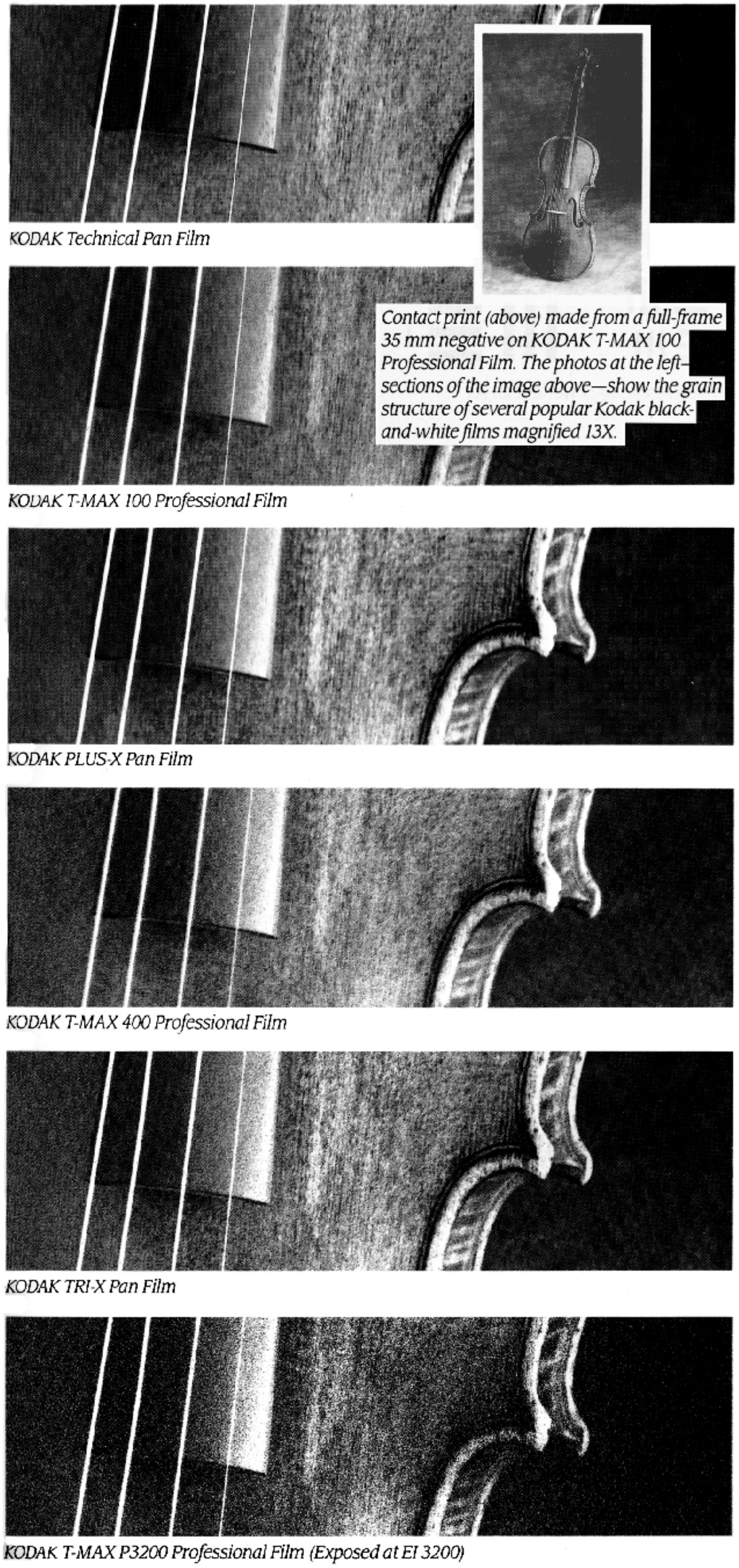


Figure 14: From **Kodak Professional Black-and White Films** (1998) p 33.

On p 32: **"The densities in black-and-white negatives are composed of microscopic grains of metallic silver. Because the grains are placed randomly in the gelatin emulsion,** [visual] **clumping occurs and forms the familiar granular** [film grain] **pattern that becomes increasingly visible as negatives are enlarged to greater degrees.**

As a rule, the faster the film, the greater the tendency towards graininess. Kodak T-Max Professional films, however, bend this rule. Because these films have Kodak T-Grain Emulsion, they have finer grain than conventional films of comparable speed."

On p 33: **"The type of developer you use affects graininess. A fine grain developer decreases graininess, usually with some loss in speed. Overdevelopment, i.e., using and extended development time, a high temperature, or a highly active developer, increases graininess.**

High density [produced] **by overexposure of a negative also increases *graininess*. Proper exposure and development almost always produce an optimum level of graininess. (Large, even-toned areas in the mid-tones of a photograph will appear more grainy than dark- or light-toned areas or areas that include fine detail.)"**

On p 32: **"The ability of a film to record fine detail is called *definition*, which is a composite of granularity, resolving power, and sharpness. The measurement of this characteristic is called *resolving power* or *resolution.***

The visual effect of unevenness in areas that should be uniform is called *graininess*. An objective measurement of graininess is call *granularity.* [Referred to as RMS Granularity and Noise in this essay]

On p 34: **"The *sharpness* of a film is the subjective perception of good edge distinction between details in a photograph.**

Film manufacturers …measure this using a sine-wave test pattern …recorded on film…and scanned by sensitive measuring equipment. [Called an MTF Curve]

On the previous page are several images of the same subject shot on different films showing increasing "graininess" in the series from top to bottom. The images were taken from **Kodak Professional Black-and-White Films**, Pub F-5 (1998) p 33. The quotes on the right were pulled from pp 32-34 in the same publication.

Cross-Section of Film

While microscopic images of discrete silver particles can be made under special circumstances, the thickness of silver-halide-gelatin emulsion has tens, to hundreds, of silver particle stacked on one another in a small region. Even if human vision was more acute, individual particles could not be resolved because they are too close to each other when observed through the thickness of the emulsion.

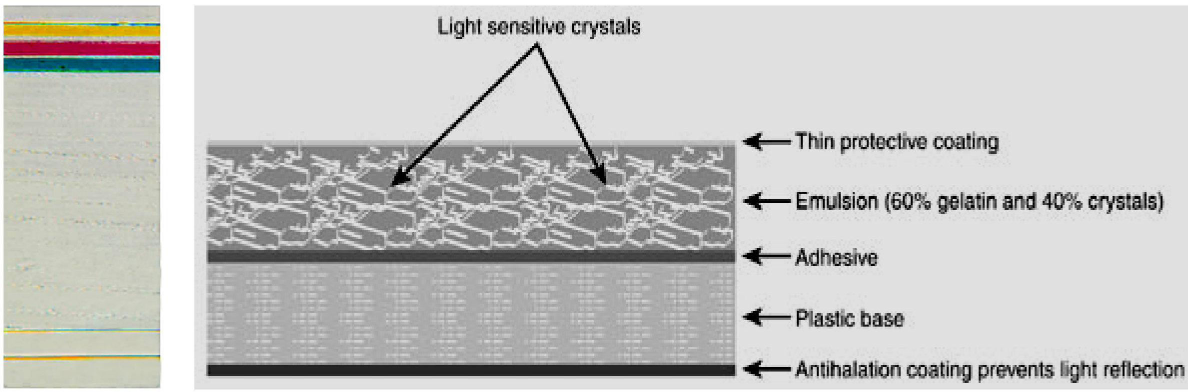


Figure 15: On the left: Figure 46 from Kodak H1, is a cross-section of a Kodak color negative film, the film is 0.075" thick, each dye layer is 0.003" thick. On the right: is a cross-section diagram from Sams Publication, ***Film Basics for Digital Photographers*** by John Upton, Joseph Ciaglia, Peter Kuhns & Barbara London: Ch 4, June 2004, it can be seen that individual silver particles would be difficult to resolve within the emulsion layer.

Grain Size Variability

Grain size is highly dependent on exposure and development. In general, higher temperature favors larger grain; longer development time favors larger film grain size; and specific developers produced larger or smaller grain depending on aggressiveness and pH. Short exposures use the larger more sensitive silver-halide particles in the film, creating an image with larger film grain for a quick exposure.

Most films have low, medium and fast light sensitive layers, based mostly on silver-halide particle size. Film grain size, therefore, will vary from image to image but will probably stay within a range based on the specific film emulsion being exposed.

RMS Granularity – Measure of Film Noise not Film Grain Size

RMS Granularity measures the noise in film. The protocol measures the variation of tone in an area of uniform density (usually 1.0D). RMS Granularity is not a measure of "graininess," even though several publications have made this mistake.

RMS Granularity is a measure of the variability of an area of uniform film density, using a densitometer, through a 48 um aperture <http://www.kodak.com/US/en/motion/support/h1/exposureP.shtml - tgrain>. Root Mean Square (RMS) is the standard deviation (variability) of the Mean (average) of a series of density measurements made through 48 um aperture; see Fig 16. It does not measure film grain size, but rather the variability of image density in an area with "theoretically" uniform density.

The 48 um measurement aperture is much larger than actual silver particles or perceived film grain, so it can only measure the **variability** of film density. The variability of the measured region, which is ideally uniform, is called **noise.** RMS Granularity is a measure of film noise. RMS Granularity numbers range from 5-50 and they have **no units.** The lower the RMS Granularity number the lower the noise in a specific film. Measurements without units are relative to the measurement.

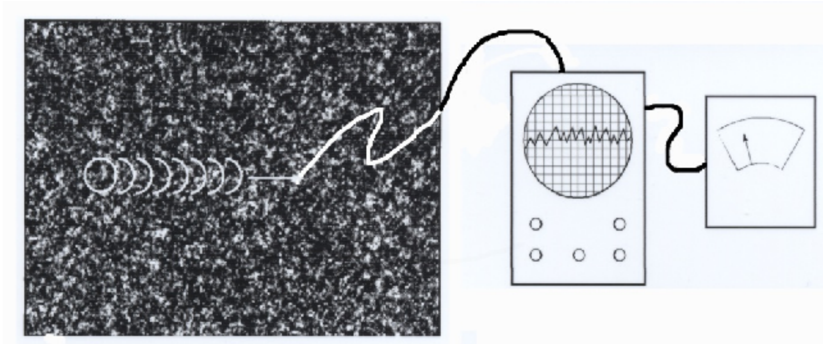


Figure 16: Measuring a RMS Granularity using a 48-micron sample area. Root Mean Square is the Standard Deviation of the Mean of the range of density measurements made on 1.0 D film. Image is from Kodak H-1(1999) p24.

After about 1980, film manufactures began measuring film "granularity" using the RMS Granularity protocol. Kodak slide films have a RMS Granularity of between 8 and 13 and Fuji reversal films have values between 7 and 10. [Remember: no units, not a measure of grain size.] Some color negative films have RMS Granularity rating of 5, as noise free as film can achieve. However, negative film must be printed, therefore the overall RMS Granularity of the system is much higher because it is combined with the grain of the print.

Table 3: RMS Granularity of Several Films with their Native Resolution

Film Name	RMS Granularity*	Native Resolution lp/mm @ 30%	Native Resolution ppi @ 30%
Kodak PORTRA 160NC	NA	73	3708
Kodak ULTRA 100UC	NA	60	3050
Kodak EDUPE	8.7	60	3050
Kodachrome 25	9	50	2540
Kodachrome 64	10	50	2540
Ektachrome 5071 (dup)	9	50	2540
Ektachrome 50	13	40	2030
Ektachrome 64	12	40	2030
Ektachrome 100	11	45	2290
Ektachrome 100GX	8	60	3050
Ektachrome 100plus EPP	11	45	2290
Ektachrome 160	13	35	1780
Fuji Velvia 50 RVP	8	80	4064
Fuji Velvia 100 RVP100F	8	80	3300
Fuji Provia 100F RPD	9	55	2800
Fuji Astra 100 RAP	10	45	2290
Fuji Astra 100F RAP100F	7	65	3300
Fujichrome EI 100	10	45	2290
Average	9.8	64.3	3264

Film Resolution - Sharpness

Film Resolution defines the potential resolving power of a film; Kodak calls this ***sharpness***. Herein, it is referred to the "native" resolution of film. Native resolution is determined from manufacture-published MTF Curves, which are found in the film data sheets. The MTF Curve is measured using a sine wave bar (see below) that is contact printed directly onto the film without using a lens; each measurement required about 2 weeks by manufacturer technicians. [**Note**: sharpness is determined herein at 30% contrast (% Response).]

In reality the resolution of film involves using a camera lens. Thus, true evaluation of film resolution must use the Resolving Power Equation (p 13). Both Kodak and Fuji have their own versions of the equation. When a lens is in the system (camera), the resolution of the film is about 30% to 80% of native resolution. It can be said that the greater the "native" resolution of the film, the greater the loss of the resolution in the system due to the use of a lens. The loss of system resolution is due to image deterioration by (1) exposed through a lens, (2) variables in film transport and (3) film processing. This evaluation is covered in great detail in another essay by the author held in the AIC-EMG Library <http://aic.stanford.edu/sg/emg/library/index.html>, see "Image File Formats: TIFF, JPEG & JPEG2000."

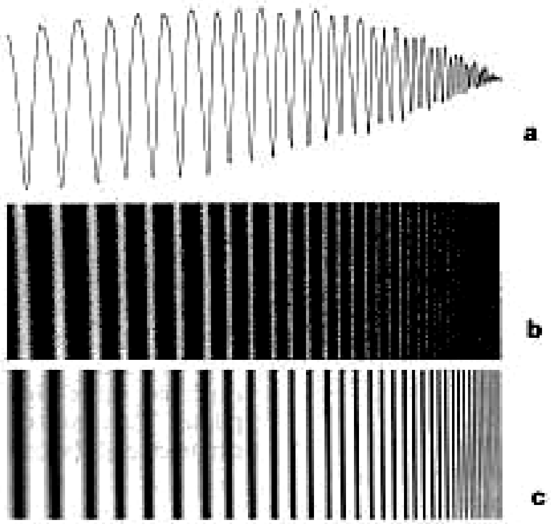


Figure 34
Image (b) of a sinusoidal test object (a) recorded on a photographic emulsion and a microdensitometer tracing (c) of the image

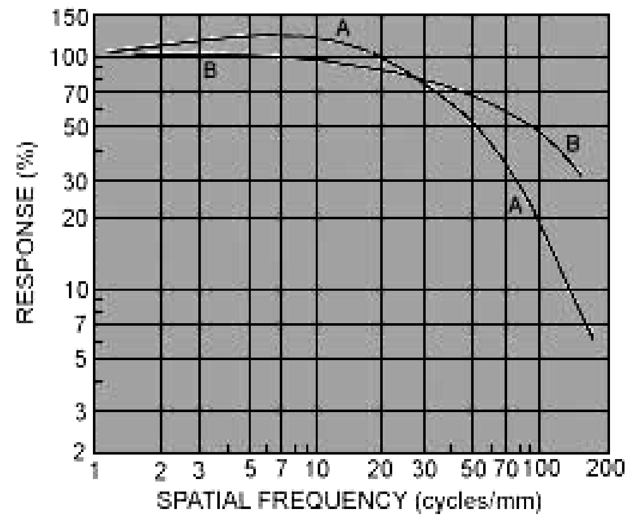
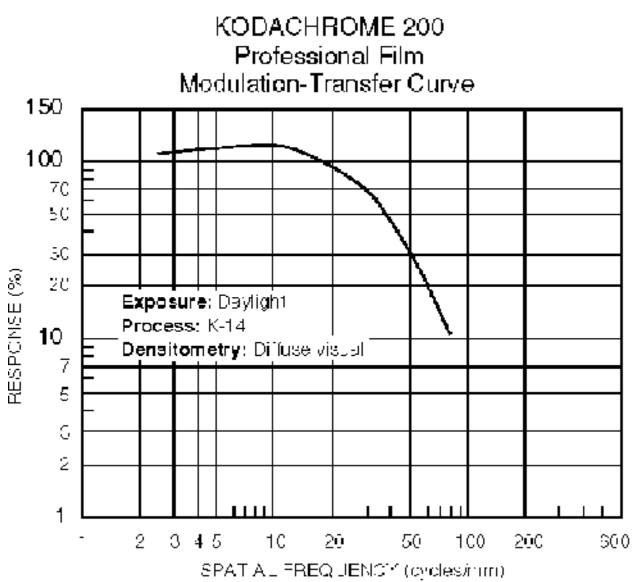


Figure 35
Modulation-transfer curves



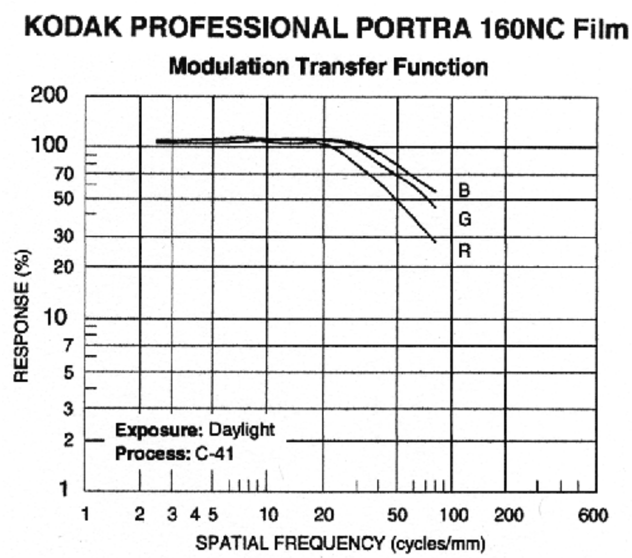


Figure 17: The images labeled "Figures 34 & 35" are from Kodak H-1 (1999) p 38. Fig. 34 shows an example of the decreasing sine wave object used for determining MTF data. In Fig. 35 plot line **A** shows edge-contrast sharpening while plot **B** shows no edge sharpening effect. In the lower two MTF Curves, taken from Kodak film data sheets, examples depict both A & B behaviors. Lower row on the left, is the MFT Curve for Kodachrome 200 (PKL); it shows edge enhancement with a direct-contact, the MTF value at 30% contrast difference (y axis) is 50-lp/mm, or 2540 ppi digital equivalent. On the right, the MTF Curve from Kodak PORTRA 160NC color negative film that has only slight edge enhancement with a native resolution at 30% contrast difference of 63-lp/mm, or 3200 ppi digital equivalent. Note that both MTF Curves turn down (sharp decrease in resolution) at about 20 lp/mm (25 um), the possible influence of film grain on film resolution.

The MTF Curve of Kodachrome 200 (PKL) transparency film shows a native resolution of 50-lp/mm, (2540 ppi digital equivalent). Using the Fuji Resolving Power Equation [EQ2, below], PKL film shot through an excellent 35mm format lens (100 lp/mm lens) will have a final resolution of 33-lp/mm, with a digital equivalent resolution of 1962 ppi; a loss of 34% from the native MTF data.

Note the convention used herein: apply the “digital equivalent” units of ppi (pixels per inch) to analog film. Film is an analog media; the units of lp/mm (line pairs per millimeter) are best applied when describing its resolution. However, expediency when comparing between the analog and digital domains is enhanced by applying the same units to both.

The Kodak PORTRA 160NC color negative film’s MTF Curve (lower right in Fig 17) shows a resolution of 73 lp/mm for the red dye at 30% contrast (% Response) or 3680 ppi digital equivalent. The blue and green dye layers have higher contrast at 73 lp/mm, but the red dye value is used here. When 160NC film is run through the Fuji Resolving Power Equation [EQ2, below], using an excellent 35mm format lens (100 lp/mm lens) the final resolution of the system is 42-lp/mm (2143 ppi digital equivalent) a loss of 42%, from the native MTF data at 30% contrast.

System Resolving Power Equation

There are many factors rolled onto the system resolving power equations. A "system" is the whole photographic unit, (a) camera [lens to film alignment], (b) lens [resolution and color shift], (c) film and (d) processing.

In the following equations, one term (1/r) is for the film and other(s) are for the lens(es). The resolving power for a “print” system (EQ1) includes terms for an enlarging lens and the resolution of the paper the equation, lowering the overall image resolution profoundly.

$$\textbf{EQ1: } 1/R = 1/r_{\text{[film]}} + 1/r_{\text{[camera lens]}} + 1/r_{\text{[enlarging lens]}} + 1/r_{\text{[printing paper]}}$$

The FujiFilm Resolving Power for a simple camera and film system (EQ2) such as for creating transparencies (slides) can be found in the Fuji Data Guide (p102, 1998):

$$\textbf{EQ2: } 1/R_{\text{[system]}} = 1/r_{\text{[film]}} + 1/r_{\text{[lens]}}$$

Where: (1) R = overall resolving power, and (2) r = resolving power of each component

Kodak uses the following equation, EQ3, in its data sheets and handbooks. It is more complicated, where each term is squared, but yields almost the same results. **It is NOT used in Table 5 or other arguments in this essay.**

$$\textbf{EQ3: } 1/R^2_{\text{[system]}} = 1/r^2_{\text{[film]}} + 1/r^2_{\text{[lens]}}$$

Lens Issues Affecting Resolution

There are at least 7 different types of lens aberrations:

- **Chromatic aberration**
- **Spherical aberration**
- **Coma (uneven magnification)**
- **Astigmatism (non-flat focus)**
- **Flare (external light scattering)**
- **Dispersion (internal light scattering)**
- **Misaligned lens elements**

The center of the lens is generally the sharpest. Resolution declines towards the edge of the image circle. Good modern lenses are not capable of more than 80-120 line-pairs per millimeter (lp/mm) at the center of the lens, and much less, towards the edges. Wide apertures compromise image quality dramatically because the light goes through most of the glass in the lens. Low f-stops (f3.5 to f5.6) in large format lenses are only capable of 10-20 lp/mm at the edges wide open and chromatic aberrations can be extreme - producing a rainbow of colors on large high-contrast features (black line on white) near the edges, where the various colors in light focus in different locations.

Film Issues Affecting Resolution

The problems with film have been described in detail within many online publications. Achieving crisp focus is the principal problem. However, keeping the film flat in any camera, and perpendicular to the lens axis is the critical issue. This is especially critical in film holders with large format view cameras. The next most critical issues are the variants in temperature and humidity through the life of the film and time period between exposure and processing. The issues forming an image on film include:

- **Goodness of focus**
- **Trueness of lens axis to film axis**
- **Warp of the film in the film holder or film path**
- **Aperture size (f-stop)**
- **Shutter Speed**
- **Vibration in all phases**
- **Dirt and haze on lens (light scatter)**
- **Film developing variables (exhaustion, impure water or impure chemicals)**
- **Heat and humidity in storage before and after exposure and processing**
- **Time since exposure and possible exposure to x-rays during airport screening**

The exposure parameters of shutter speed and f-stop effect sharpness markedly. The f-stops above and below the optimal lens iris opening, of f5.6 to f8, degrade the image noticeably. Slow shutter speeds allow for hand-induced shake during exposure decreasing image sharpness. Fast shutter speeds require longer processing times which enlarges film silver particle size, decreasing film resolution. A short exposure self-selects the more sensitive silver particle, which happens to be the larger silver particles. Mirror travel followed by an abrupt stop in SLRs can have an affect on camera movement (even while on a tripod) when using faster shutter speeds where the early period of "shake" is a relatively large portion of the full exposure time.

Evaluating a System: Camera, Lens and Film

Using the photographic system "Resolving Power Equation" EQ2 (above) from **FujiFilm Professional Data Guide** AF3-141E (2002) p 129; and the film resolution data in Table 4 below, the results are reported in Table 5, on the following page.

Table 4: Selected Film and Lens Resolution Data

Film	Resolution	$1/r_{[film]}$	Native Film Resolution in ppi No Lens in Path at 30% Contrast
Kodak Ektachrome 160	35 lp/mm	0.0286	1778
Fuji Astia RAP	45 lp/mm	0.022	2286
Fuji Provia 100F RDP	55 lp/mm	0.0182	2794
Kodak Ektachrome 100GX	60 lp/mm	0.0167	3050
Kodak Tri-X 400 (2004)	65 lp/mm	0.0154	3302
Fuji Velvia RVP	80 lp/mm	0.0125	4064
Kodak Portra 160NC Color Neg	80 lp/mm	0.0125	4064
Kodak Plus-X 125 (2006)	80 lp/mm	0.0125	4064
Kodak VR100 Color Neg	100 lp/mm	0.0100	5080
Kodak Technical Pan (2004)	142 lp/mm	0.007	7214
Kodak Panatomic-X	170 lp/mm	0.0059	8636

Lens	Resolution	$1/r_{[lens]}$	Lens Cost
Old lens (1840-1930) & LF lens	20 lp/mm	0.05	$50-1500
Average lens	40 lp/mm	0.025	$150-500
Very Good LF lens	60 lp/mm	0.0167	$300-800*
Excellent LF lens	80 lp/mm	0.0125	$1000-3000**
Superior 35 mm format lens	100 lp/mm	0.01	$350-5000***
Outstanding 35 mm lens	120 lp/mm	0.0083	$350-1000**§**
Exceptional 35mm lens	140 lp/mm	0.0071	$350-1000**Δ**
Best Possible 35mm lens	200 lp/mm	0.005	you won't find one
Vapor-ware lens	600 lp/mm	0.00167	you'll hear about it, but you can't find one

* Many 35 mm, medium format and large format lenses at f8; or better lenses at f11 or f16.
** Schneider 150 APO Symmar f5.6 at f8.
*** Many second-tier lenses at f8.
§ Nikkor & Canon 50mm & 85mm lenses at f8, on a tripod, superior processing, film only, no prints.
Δ Leica or Zeiss 35 mm or medium format lenses.

In the film and lens systems described below, the image is dramatically degraded by all lens and film issues described above (p 13-14). Loss of image quality ranges from 23-90% of native MTF resolution. Fixed cameras, such as 35 mm rangefinders and SLR bodies, and, medium format (MF), 2¼ x 2¼, or 6 x 6 cm and 2¼ x 2¾, or 6 x 7 cm, have fairly flat film planes and rigidly fixed lens-to-film axis.

Large format (LF) cameras use film holders that do not have flat film planes. Large film (8 x 10) can sag and the center of all sizes can have a slight warp. The lens-to-film axis in a view camera is never fixed and needs to be aligned at each setup. The Zigalign tool is commonly used by view camera operators to assure perfect alignment between lens and image plane. In digital cameras the media is never warped or out of plane unless manufactured poorly.

Figure 18 shows the effect of lens quality on specific films found in the Table 4. Selected modern films are processed through EQ2 using hypothetical lenses of various resolving capabilities:

- **average (40 lp/mm)**
- **good (60 lp/mm)**
- **very good (80 lp/mm)**
- **excellent (100 lp/mm)**
- **superior (120 lp/mm)**

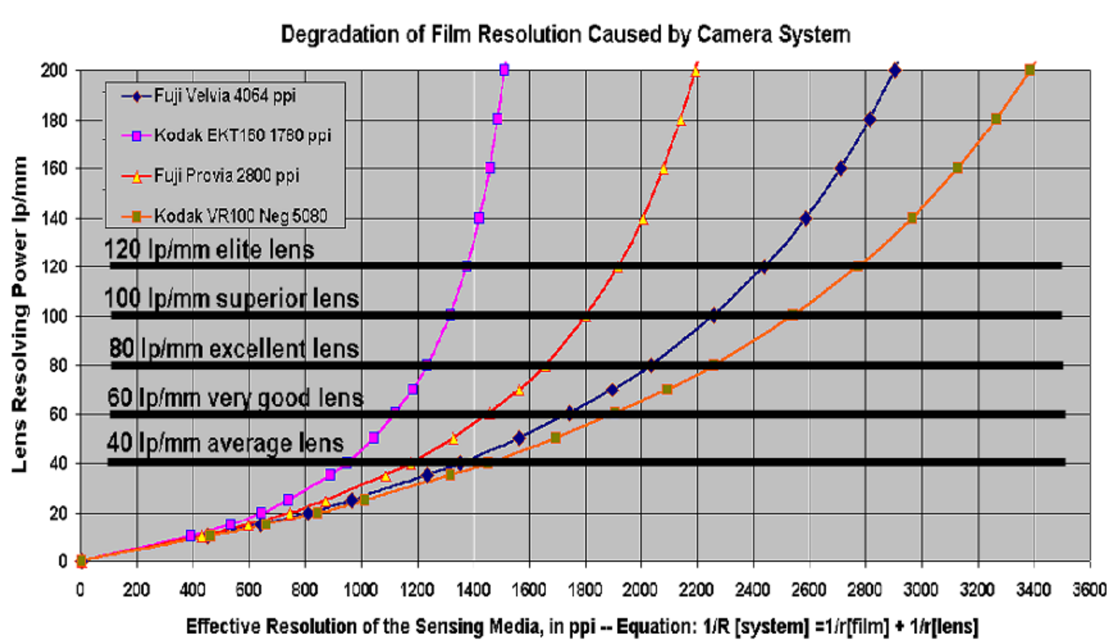


Figure 18: The graph shows the effects of lens quality on films with increasing native resolution (more acute curve). The data points on the curve are the System Resolution calculations for the combination of film and lens; see Table 5 for details. The higher the native resolution of the film the more it is affected by the lens.

Table 5 (next page) shows the incremental effects of (a) lens issues and (b) film issues on the final resolution of a system (camera) using the Fuji Resolving Power Equation [EQ 2]. The modern films listed in Table 4 are processed through EQ2 using lens of increasing quality: (1) 40 lp/mm, (2) 60 lp/mm, (3) 80 lp/mm, (4) 100 lp/mm, (5) 120 lp/mm, (6) 140 lp/mm), (7) 200 lp/mm and sometimes the mythical (8) 600 lp/mm lens.

The best 35 mm camera lenses will have a resolution of 60-120 lp/mm. In most cases the lens quality will not be better than 80 lp/mm, and will likely be only about 40-60 lp/mm; especially if a zoom lens is being used. This is statement is based on MTF lens evaluations posted on the PhotoDo website <http://www.photodo.com/products.html>, such as the 35 mm, 50 mm and 85mm prime lenses made by Canon and Nikon. Zoom lenses have lower resolution, about 60-85% that of prime lenses because of their complexity and numerous compromises made to achieve a fast performance over the range of the zoom.

Large format lens are not inferior in quality, but their overall resolution is lower because they use more glass to cover the larger film area. The image circle of a 35 mm lens is about 43 mm, while a 4 x 5 view camera has an image area of 160 mm; almost 4 times larger. The best large format lenses will range from 40-80 lp/mm with the average about 40-60 lp/mm. Only the rare lens will reach 80 lp/mm; none will reach 100 lp/mm. View cameras have the very real problems of achieving focus and aligning the lens axis to the film plane.

Table 5: System Resolving Power Data

Kodak Ektachrome 160 has 1778 ppi (35-lp/mm) native resolution

EKT 160	0.0286 + 0.05	= 0.0786	= 13 lp/mm	= 646 ppi	64% loss	thru 20 lp/mm lens
EKT 160	0.0286 + 0.025	= 0.0536	= 19 lp/mm	= 948 ppi	47% loss	thru 40 lp/mm lens
EKT 160	0.0286 + 0.0167	= 0.0453	= 22 lp/mm	= 1121 ppi	37% loss	thru 60 lp/mm lens
EKT 160	0.0286 + 0.0125	= 0.041	= 24 lp/mm	= 1236 ppi	30% loss	thru 80 lp/mm lens
EKT 160	0.0286 + 0.010	= 0.0386	= 26 lp/mm	= 1316 ppi	26% loss	thru 100 lp/mm lens
EKT 160	0.0286 + 0.0083	= 0.0369	= 27 lp/mm	= 1377 ppi	23% loss	thru 120 lp/mm lens

Fuji Astia RAP has 2286 ppi (45 lp/mm)native resolution

Fuji RAP	0.022 + 0.025	= 0.045	= 22 lp/mm	= 1121 ppi	51% loss	thru 40 lp/mm lens
Fuji RAP	0.022 + 0.0167	= 0.0387	= 26 lp/mm	= 1316 ppi	42% loss	thru 60 lp/mm lens
Fuji RAP	0.022 + 0.0125	= 0.0345	= 29 lp/mm	= 1473 ppi	36% loss	thru 80 lp/mm lens
Fuji RAP	0.022 + 0.010	= 0.032	= 31 lp/mm	= 1575 ppi	31% loss	thru 100 lp/mm lens
Fuji RAP	0.022 + 0.0083	= 0.0303	= 33 lp/mm	= 1575 ppi	27% loss	thru 120 lp/mm lens

Kodak Ektachrome 100GX has 3050 ppi (60 lp/mm) native resolution

EKT 100GX	0.0167 + 0.025	= 0.0417	= 24 lp/mm	= 1220 ppi	60% loss	thru 40 lp/mm lens
EKT 100GX	0.0167 + 0.0167	= 0.0334	= 30 lp/mm	= 1524 ppi	50% loss	thru 60 lp/mm lens
EKT 100GX	0.0167 + 0.0125	= 0.0294	= 34 lp/mm	= 1727 ppi	43% loss	thru 80 lp/mm lens
EKT 100GX	0.0167 + 0.010	= 0.0267	= 37 lp/mm	= 1880 ppi	38% loss	thru 100 lp/mm lens
EKT 100GX	0.0167 + 0.0083	= 0.025	= 40 lp/mm	= 2032 ppi	33% loss	thru 120 lp/mm lens

Kodak Tri-X 400 (2004) has 3302 ppi (65 lp/mm) native resolution

Kodak Tri-X	0.0154 + 0.05	= 0.0654	= 25 lp/mm	= 1257 ppi	58% loss	thru 40 lp/mm lens
Kodak Tri-X	0.0154 + 0.0167	= 0.0321	= 31 lp/mm	= 1582 ppi	52% loss	thru 60 lp/mm lens
Kodak Tri-X	0.0154 + 0.0125	= 0.0275	= 36 lp/mm	= 1847 ppi	44% loss	thru 80 lp/mm lens
Kodak Tri-X	0.0154 + 0.010	= 0.0254	= 39 lp/mm	= 2000 ppi	39% loss	thru 100 lp/mm lens
Kodak Tri-X	0.0154 + 0.0083	= 0.0237	= 42 lp/mm	= 2143 ppi	35% loss	thru 120 lp/mm lens
Kodak Tri-X	0.0154 + 0.0071	= 0.0225	= 44 lp/mm	= 2258 ppi	32% loss	thru 140 lp/mm lens
Kodak Tri-X	0.0154 + 0.005	= 0.0204	= 49 lp/mm	= 2490 ppi	25% loss	thru 200 lp/mm lens

Fuji Velvia RVP has 4064 (80 lp/mm) native resolution
Kodak Portra 160NC color negative film has 4064 ppi (80 lp/mm) native resolution
Kodak Plus-X 125 (2006) has 4064 ppi (80 lp/mm) native resolution

Kodak Plus-X	0.0125 + 0.05	= 0.0625	= 16 lp/mm	= 813 ppi	75% loss	thru 20 lp/mm lens
Kodak Plus-X	0.0125 + 0.025	= 0.0375	= 27 lp/mm	= 1355 ppi	66% loss	thru 40 lp/mm lens
Kodak Plus-X	0.0125 + 0.0167	= 0.0292	= 34 lp/mm	= 1740 ppi	57% loss	thru 60 lp/mm lens
Kodak Plus-X	0.0125 + 0.0125	= 0.025	= 40 lp/mm	= 2032 ppi	50% loss	thru 80 lp/mm lens
Kodak Plus-X	0.0125 + 0.010	= 0.0225	= 44 lp/mm	= 2235 ppi	45% loss	thru 100 lp/mm lens
Kodak Plus-X	0.0125 + 0.0083	= 0.0208	= 48 lp/mm	= 2442 ppi	40% loss	thru 120 lp/mm lens
Kodak Plus-X	0.0125 + 0.0071	= 0.0196	= 51 lp/mm	= 2592 ppi	36% loss	thru 140 lp/mm lens
Kodak Plus-X	0.0125 + 0.005	= 0.0175	= 57 lp/mm	= 2896 ppi	29% loss	thru 200 lp/mm lens

Kodak VR100 color negative film has 5080 (100 lp/mm) ppi native resolution

Kodak VR 100	0.010 + 0.05	= 0.06	= 17 lp/mm	= 847 ppi	83% loss	thru 20 lp/mm lens
Kodak VR 100	0.010 + 0.025	= 0.035	= 29 lp/mm	= 1473 ppi	75% loss	thru 40 lp/mm lens
Kodak VR 100	0.010 + 0.0167	= 0.0267	= 37 lp/mm	= 1880 ppi	63% loss	thru 60 lp/mm lens
Kodak VR 100	0.010 + 0.0125	= 0.0225	= 44 lp/mm	= 2235 ppi	56% loss	thru 80 lp/mm lens
Kodak VR 100	0.010 + 0.010	= 0.020	= 50 lp/mm	= 2540 ppi	50% loss	thru 100 lp/mm lens
Kodak VR 100	0.010 + 0.0083	= 0.0183	= 54 lp/mm	= 2776 ppi	45% loss	thru 120 lp/mm lens
Kodak VR 100	0.010 + 0.0071	= 0.0171	= 54 lp/mm	= 2776 ppi	45% loss	thru 140 lp/mm lens
Kodak VR 100	0.010 + 0.005	= 0.015	= 67 lp/mm	= 3387 ppi	33% loss	thru 200 lp/mm lens

Kodak Technical Pan (2004 & discontinued) has 7214 ppi (142 lp/mm) native resolution

Technical Pan	0.007 + 0.05	= 0.057	= 18 lp/mm	= 891 ppi	88%loss	thru 20 lp/mm lens
Technical Pan	0.007 + 0.025	= 0.032	= 31 lp/mm	= 1587 ppi	78%loss	thru 40 lp/mm lens
Technical Pan	0.007 + 0.0167	= 0.0237	= 42 lp/mm	= 2143 ppi	70% loss	thru 60 lp/mm lens
Technical Pan	0.007 + 0.0125	= 0.0195	= 51 lp/mm	= 2605 ppi	64% loss	thru 80 lp/mm lens
Technical Pan	0.007 + 0.010	= 0.017	= 58 lp/mm	= 2988 ppi	59% loss	thru 100 lp/mm lens
Technical Pan	0.007 + 0.0083	= 0.0153	= 65 lp/mm	= 3320 ppi	54% loss	thru 120 lp/mm lens
Technical Pan	0.007 + 0.0071	= 0.0141	= 71 lp/mm	= 3602 ppi	50% loss	thru 140 lp/mm lens
Technical Pan	0.007 + 0.005	= 0.012	= 83 lp/mm	= 4216 ppi	42% loss	thru 200 lp/mm lens
Technical Pan	0.007 + 0.00167	= 0.00867	= 115 lp/mm	= 5859 ppi	19% loss	thru 600 lp/mm lens

Kodak Panatomic-X (1976, probably high) has 8636 ppi (170 lp/mm) native resolution

Panatomic-X	0.0059 + 0.05	= 0.0618	= 16 lp/mm	= 822 ppi	90% loss	thru 20 lp/mm lens
Panatomic-X	0.0059 + 0.025	= 0.0321	= 32 lp/mm	= 1628 ppi	81% loss	thru 40 lp/mm lens
Panatomic-X	0.0059 + 0.0167	= 0.0238	= 42 lp/mm	= 2134 ppi	75% loss	thru 60 lp/mm lens
Panatomic-X	0.0059 + 0.0125	= 0.0184	= 54 lp/mm	= 2755 ppi	68% loss	thru 80 lp/mm lens
Panatomic-X	0.0059 + 0.010	= 0.0159	= 63 lp/mm	= 3195 ppi	63% loss	thru 100 lp/mm lens
Panatomic-X	0.0059 + 0.0083	= 0.0142	= 70 lp/mm	= 3577 ppi	59% loss	thru 120 lp/mm lens
Panatomic-X	0.0059 + 0.0071	= 0.013	= 77 lp/mm	= 3908 ppi	55% loss	thru 140 lp/mm lens
Panatomic-X	0.0059 + 0.005	= 0.0109	= 92 lp/mm	= 4661 ppi	46% loss	thru 200 lp/mm lens
Panatomic-X	0.0059 + 0.00167	= 0.00867	= 115 lp/mm	= 5860 ppi	32% loss	thru 600 lp/mm lens

Measuring Film Grain

The most common method of evaluating film grain is to enlarge the image until the “modulation,” or unevenness, of an area of uniform density, becomes obvious (***The Science of Photography***, Baines, 1976, Ch 18, p 228). The modulation never has sharp edges because it is not made of discrete particles. In an area of 1.0D (dark gray film) the image is made of hundreds of unseen silver particles, side by side and one piled on another through the depth of the film emulsion layer. The “modulation” is film grain; it is image noise.

In Mees & James (1967) they also say the only effective way to measure grain is to enlarge the film photographically until the film grain becomes evident. They warn that the results can be highly variable, based on the capabilities and skills of the people doing the evaluations and recommend using statistics. Training the observers also helps reduce variation in data.

Magnification (by loupe or microscope) is uniformly discouraged as a method because the evaluation is perceptual rather than an objective evaluation of discrete particles of a specific size. All these problems explain why the film manufacturers moved towards using Print Grain Index as a tool for defining film grain.

Print Grain Index

Print Grain Index is a modern tool used to evaluate graininess in an enlargement of color film negatives. Kodak Portra 160NC shows just perceptible film grain at 4.3X enlargement.

The terms Graininess and RMS Granularity are often confused or even used as synonyms in discussions of silver-halide or silver-to-dye-deposit distributions in photographic emulsions. The two terms refer to two distinctly different ways of evaluating film. When a photographic image is viewed with sufficient magnification, the viewer experiences the visual sensation of graininess, a subjective impression of a random round pattern in an image. This pattern can also be measured for its variability of film density (only) using a microdensitometer: this is known as RMS Granularity.

B&W films consist of silver-halide crystals dispersed in gelatin (the emulsion) and coated in a thin layer on a plastic support (the film base). The exposure and development of these silver crystals forms the photographic image. Residual silver (unexposed and undeveloped) is removed by the fixer.

In color processes the initial light sensitive silver particles are removed after development. The dye clouds are center on, and form around, the silver-halide crystals. The original silver-halide crystals, and clumps of crystals, vary in size, shape and sensitivity. Large particles are more sensitive while the smaller, are less sensitive to light.

Silver particles are randomly distributed within an emulsion. Within an area of uniform exposure, some of the silver crystals will be made developable by exposure to light while others will not. Development usually does not change the position of a silver particle.

Randomness is a necessary condition for the perceptual phenomenon of film grain. If the particles were arranged in a regular pattern, such as a halftone dot pattern used in graphic arts, no sensation of graininess would be created. When a halftone is viewed at a magnification sufficient for the dots to be distinguished, the eye notices the regular dot pattern and does not group dots into random patterns, just the half-tone pattern. Even though the half-tone dot pattern can be seen, the eye does not perceive graininess because the pattern is regular and not random. At lower magnifications, where the half-tone dots can no longer be resolved, the awareness of half-tone pattern fades away and the image appears smooth, patternless and grainless.

When a random pattern of small dots is viewed with magnification sufficient to resolve the individual dots no pattern can be recognized. When the magnification is decreased so the dots cannot be resolved, they appear to blend together to form a grainy pattern. Further explanations can be found in the Kodak Publication E-58 on graininess and granularity:

Technical Publication: Print Grain Index found at URL
<http://www.kodak.com/global/en/professional/support/techPubs/e58/e58.pdf>.

Size of Film Grain: Example

Film grain will be examined using two methods: **(1)** magnification and **(2)** print enlargement.

Table 6: Size Domains for Magnification and Enlargement Methods

Sample	Magnification	Method	Estimated Film Grain Size
Unknown B&W film, Fig. 21d	400x	Light Microscope	0.5 um
Unknown B&W film, Fig. 21c	60x	Light Microscope	2.1 um
Unknown B&W film, Fig. 21b	20x	Light Microscope	11.2 um
Portra 160NC	4.3x	Print Enlargement PGI	20.0 um
Unknown B&W film, Fig. 21a	2.5x	Light Microscope	34.0 um
Average Human Visual Acuity	1x	Human Eye	85.0 um
Best Possible Human Acuity	1x	Human Eye	60.0 um

Figure 21c, below, is taken from Kodak **H-1** <http://www.kodak.com/US/en/motion/support/h1/exposureP.shtml - tgrain>. It shows one B&W image at **(a)** 2.5**X**, **(b)** 20**X**, **(c)** 60**X**, **(d)** 400**X** and **(e)** ≈800**X** in an SEM. The absolute limits of resolution for the various magnifications are listed in Data Table 3, above. This is based on the average human visual acuity of 85 um; the best reported visual acuity is 60 um (8 lp/mm) and the worst is 120 um (4 lp/mm).

In the table above the rate of magnification was divided by the average limit of human visual acuity, 85 um, or 6-lp/mm, to yield the smallest estimated particle that could be resolved under ideal circumstances (high-NA objective using oil immersion of objective and Abbe condenser). The light microscope is capable of resolving 0.2 um (microns) using a **(1)** 1.25 NA 100x objective and **(2)** a 1.25 NA Abbe Condenser both with oil immersion.

Figure 19: Images pulled from <http://www.microscope-microscope.org/advanced/numerical-aperture.htm>

Since the silver metal particles after development, in average B&W film, are about 1-2 um, they are just visible in the light microscope at 400**X**.

$$\textbf{EQ4:}\quad \mathbf{d} = 1.22 \cdot \lambda \,/\, \mathbf{NA}_{(objective)} + \mathbf{NA}_{(condenser)}$$

Where **d** is the distance between two dark particles in microns, **λ** is the wavelength of light, such as green light at 0.55 um (550 nm) and **NA** is the numerical aperture of the lenses being used (objective or condenser). The condenser's NA cannot be greater than the objective's NA. Note that the objective lens is usually magnified by a 10x ocular (eyepiece), resulting in a 60x objective producing 600x magnification at the specimen.

Table 7: Maximum Resolution of the Light Microscope using 550 nm light

Objective	Oil Immersion	NA	Abbe Condenser	NA	Oil Immersion	Resolution (um)
2x	no	0.06	no	0.00	no	11.2
4x	no	0.10	no	0.00	no	6.7
4x	no	0.10	yes	0.10	no	3.4
6x	no	0.16	yes	0.16	no	2.1
10x	no	0.25	yes	0.25	no	1.3
20x	no	0.40	yes	0.40	no	0.83
40x	no	0.65	yes	0.65	no	0.51

50x	**yes**	**0.90**	**yes**	**0.90**	**no**	**0.37**
60x	**no**	**0.75**	**yes**	**0.75**	**no**	**0.45**
100x	**no**	**0.90**	**yes**	**0.90**	**no**	**0.37**
100x	**yes**	**1.25**	**yes**	**1.25**	**yes**	**0.26**

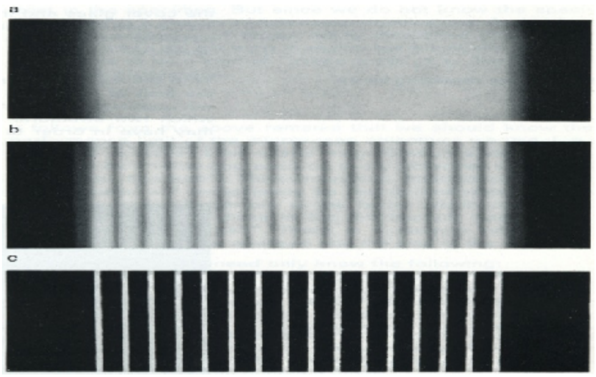


Figure 20

The image on the left (Fig 20) shows the effect of increasing lens resolution, or numerical aperture (NA) for microscope lenses, so that the **scatter of light** coming from the lighter bars, between the black bars, are diminished as the black bar features are resolved by the lens. The image is taken from **Microscopy from the Very Beginning,** Friedrich K Mollring, Carl Zeiss Publisher, West Germany (1971) p 40.

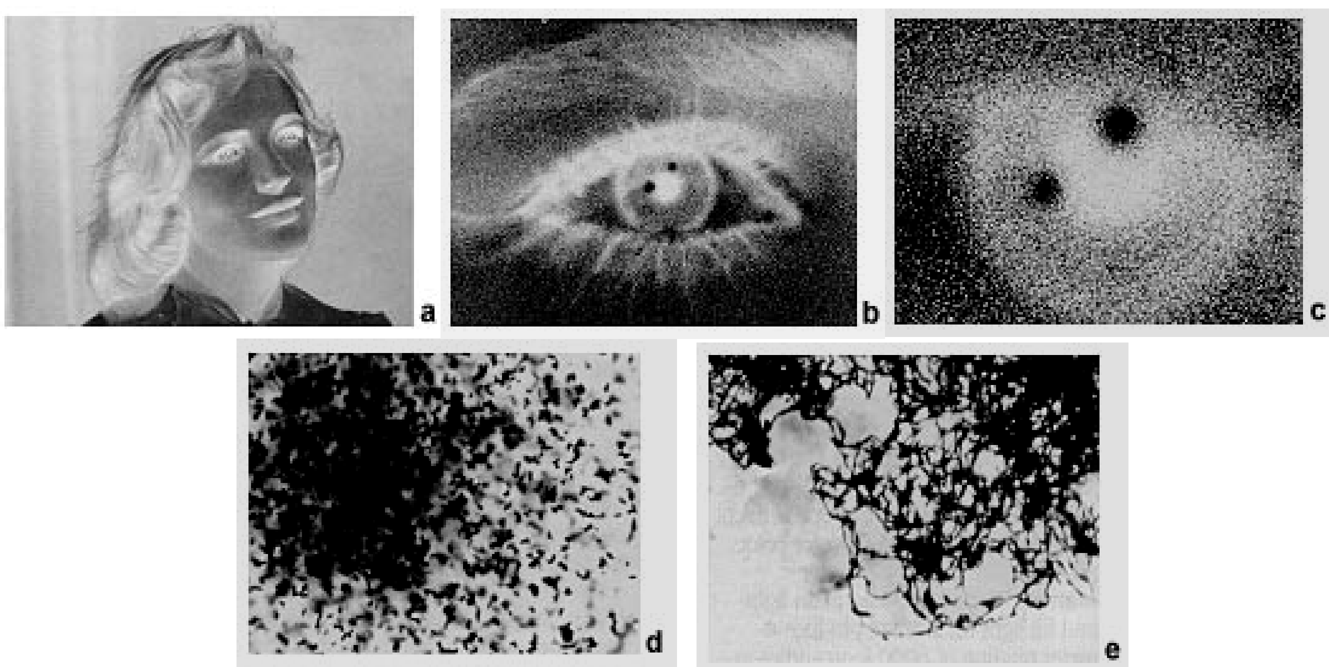


Figure 21: from Kodak **H-1**, Fig. 15: **(a)** a 2.5X enlargement of a negative shows no apparent graininess; **(b)** at 20X some graininess shows; **(c)** when inspected at 60X the individual film grains become distinguishable; **(d)** at 400X magnification, the discrete particles can be seen, note that surface particles are in focus while those deeper in the emulsion are out of focus, the apparent "clumping" of silver grains is actually caused by the overlap of grains at different depths when viewed; **(e)** the makeup of individual grains takes different forms, this image shows filamentary silver enlarged in an electron microscope, when at low magnification filaments appear s a single particle.

Kodak uses Print Grain Index (PGI) to define the degree of usable enlargement for some of its color negative films: PORTRA and ULTRA. The PGI data for Portra 160NC color negative film <http://www.kodak.com/global/en/professional/support/techPubs/e190/e190.pdf> is on page 7 in the PDF; see screen captures below.

The data shows that a **4.2x** to **4.4x** enlargement has “just visible” film grain. This 4.4**x** enlargement has a 36 PGI rating (when 25 PGI is just visible). At that magnification, individual dye clouds can’t be distinguished within a region of normal density (0.3 -1.0 D), but only at the edges of very thin regions.

IMAGE STRUCTURE

Print Grain Index

The Print Grain Index number refers to a method of defining graininess in a print made with diffuse-printing illumination. It replaces rms granularity and has a different scale which cannot be compared to rms granularity.

- The method uses a uniform perceptual scale, with a change of four units equaling a *just noticeable difference* in graininess to 90 percent of observers.
- A Print Grain Index rating of 25 on the scale represents the approximate visual threshold for graininess. A higher number indicates an increase in the amount of graininess observed.
- The standardized inspection (print-to-viewer) distance for all print sizes is 14 inches, the typical viewing distance for a 4 x 6-inch print.
- In practice, larger prints will likely be viewed from distances greater than 14 inches, which reduces apparent graininess.
- Print Grain Index numbers may not represent graininess observed from more specular printing illuminants, such as condenser enlargers.

Negative Size: 24 x 36 mm (Size 135)

Print Size in inches	4x6	8x10	16x20
Magnification	4.4X	8.8X	17.8X
Print Grain Index for—			
160NC Film	36	58	87
160VC Film	40	62	91
400NC Film	44	66	96
400VC Film	48	70	99
800 Film	48	70	99

Negative Size: 6 x 6 cm (Size 120/220)

Print Size in inches	4x6	8x10	16x20
Magnification	2.6X	4.4X	8.8X
Print Grain Index for—			
160NC Film	Less than 25	36	58
160VC Film	28	40	62
400NC Film	32	44	66
400VC Film	36	48	70
800 Film	36	48	70

Negative Size: 4 x 5 Inches (Sheets)

Print Size in inches	4x6	8x10	16x20
Magnification	1.2X	2.1X	4.2X
Print Grain Index for—			
160NC Film	Less than 25	Less than 25	35
160VC Film	Less than 25	Less than 25	39
400NC Film	Less than 25	28	43

For more information, see KODAK Publication No. E-58, *Print Grain Index—An Assessment of Print Graininess*

Figure 22: Taken from Kodak publication E-58 http://www.kodak.com/global/en/professional/support/techPubs/e190/e190.pdf.

4 - Eliminating Film Grain from an Image

Scanner operators have two procedures that are used to approach the goal of eliminating film grain: **(1)** wet mounting, **(2 - drum)** scan aperture [on drum scanners only] and **(2 - flatbed)** image resolution [level of grain control in a flatbed scanner].

Wet mounting can be used with equal effectiveness by flatbed and drum scanner operators to diminish perceived film grain. However, the wet mounting procedure cannot be used on "film scanners" because of their physical configuration. The Nikon Coolscan 9000 has been updated recently with the introduction of wet mounting tray; see the web for sources of these aftermarket devices.

The other method for drum scanners is to control the size of the aperture used to limit the area of the film being drum scanned for each pixel. If the drum scan aperture is larger than the grain size, the edges of the film grain are not defined; they are lost. The aperture must be about 2 times smaller than the grain to capture the soft edges of the grain with some degree of clarity. An aperture 2-3 times smaller will produce very clear grain definition. The critical factor working against diminishing film grain is that resolution will be lowered by using a larger aperture size than pixel size. Film resolution is independent of film grain, but resolution is harmed by the presence of film grain because it is image noise.

An operator that uses a flatbed scanner has only two options to diminish film grain, wet mounting and decreasing the resolution of the scan. A resolution that is about three-quarters of the perceived grain size allows a fair compromise between resolving image detail and breaking up the regularity of image noise that is film grain. However, decreasing resolution below twice-the-system-resolution, as calculated by the Resolving Power Equation (p 13), will degrade image quality markedly; see Nyquist 2x-oversampling rate on p 23.

Thus far, software that reduces film grain sacrifices image detail (see p 27).

The image in Figure 23 was taken from the ICG website's technical paper **A Drum Scanner or a Flatbed** at <http://www.icg.ltd.uk/icg/whydrum.htm>.

Drum Scan Aperture

Aperture is the opening at which the analog PMT (photo-multiplier tube) measures the intensity of light coming from the film. The analog light value measured by the PMT is converted into a digital RGB value in the analog-to-digital converter (A-D), commonly 12-bit native, for most drum scanners.

If the scan aperture is approximately equal to the perceived grain size, (a value determined from the experience of the operator) the noise of the "variations" across perceived "film grains" is eliminated when the average density for that region (pixel) is measured by the PMT.

The measured image density for the pixel -- minus the image noise introduced by the variations across the film grain -- is rendered as a uniform RGB value for each individual pixel. This eliminates film grain on the capture level. Note that each pixel has the same RGB value within that pixel, such as RGB = 128, 128, 128, representing 0.65 D for gray.

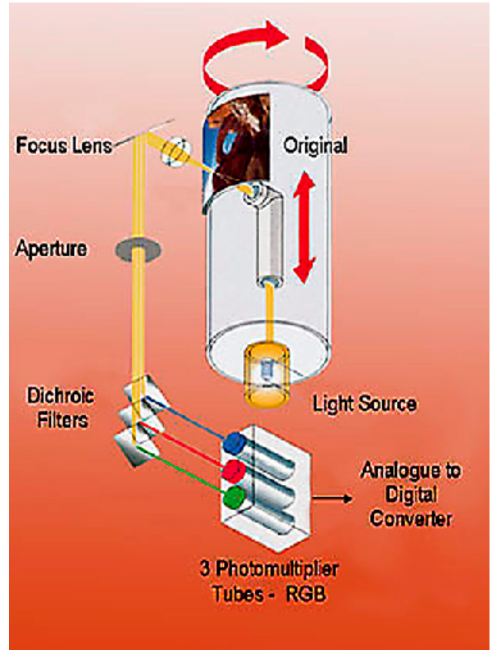


Figure 23: Drum scanner schematic pulled from ICG website.

Art of Drum Scanning -- No Film Grain with Higher Digital Image Resolution

Often, a drum scanner operator will choose a pixel pitch (ppi) that is much smaller than the aperture. An example: the operator selects a 12 um aperture (113 um^2 round) because it is known to eliminated film grain for the film being scanned, and then scans the image at 4000 ppi pixel pitch, which has an equivalent pixel size of 6.3 um, smaller than the aperture size.

The aperture size is 12 um, but the pixel size is 6.3 um; all detail between 6.3 um and 12 um is lost, but the image file has a large number of pixels based on the 4000 ppi pixel pitch. The PMT sees uniformly mixed light through the 12 um aperture, from the region of the film corresponding to the pixel pitch selected (4000 ppi). The light is measured and converted to digital values, and then applied to each of the 6.3 um pixels (each pixel has 40 um^2 area).

The large aperture size (12 um) corresponds to a resolution of 2117 ppi, but the pixel pitch is 4000 ppi. Each of the 6.3- um pixel's is seeing light from an area about 3 times larger (113 ÷ 40 = 2.8) than the pixels. The greater pixel population created by the denser pixel pitch has had the grain removed by the larger aperture size. This creates a digital image file that will make a large print with no grain. The downside is the image resolution is sacrificed in favor removing film grain. In the language of a flatbed scanner operator: the image has empty pixels. Not that there are clones of parent pixels, but that each pixel was made with an aperture that was 3 times larger than the size of the pixel; different process same concept.

The image could have been captured using a 7 um aperture at 4000 ppi pitch, where each of the 6.3 x 6.3 pixels would have an equivalent area of the film measured for each pixel, rather than the large area (12 um) in the example above. If the image was a 35 mm transparency, each pixel would be measured from approximately the same sized area on the film, but at a pixel density about 3.6 times higher, twice the scanning resolution. In this procedure, if film grain was about 12 um, it would be resolved with more detail. However, if there was image detail smaller than 12 um, it would be captured rather than lost due to the use of the larger aperture size.

Table 8: Feature Size versus Digital Resolution (ppi) versus Film Resolution (lp/mm)

Feature Size	Digital Resolution	Film Resolution
0.1 um	254,000 ppi	NA
0.2 um	127,000 ppi	NA
0.5 um	50,800 ppi	NA
0.8 um	31,750 ppi	NA
1.0 um	25,400 ppi	500 lp/mm
2.0 um	12,700 ppi	250 lp/mm
3.3 um	8,382 ppi	166 lp/mm
4.0 um	6,350 ppi	125 lp/mm
5.0 um	5,080 ppi	100 lp/mm
5.3 um	4,800 ppi	94 lp/mm
5.5 um	4,618 ppi	91 lp/mm
6.0 um	4,233 ppi	83 lp/mm
6.34 um	4,000 ppi	79 lp/mm
7.0 um	3,629 ppi	71 lp/mm
8.0 um	3,175 ppi	63 lp/mm
8.47 um	3,000 ppi	59 lp/mm
9.0 um	2,822 ppi	56 lp/mm
10.0 um	2,540 ppi	50 lp/mm
10.5 um	2,400 ppi	48 lp/mm
12.0 um	2,117 ppi	42 lp/mm
13.0 um	1,954 ppi	38 lp/mm
15.0 um	1,693 ppi	33 lp/mm
20.0 um	1,270 ppi	25 lp/mm
21.2 um	1,200 ppi	24 lp/mm
25.0 um	1,016 ppi	20 lp/mm
50.0 um	508 ppi	10 lp/mm
60.0 um	423 ppi	8 lp/mm
75.0 um	340 ppi	7 lp/mm
85.0 um	300 ppi	6 lp/mm
100 um	254 ppi	5 lp/mm
1000 um	25.4 ppi	1 lp/mm
1000000 um	One Meter	0.01 lp/mm

A 35 mm image capture at 12 um (2117 ppi) would enlarge to a standard 7 x 10 print. The image with 2117 x 3176 pixels has the equivalent of 7 inches of 300 ppi of information (7 x 300 = 2100 pixels). On the other hand, if the image was scanned at 4000 ppi, it could be enlarged to a 14" x 20" print, about 4 times larger, with individual pixels printed at 300 dpi (the limit of the average human's visual capabilities).

Balancing aperture and pixel pitch is the art of drum scanning. This sort of graceful lying is common in drum scans. Note that these procedures remain highly prized; based on the high monetary value these scans fetch in the marketplace. This is all the more interesting with the presence of flatbed scanners with equal or greater resolution, generally with greater bit depth in the A-D chip.

Scan Resolution in Flatbed Scanning

The same workflow (increasing number of pixels over the scan pitch) could be followed using a flatbed scanner. However, this is not commonly done because it is seen as padding the actual image resolution. However, it is essentially the same procedure, but done by the operator rather than the scanning device.

In an analogous workflow, a 35mm transparence would be scanned at 2100 ppi, which would be equivalent to a 12 um aperture on a drum scanner. The file would have 2100 x 3150 pixels, or 6.3 million pixels. In Photoshop, the total number of pixels would be increased four times (6.3 x 4 = 25.2 million pixels) using, >Image>Image Size, to a 4200 x 6300 pixel image. The process is not exactly the same as drum scanning process described above as the "art of drum scanning" for many reasons, but the effect is the almost the same. It is clear that the flatbed scanned image was padded with cloned pixels. However, a conceptually equivalent operation was done by the drum scan operator that scanned at a higher pixel pitch than was equivalent to the aperture size.

Lens is Limiting Factor for Flatbed Scanners

The major difference between the lens used in a flatbed scanner and the one used in a drum scanner is that scanner must transmit the image, while the lens in the drum scanner transmits no image detail it just shapes the light intensity. Thus the lens in the flatbed scanner is the limiting factor in resolution of the system. This is the same phenomenon found in image capture using a film or digital camera.

Art of Flatbed Scanning

The "art" of this process would be to scan at a low enough resolution (2000 to 2400ppi) to eliminate the perceived film grain, and then enlarge the resulting pixel count in Photoshop, producing directly cloned pixels of smaller dimensions. If one wanted to print a grainless 13" x 20" image from the 35 mm negative at the standard 300 dpi, one would need an image file with about 4000 x 6000 pixels. [However, I prefer to live with the film grain and scan at twice (or 3 times) the system resolution of the film, capturing as much image resolution as possible.]

The master pixels would be 13 um squares [169 um^2] made from the film, when scanned at the digital resolution of 2000 ppi. The four cloned pixels would be 6.3 x 6.3 um square [40 um^2] with a digital resolution of 4000ppi. Each cloned pixel would be one-fourth the size of the master, and possess exactly the same RGB value as the master.

Wet Mounting for Film Scanning

The other method of diminishing film grain pioneered by drum scan operators is wet mounting the film in organic solvent. This is also known as wet gate scanning in the world of motion picture film digitization. In both digital capture realms it is known for eliminating scratches in the base and reducing grain by making it look more like it should, soft, because grain is soft due to its diffuse nature.

Figure 24: Scanned by author using both dry (left) and wet mount (right) techniques, at 4800 ppi optical resolution, using 16-bit B&W dynamic range, on an Epson 4870 flatbed. Film grain should look soft because it is perceived through the thickness of the emulsion layer and is soft in reality. Note how the wet-scanned image actually has better definition between the dark rib and the gray panel on the far left of the dome. Also note how the dry scanned grain detracts from resolving information in the 100 year old film; the image is much nosier. Some believe that the dry scanned image looks sharper because the film grain appears sharp, but comparing the images will show more image information in the wet scanned image.

In the images above, both scans were made on the same scanner with the same settings, such as **(a)** no sharpening, **(b)** no automatic range or contrast adjustments, **(c)** no color management and **(d)** raw to gamma 2.2 onboard, all at 4800 ppi resolution using 16-bits B&W capture (Epson 4870 flatbed, at its maximum optical resolution).

The difference between the two images is that the image on the left was done in the standard manner (film sitting on the platen, dry) and the one on the right was mounted in Stoddard's solvent on the glass platen, with another layer of Stoddard's solvent and a Mylar sheet as a top layer. Thus, the wet-mounted film was encapsulated in solvent, which eliminates light scattering from the **(1)** surfaces of the film, **(2)** any dust particles or scratches in/on the film and **(3)** minimize scattering from colloidal silver deposits caused by "silvered-out" image silver over time, while also **(4)** minimizing flare from, **(5)** the diffuse light passing through the film from the traveling light source. Diffuse light (from many directions) is known from film enlarging, to reducing the dominance of film grain.

New Generation of Flatbed Scanners

The Epson 4870 & 4990 uses two-banks of RGB pixel rows (RRGGBB – see top of Figure 22) on the CCD chip. The native resolution of the CCD is 2400ppi. However, the upper row has of each color's pixels is shifted one-half a pixel width. And, each pixel has Individual lenses in the 6-line chip. This technology was pioneered in digital camera technology, where light was gathered from the full area of the pixel rather than the 30-70% area used to gather light with the remaining area being used for localized electronics for the transfer of electrons to the analog to digital converter. The lenses focus light from half the pixel width (2400 ppi) on alternating row of the same colored pixels. In the images below pulled from the Epson website in Japan, a depiction of the process can be seen, note the half-pixel offset seen in Figure 25. The following diagrams were harvested from the Epson Japanese website <http://www.i-love-epson.co.jp/products/colorio/scanner/f3200/index.htm> and <http://www.i-love-epson.co.jp/products/colorio/scanner/gtx750/index.htm>. While largely in Japanese, there are enough English words for the diagrams to be understood after some study.

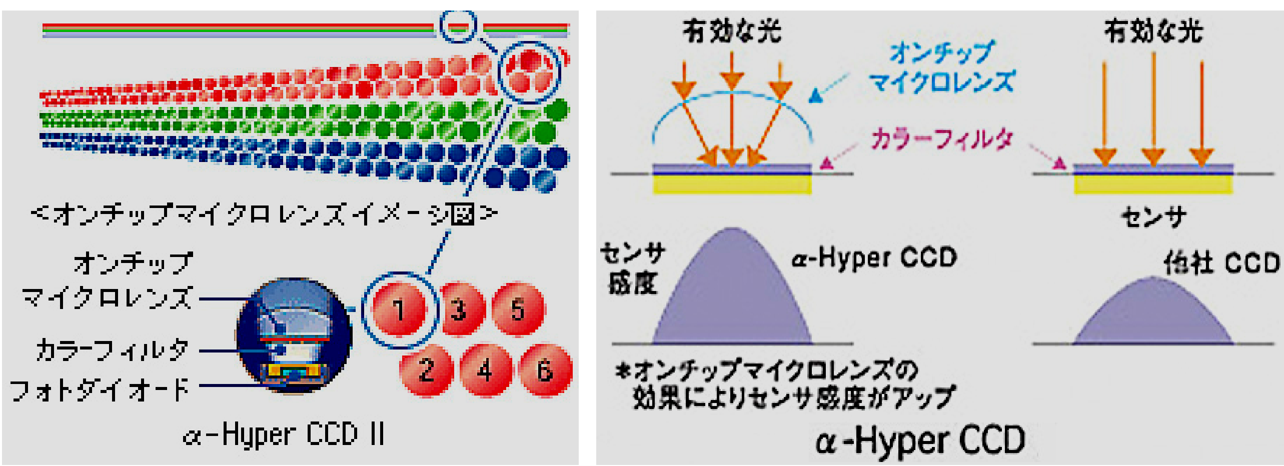


Figure 25: From Epson Japanese F-3200 webpage: (1) shows the new alpha-Hyper CCD II and its cross-section, (2) with the two rows of the same colored pixels offset by half-a-pixel including (3) the microlenses over each individual pixel that collect light at half the pitch of the full array. For the F-3200 the pitch is 1600 ppi; for the GT-X750 (Japan) or 4870/4900 (USA) the pitch is 2400 ppi. The lens makes an anamorphically compressed image that fits the width of the CCD chip. The information is captured at twice the density of a single row, because they are offset by a half-pixel width. The center and right diagrams of the top row show how the microlenses collect light and focus it on the active area of the pixel (center) while the image on the right shows the standard CCD configuration where light is focused on the chip by the system's lens. The "active" area on a CCD chip ranges from 30-70% of the full pixel area (the remaining pixel area is reserved for circuitry) and thus they gather light from a somewhat larger area than the pixel itself. The alpha-Hyper CCD has 6 lines of pixels with an "RRGGBB" configuration (top row left diagram) as opposed to the 3 lines of pixels in the normal "RGB" configuration usually found in other (a) flatbed, (b) dedicated film scanners and (c) digital scanning backs used in view cameras (LF).

The following image of a silicon-based sensor and quote is from the ExtremeTech at <http://www.extremetech.com/article2/0,1697,1157576,00.asp>. It shows microlenses over each pixel and a cross-section diagram with microlenses over a silicon array.

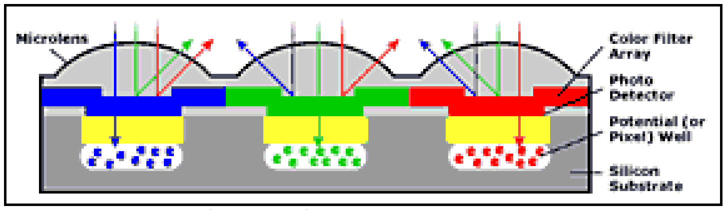


Figure 26: ExtremeTech website, "How Color Is Created: All image sensors are grayscale devices that record the intensity of light from full black to white, with the appropriate intervening gray. To add color to a digital camera image, a layer of color filters is bonded to the silicon using a photolithography process to apply color dyes. Image sensors that have micro lenses will put the color between the micro lens and the photodetector. With scanners that use trilinear CCDs (three adjacent linear CCDs using different colors, typically red, green, and blue) or high-end digital cameras that use three area array image sensors, it's a very simple issue of coating each of the three sensors with a separate color. (Note that some multi-sensor digital cameras use combinations of colors in their filters, rather than the three separate primaries). But for single sensor devices, such as the majority of consumer and prosumer digital still cameras used today, color filter arrays (CFAs) are used."

Kodak sells trilinear arrays, the following CCD being used in BetterLight scanning backs is probably the Kodak KLI-8023 which has 8002 pixels that are 9um x 9um square (no lenses) on a sensor that is 2.83" long without the enclosure, and 3.7" with; the URL for the sensor is <http://www.kodak.com/global/en/digital/ccd/products/linear/KLI-8023/specifications.jhtml?id=0.1.6.4.13.4&lc=en>.

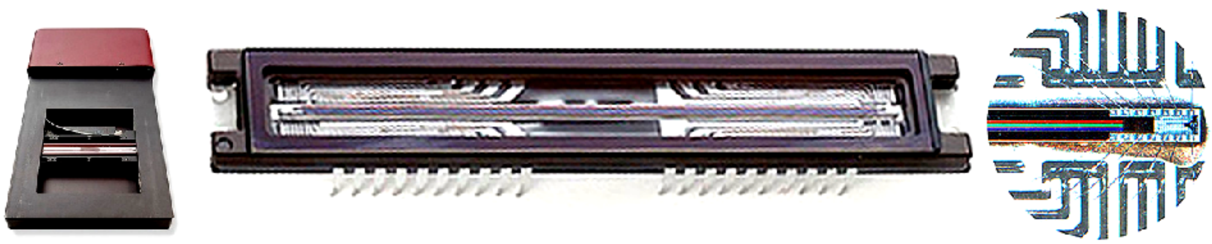


Figure 27: Taken from the BetterLight website (see below), (1) left image shows the scanning-back with the sensor parked mid-scan; (2) the center image shows an enlargement of the trilinear CCD array with "RGB" rows of pixels and (3) on the right, an end of the array is a further enlarged showing the actual red, green and blue bands of pixels.

The following is a quote from Mike Collette's "Scanning backs…How They Work" webpage on the BetterLight website **<**http://www.betterlight.com/how_they_work.html**>:**

> **"The trilinear sensor** is mounted in a ball bearing carriage that glides on a precision track cut into the metal body frame, and is accurately positioned by a matched polymer nut and stainless steel drive screw directly coupled to a high-torque step motor with up to 6400 micro-steps per revolution, for outstanding smoothness at any motor speed. This motor is driven by a dedicated microcontroller that also controls the sensor's exposure and timing, for crystal-accurate synchronization of these important functions."

This design is more solid and accurate than most flatbed scanners, which are also 4-8 times the size but it is basically the same design. Further quoting from the BetterLight webpage:

> "Within the image sensor, three rows of light-sensitive photodiodes are each covered by a red, green, or blue color filter [no lens], making the entire row sensitive to only one primary color. While Kodak's trilinear sensors use CCD (charge-coupled device) technology like many other digital cameras, in these devices the CCD structures are "blind" (not sensitive to light), and serve only as charge transport "conveyor belts" to carry the individual pixel signals from the photodiodes to an output amplifier for each row. Because there is no need to have the three rows of photodiodes immediately adjacent to each other, a wide CCD structure is positioned adjacent to each row of photodiodes, with the necessary electrical couplings between them. The CCD structure is wider than the photodiode structure so it can carry bigger charge packets (more electrons), which improves dynamic range.
>
> Because of this dual photodiode/CCD structure, these sensors can be reading out three previous rows of color pixel information via the CCD structures while the next three rows of color pixels are being collected in the photodiodes. This allows continuous exposure and readout of the sensor during a scan, without requiring any mechanical shutter. **Better Light scanning backs do not stop and start the scanning mechanism** to allow the data-collection system to "catch up" – instead, the sensor is always moved smoothly and continuously throughout each capture."

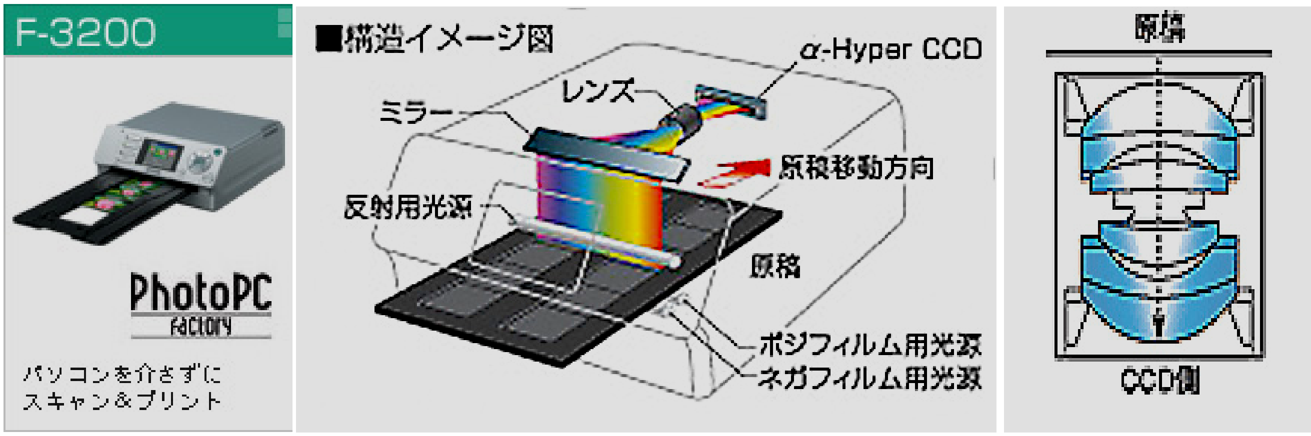


Figure 28: From Epson japanese F-3200 & GT-X750 webpages: (1) notice that the full width of the "line" being scanned is shaped into an anamorphic image that is focused on the lens, (2) notice the location of the lens between the mirror and the CCD and on the right (3) a typical Epson scanner lens (GT-X750) that has 6 elements in 4 groups, which is a very good optical configuration, especially when the elements are multicoated.

Next Generation of Scanners – Epson Perfection V750-M

The next generation of Epson flatbed scanners began in 2006, a quote from the Epson US website:

> **"**…the Epson Perfection™ V750-M Pro [is] the first flatbed scanner with ground breaking 6400 dpi resolution and unique fluid mount capabilities for photo studio applications. With amazing 6400 dpi resolution, this powerful performer consistently delivers precision color and detail. An enhanced optical system (High-Pass Optics) consisting of anti-reflective lens coatings and a high-reflection mirror provides the highest level of image quality and helps you achieve faster scans. In addition, the Dual Lens System from Epson optimizes each scan, automatically selecting from two lenses for the desired scan resolution.**"**

Figure 29: Taken from the Epson Japanese webpage for the GT-X900 (6400 ppi) scanner. The image on the left shows the Dual Lens holder and the images on the right show the individual lenses removed from the holder. There design is probably very similar to the lens schematic on the right in Figure 28.

The improvements projected for the GT-X900 (Japan) and the Perfection V750-M seem to be **(1)** better lens coatings, which will reduce flare, **(2)** more efficient moving mirror, **(3)** better overall optics and **(4)** possible CCD improvements over the alpha-Hyper CCD II. Optical components are critical in flatbed scanners because the image being scanned passes through, and is thus modified by, the lens system, which includes the moving mirror that horizontally compresses the image before it is sent to the CCD. The CCD is typically shorter in length than the width of the scan bed; it's usually a third the width. The CCD in the new scanner, at a minimum, will use the alpha-Hyper CCD II technology found in the Epson 4900 & 4870 scanners shown in Figure 24 above.

In addition, the V750-M will be shipped with a wet scanning tray. This suggests that the point of best focus will continue to be above the glass platen, on to the plane of the film in the film holders. A significant improvement would be a manual focus system as seen in part of the Epson's Expression line: the 1680 (8.5"x 11.7") and 1640XL (12.2" x 17.2", tabloid size, now discontinued) and the 10000XL, their current tabloid sized scanner.

Software for Diminishing Film Grain

I have yet to find any software that reduced grain without affecting the image in the size domain of the grain. I'm still looking for better grain removal software, but I'm less hopeful because it seems that the problem is not well understood by the software engineers.

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