Integrated Calibration and Management of Color, Tone, and Image Structure in a Digital Intermediate System

Nestor M. Rodriguez
Richard B. Wheeler

Entertainment Imaging

Kodak

DI Process Calibration Opportunity

As the number of feature films undergoing digital intermediate processes has increased, so has the need for more efficient methods to reduce system variability and preserving creative intent.

Statement of Problem

Unwanted color, tone, and image structure distortions may be introduced during scanned film digitization, intercutting of different type source material (e.g., digital origination) and subsequent image processing operations in the post-production stage.

Possible Solution

Employ a common metric for the calibration of all imaging device data

Possible Film-type Metrics for Calibration

-- Raw “**scanner-dependent” densities**.

-- Scanner densities converted to calibrated **“printing densities”** (SMPTE recommended practice – i.e. RP-180).

-- An **ISO density standard** (e.g., Status M).

-- Scanner density output converted to **scene exposure space** (e.g., film RGB logE).

But, can the Printing Density calibration metric also be applied to Digital Imaging (non-film) situations?

Therefore, an overview of the color management (calibration) steps based on the Printing Density metric will be provided for the various devices that can be employed in a DI process

Optical Density Defined

A film's Optical Density is determined from the combination of the Detector, Optics, Filters, and Light Source that compose the measurement system.

Detector – Defined by Spectral Sensitivity

Optics & Filters – Defined by Spectral Transmittance Factor

Light Source – Defined by Spectral Energy

$$\text{Responsivity}(\lambda) = \text{Detector}(\lambda) * \text{Optics}(\lambda) * \text{Filters}(\lambda) * \text{Light Source}(\lambda)$$

[where λ is the wavelength of the light]

$$I_0 = \Sigma_\lambda \text{Responsivity}(\lambda)$$

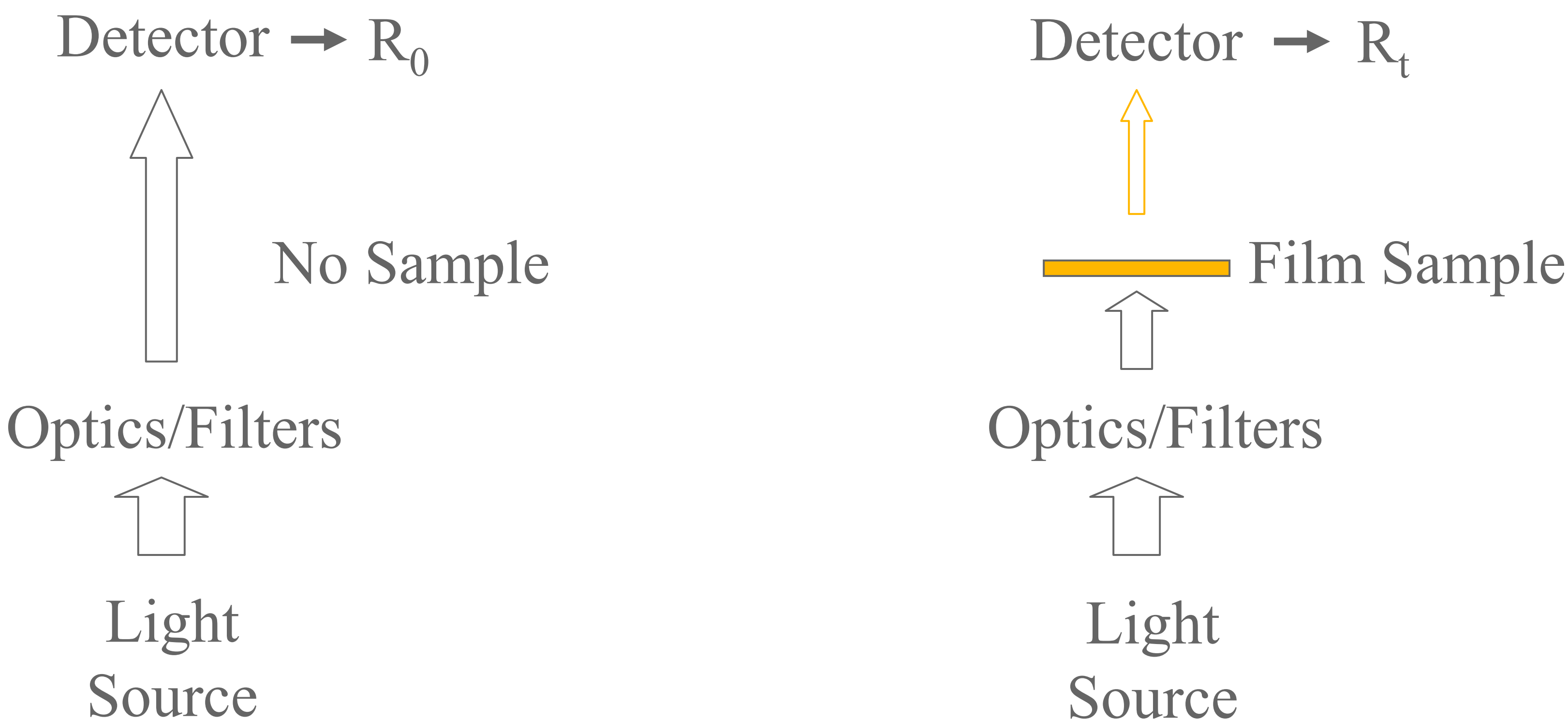
$$I_t = \Sigma_\lambda [\text{Responsivity}(\lambda) * \text{Film Transmittance Factor}(\lambda)]$$

$$\text{Transmittance Factor, } T = I_t / I_0$$

Optical Density = -log10(T)

SMPTE Kodak

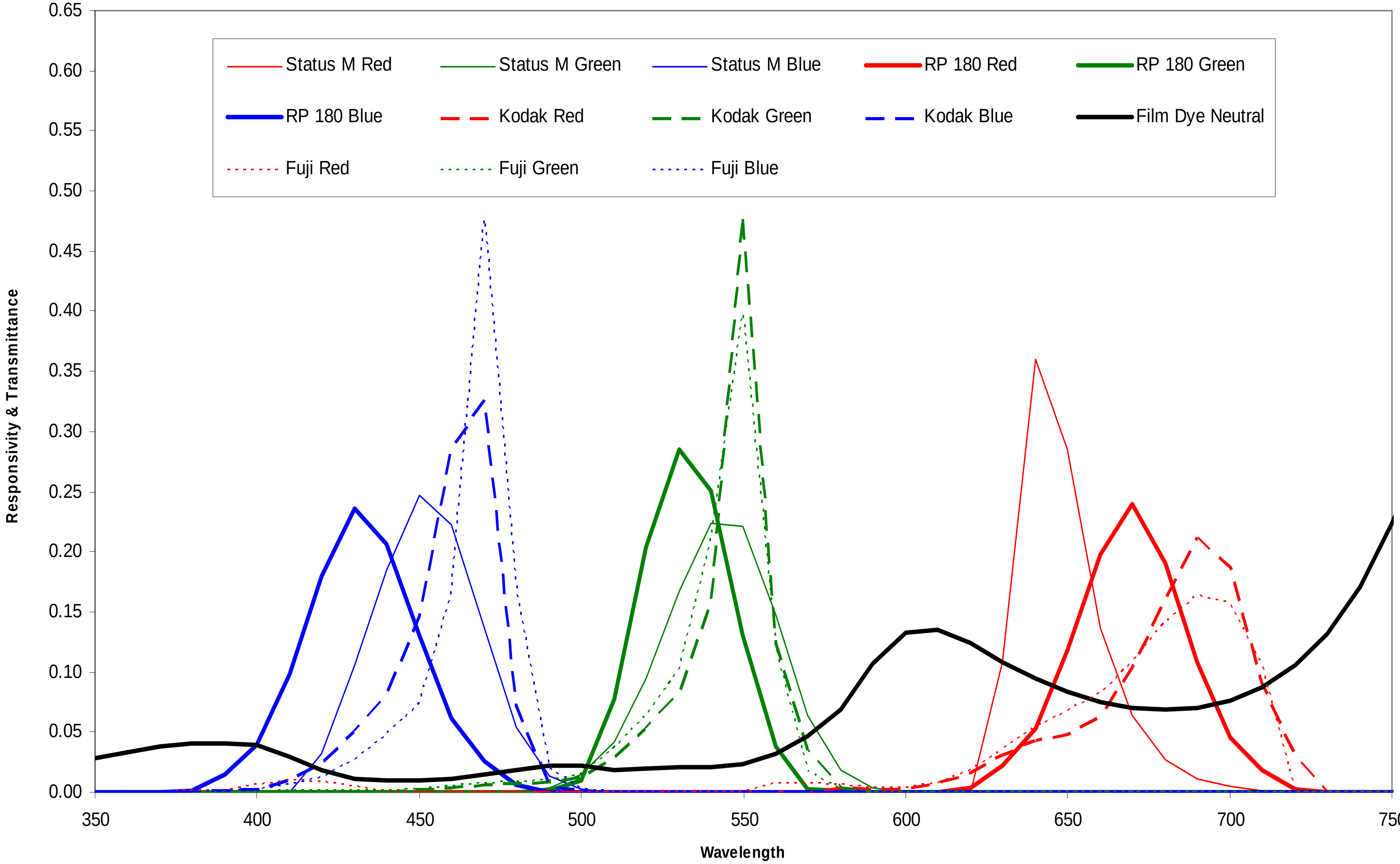
Optical Density



Transmittance Factor, $T = R_t / R_0$

Optical Density = $-\log_{10}(T)$

Various Types of Film Density Responsivities



Printing Density

Printing Density is a specific case of Optical Density where the Detector is the Print Film, and the Optics, Filters and Light Source are those of the printer.

With a color film, there are commonly three spectral sensitivities that produce three printing densities corresponding to the amount of red, green, and blue content in the image (i.e. RGB).

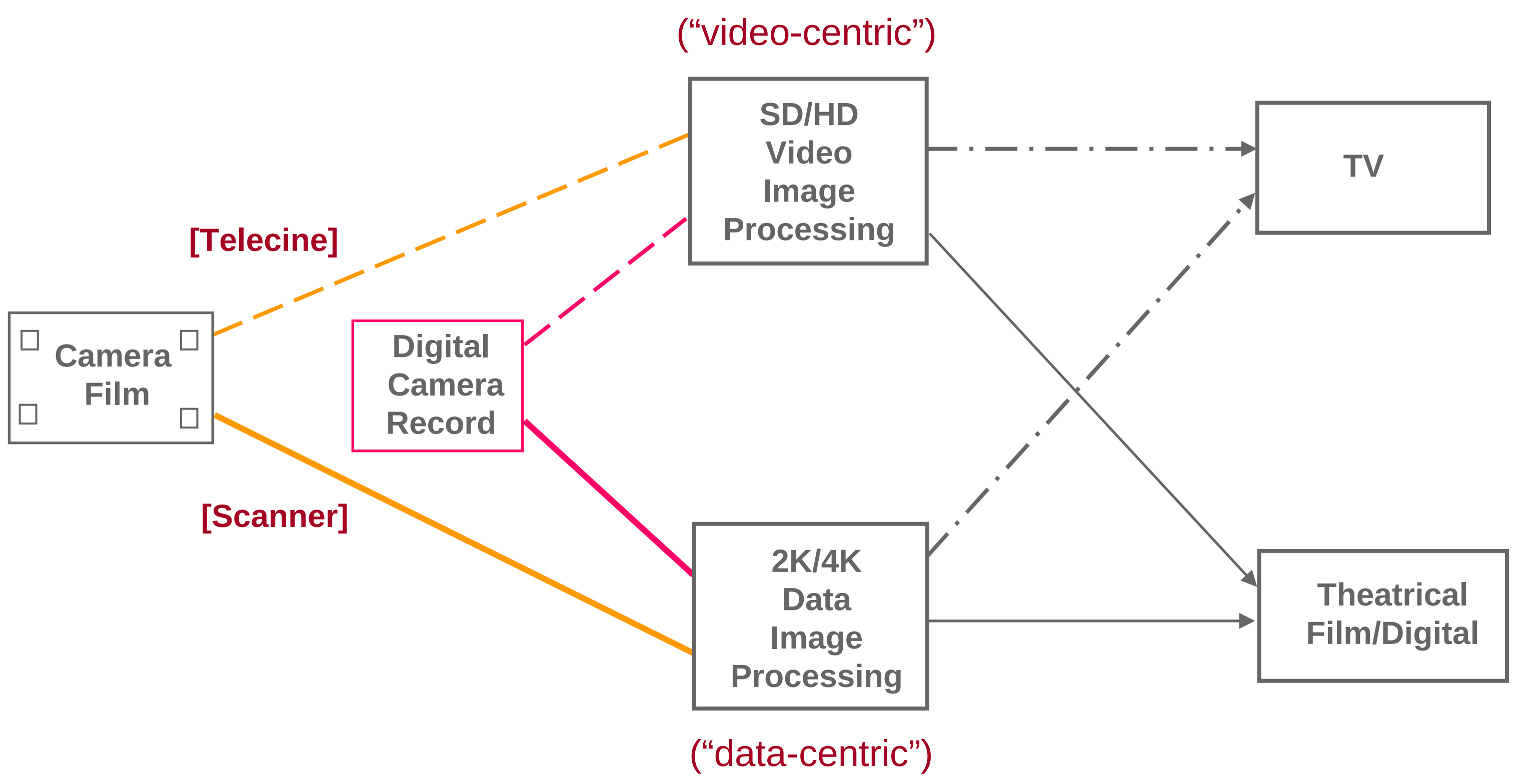
The Printing Density RGB Responsivities have been standardized in SMPTE RP-180 for a *specified print film and printer combination*.

A film patch has a defined set of Printing Densities only when the print film spectral sensitivities and the printer light sources (lights plus optical filters) are defined.

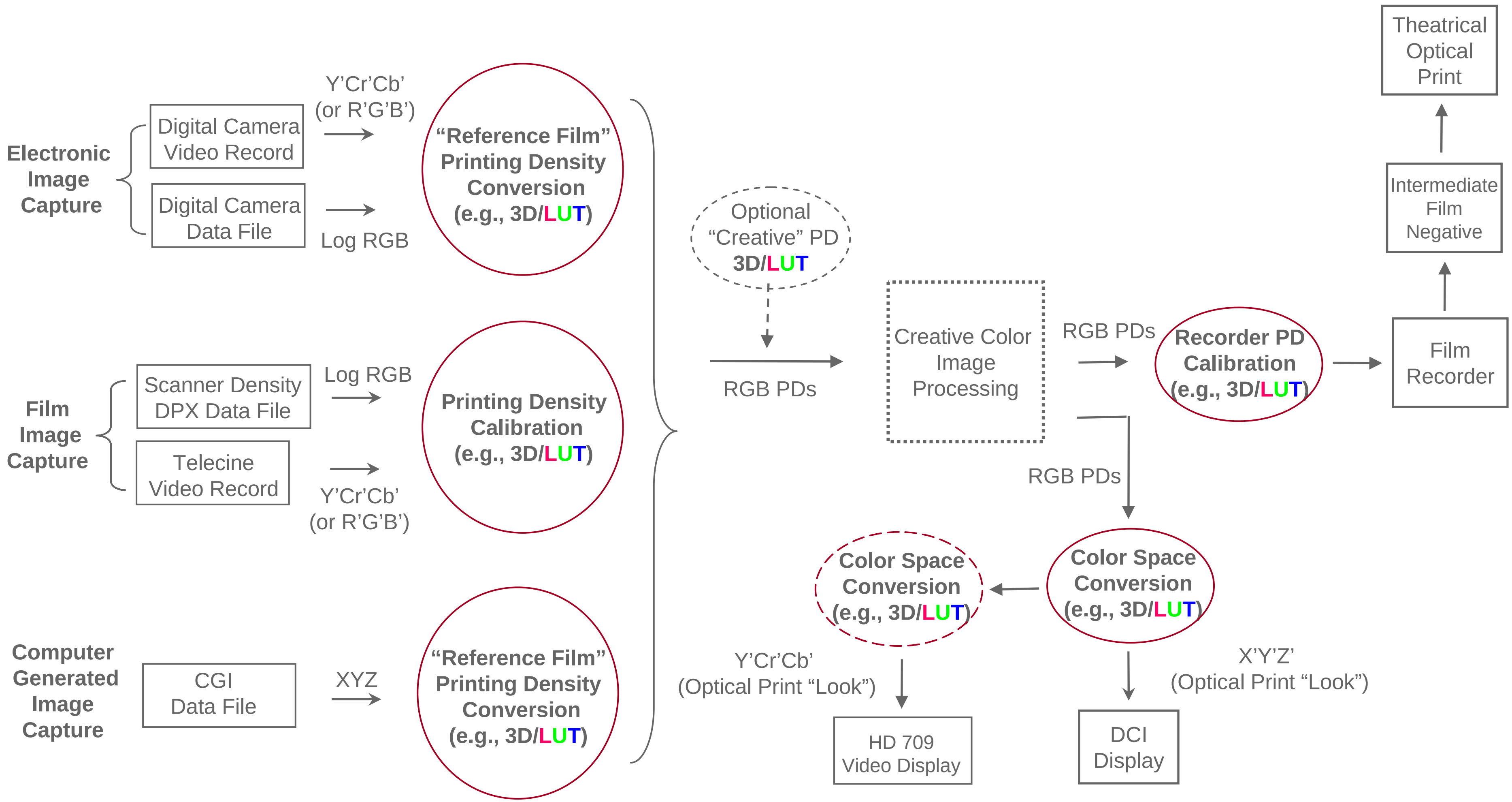
Therefore, as a result of the above, **scanner density output is not necessarily Printing Density unless calibrated to a defined PD metric.**

Possibilities for Digital Intermediate Workflow

[Image Capture] [Post Production] [Distribution]



“Printing Density” (PD) Metric Workflow (for Digital Intermediate Color Management)



All device PD color management calibration/conversion functions

(scan density → printing density,

digital camera exposure → film exposure, etc.)

can be accomplished via 3D and 1D LUTs

to reduce the math to simple indexing (mapping) operations

removes the burden of having to perform a non-linear type calculation (e.g., polynomial) each time a value is needed

(or alternatively, a 3x4 matrix and 1D/LUT can be used if one metric is

a mathematical linear combination of the other)

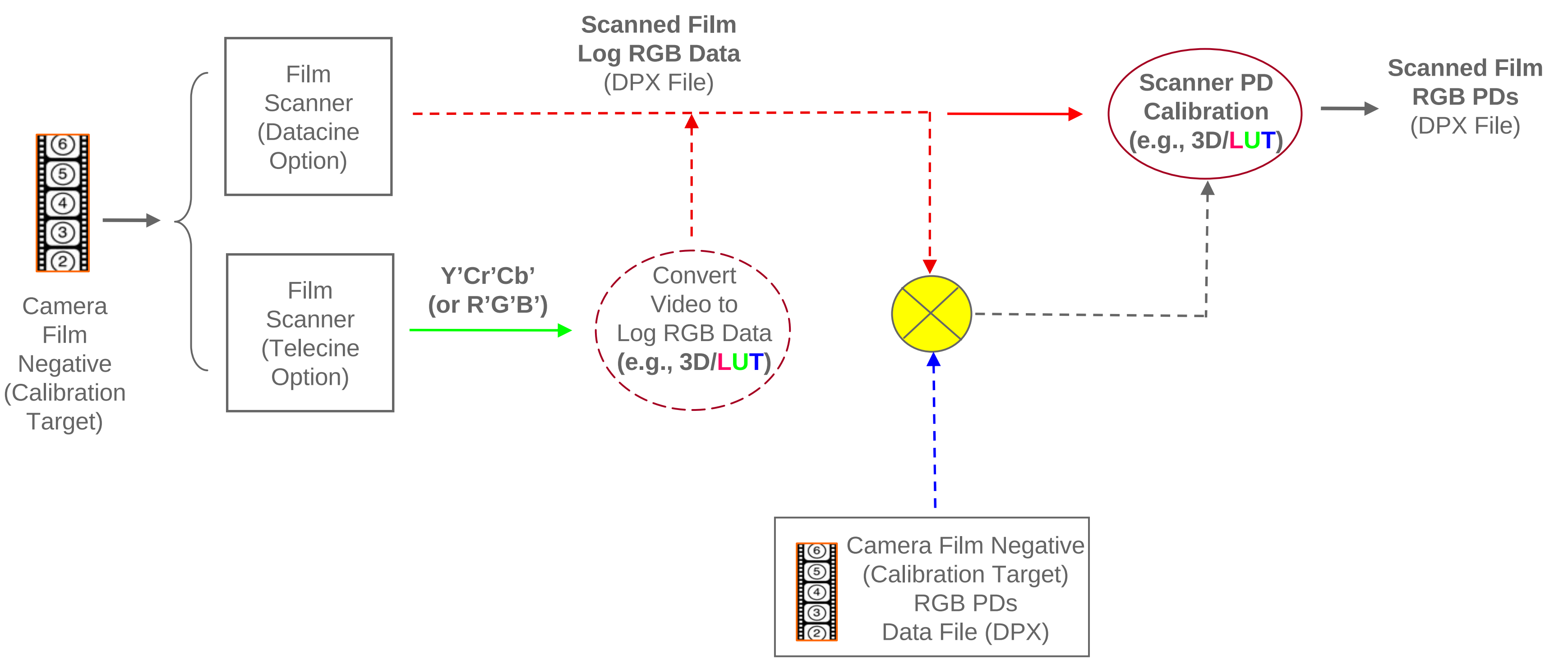
In all cases, we are talking about processing of digital data (code values) so that a set of input code values is transformed into a set of output values

There are usually two categories for the code values: device code values and color space code values

Thus, the image processing is a transform between these two categories:

Device to Device (e.g., scanner code values to printing density code values)
Device to Color Space (e.g., digital camera code values to CIE XYZ code values)
Color Space to Color Space (e.g., CIE XYZ to CIE L*a*b*)
Color Space to Device (e.g., CIE XYZ to monitor code values)

"Printing Density" (PD) Metric Workflow
Film Scanner Data Calibration

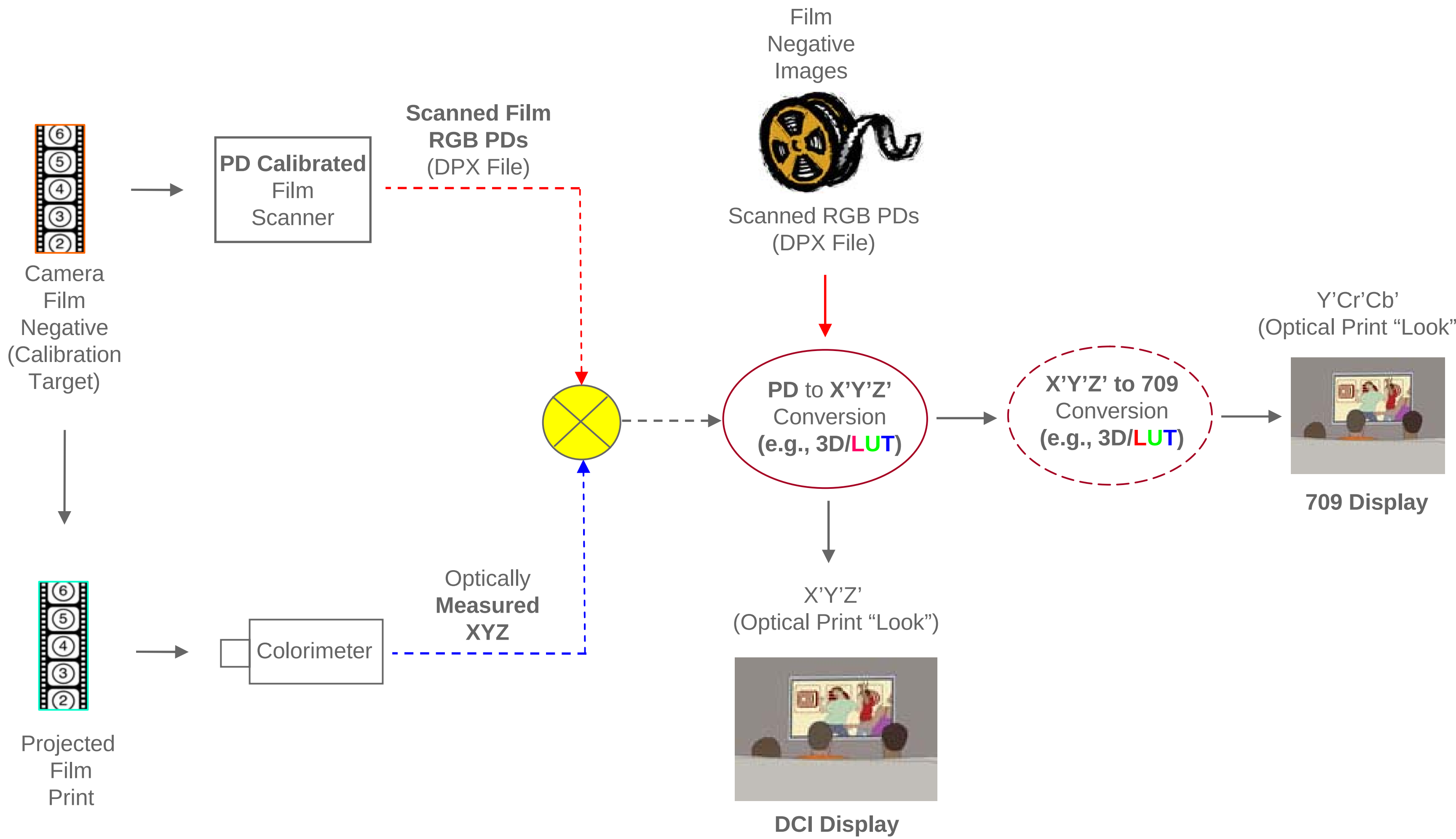


Scanner Color Variability

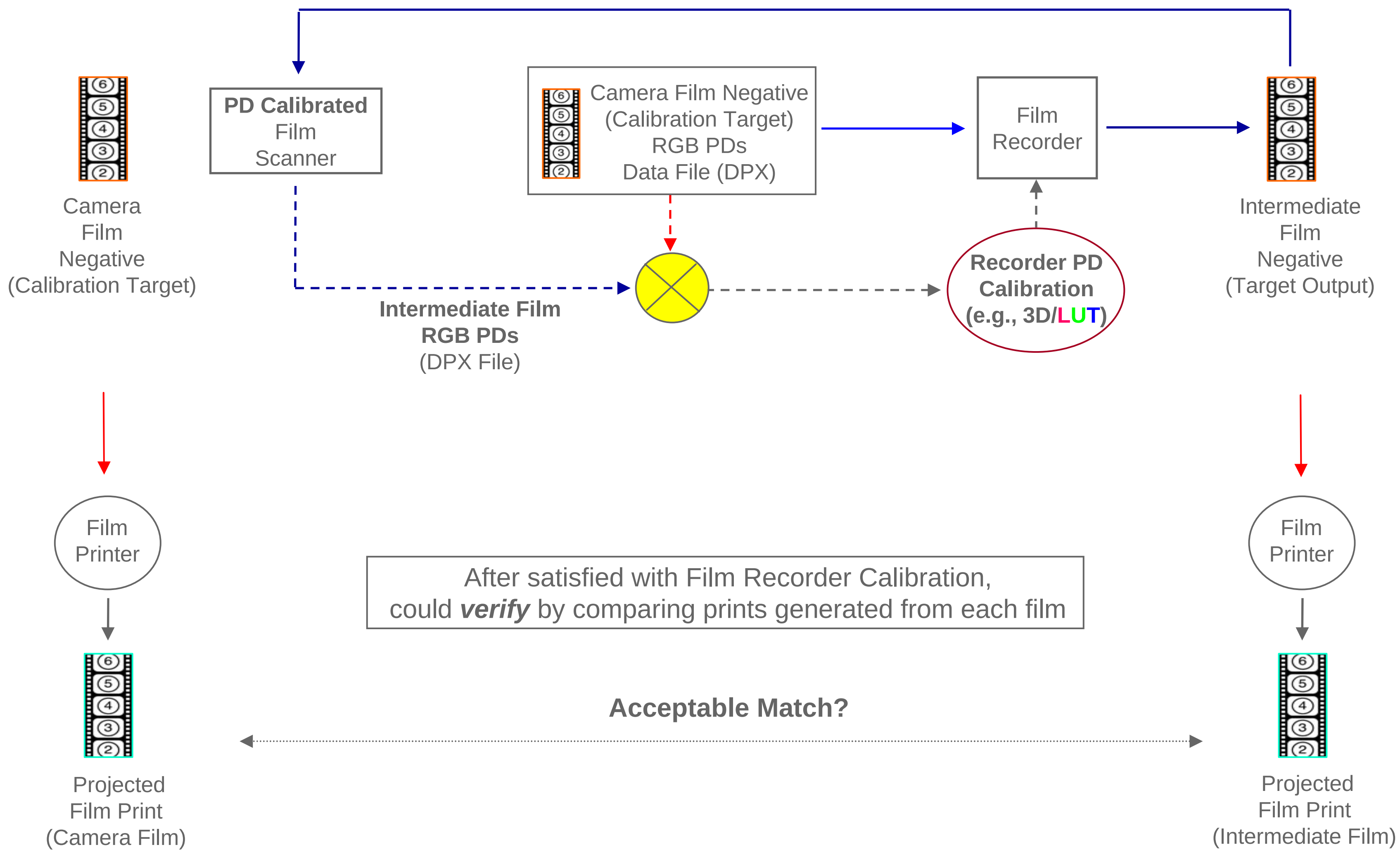
Sources include

- Light source spectral output
- Optical system geometry and flare
- Optics and filter transmittances
- Sensor pixel responsivities
- Calibration strip integrity
- Color and tone scale calibration parameters

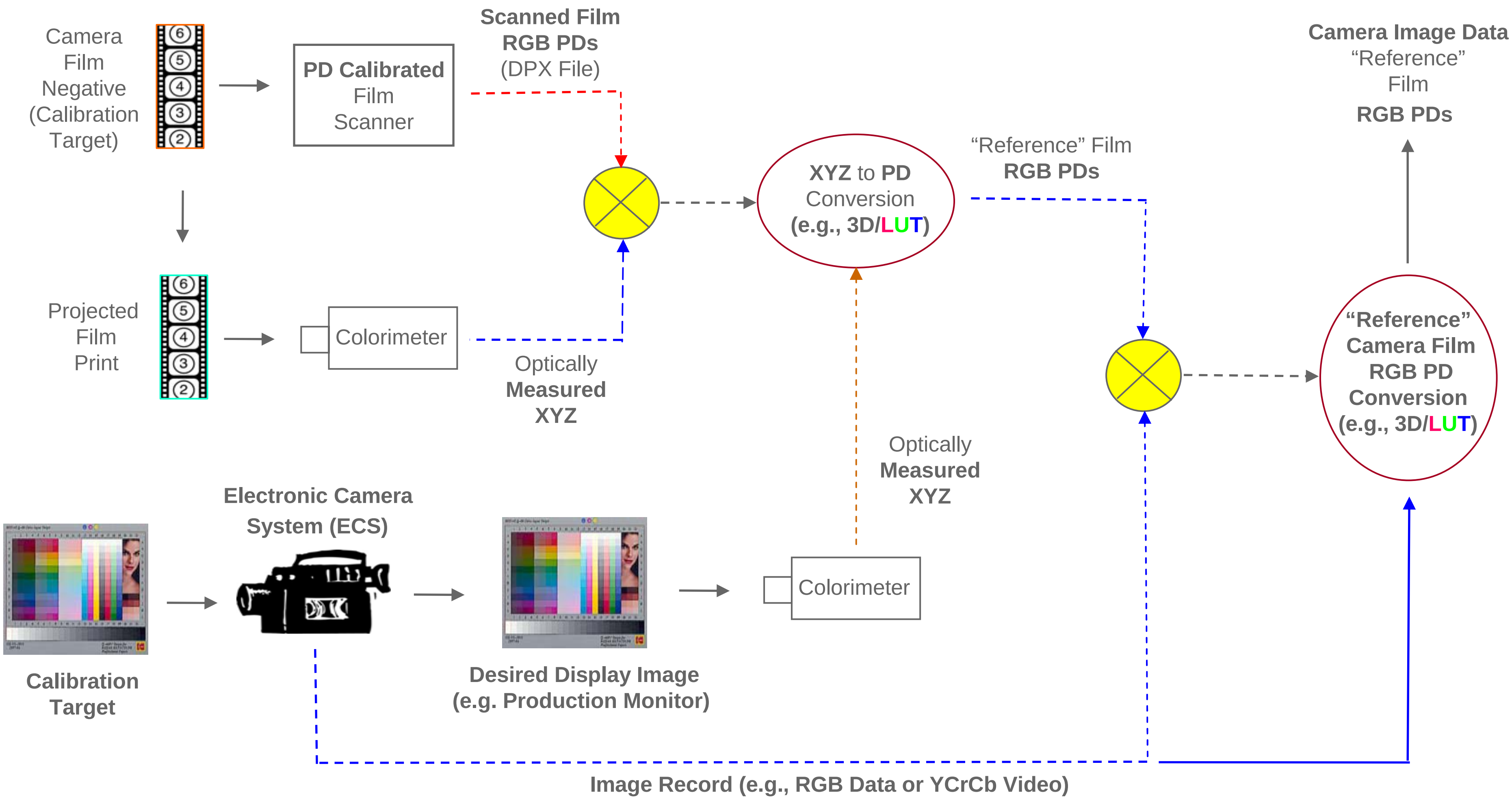
“Printing Density” (PD) Metric Workflow
Display Calibration (e.g., Data-scanner → DCI Display)



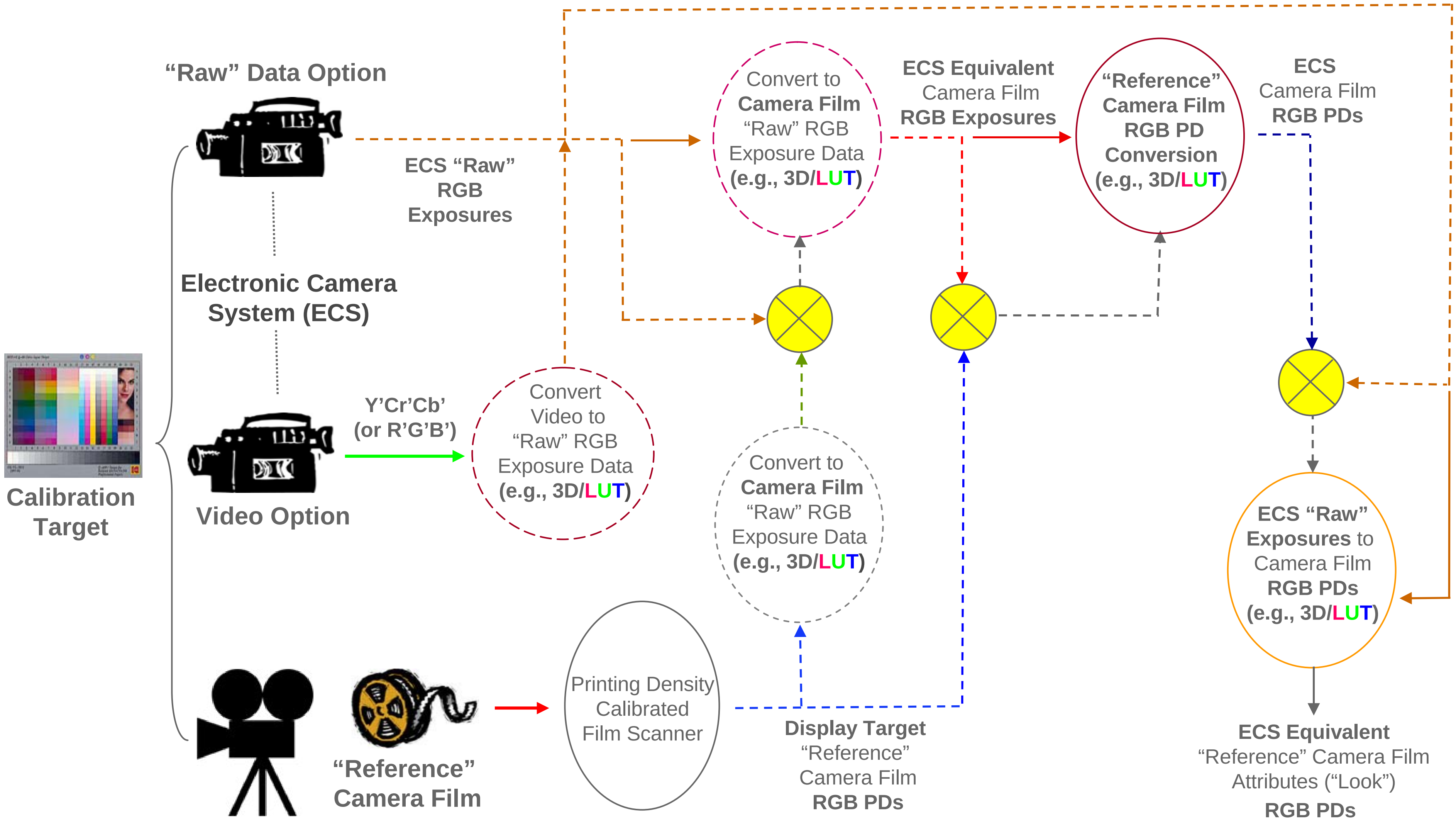
“Printing Density” (PD) Metric Workflow Film Recorder Calibration



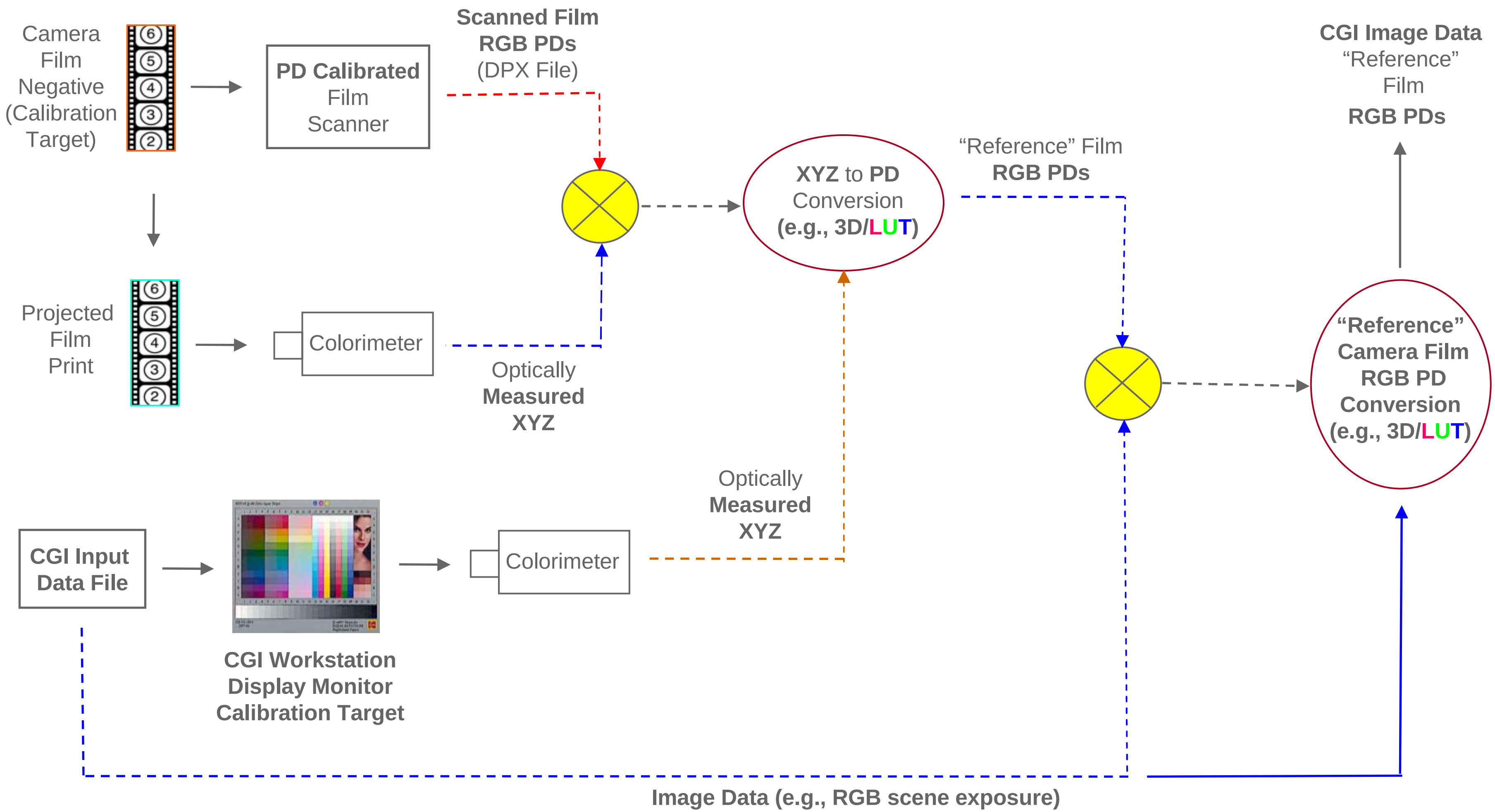
"Printing Density" (PD) Metric Workflow
Electronic Camera PD Conversion



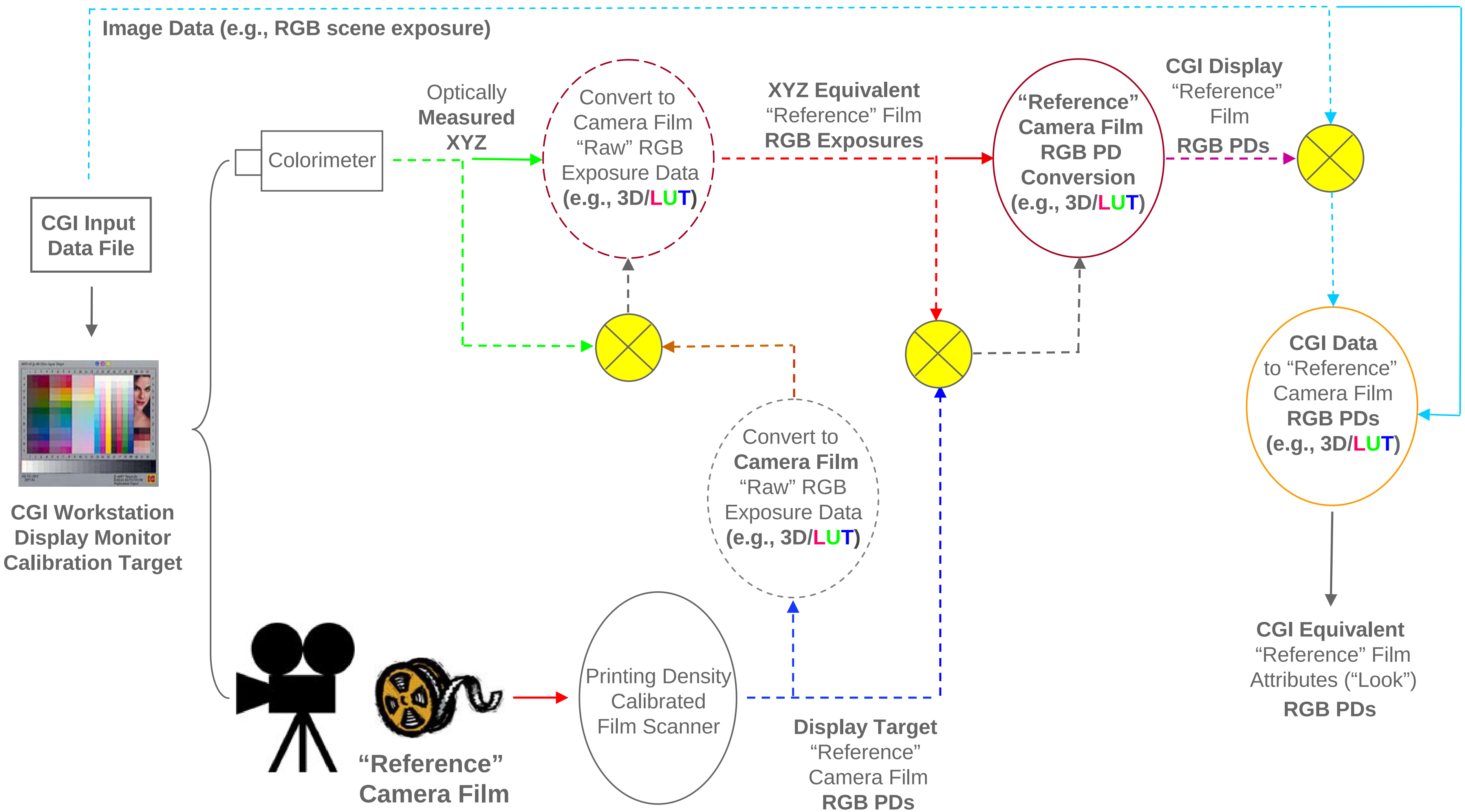
“Printing Density” (PD) Metric Workflow
Electronic Camera System (PD Camera Film Attributes)



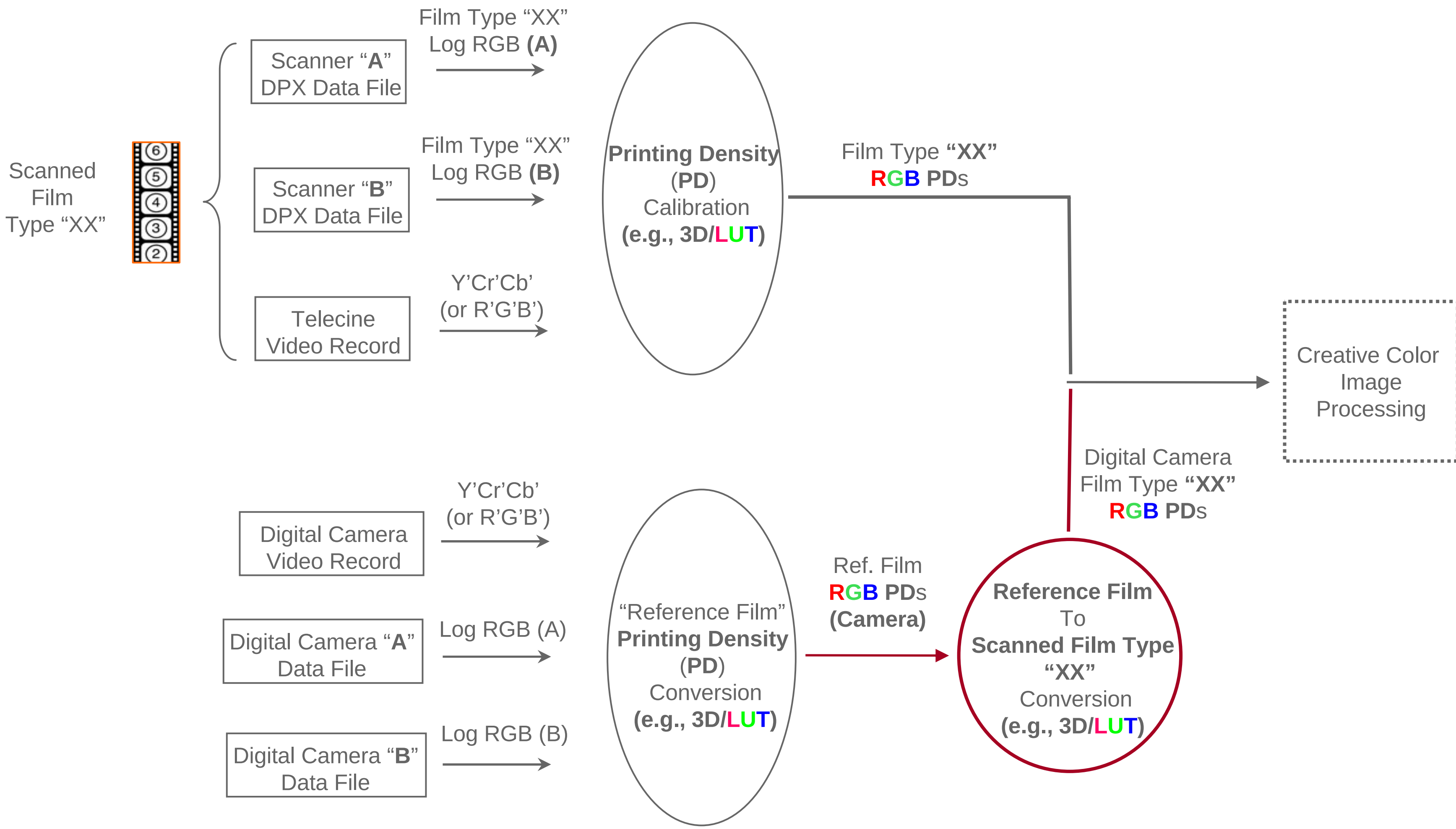
"Printing Density" (PD) Metric Workflow
CGI Data PD Conversion



"Printing Density" (PD) Metric Workflow CGI Data (PD Camera Film Attributes)



“Printing Density” (PD) Metric Workflow (for Inter-cutting Film and Digital Camera Images)

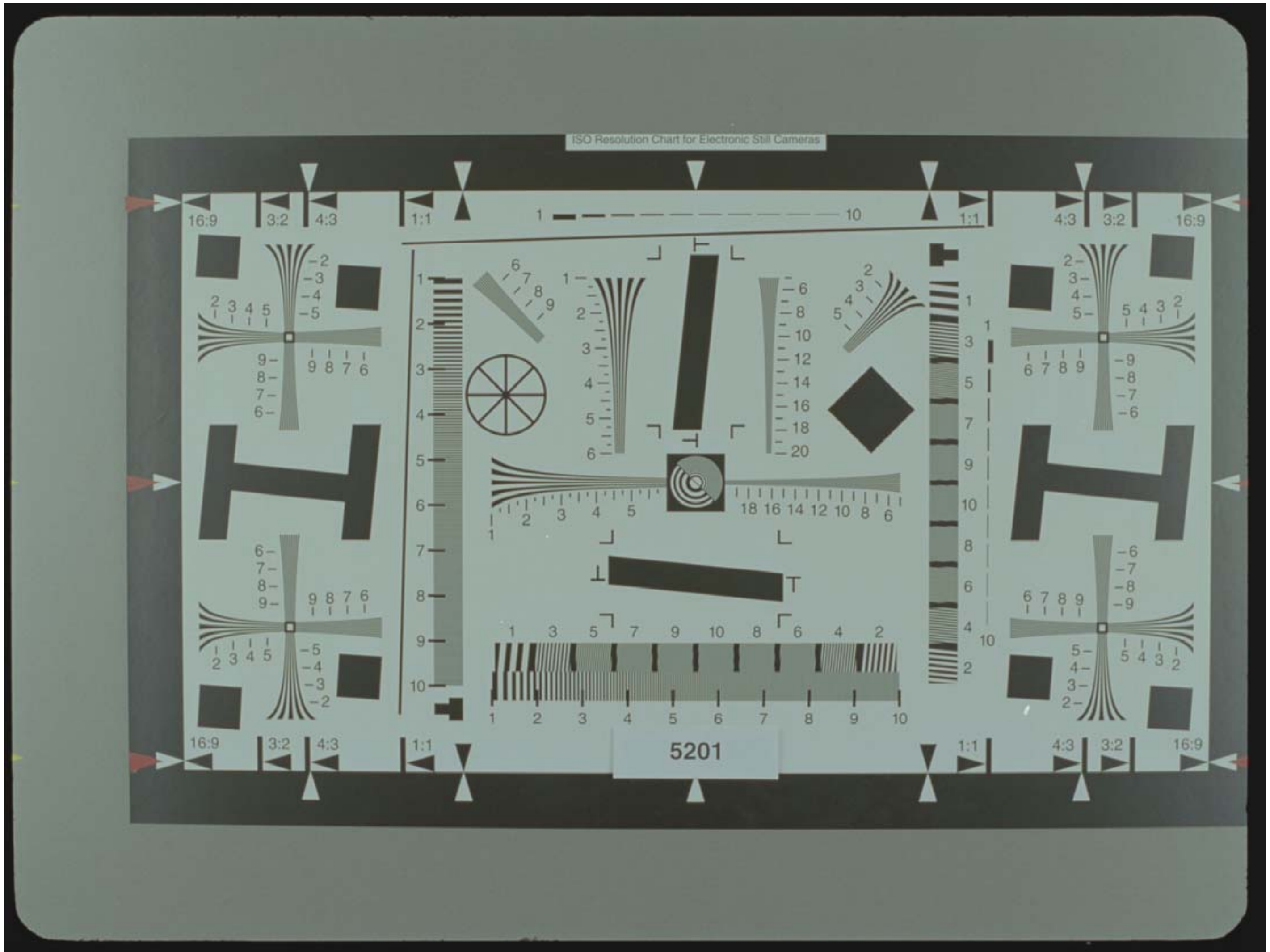


Scanner Image Structure Variability

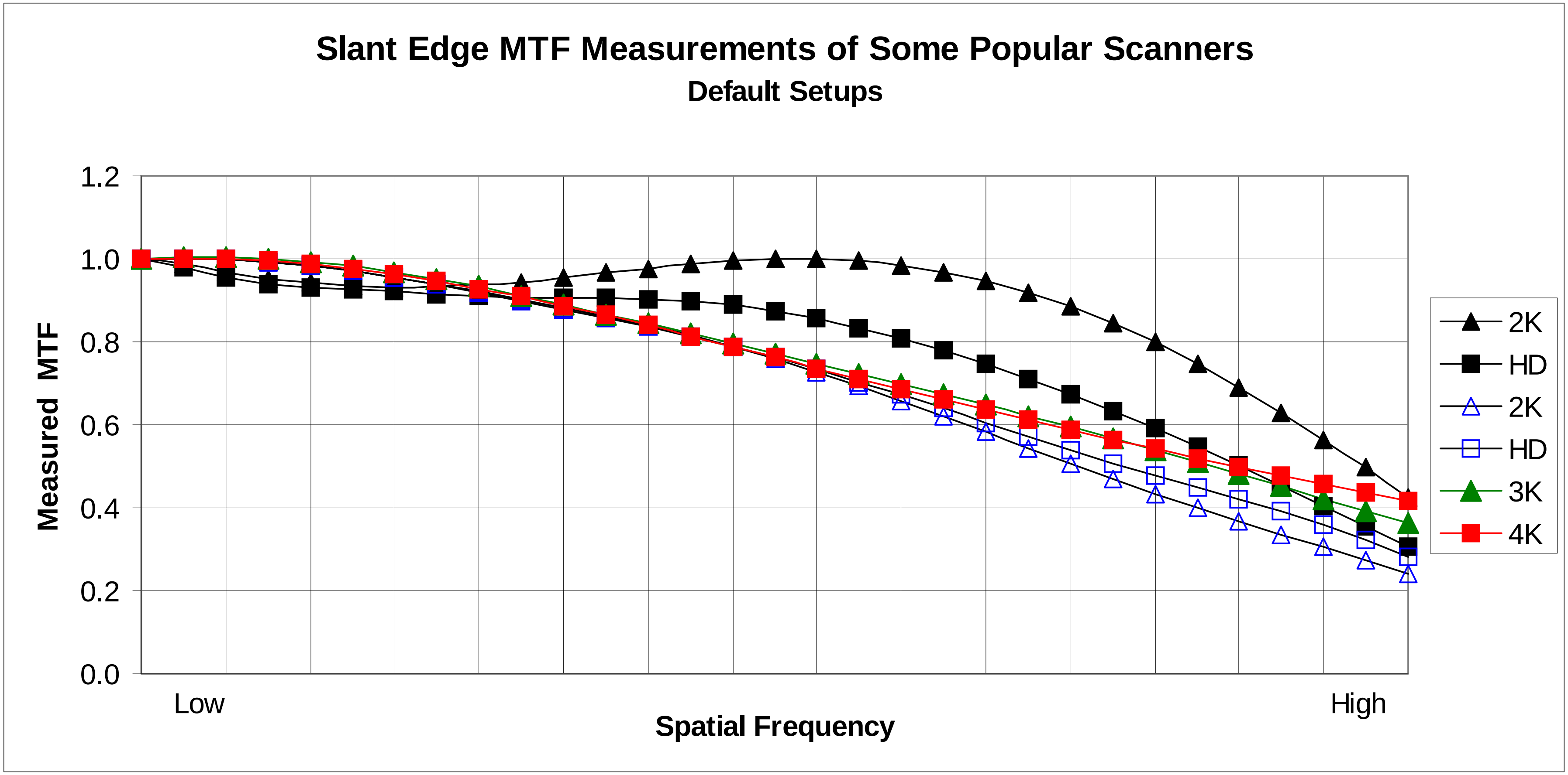
Sources include

- Sensor resolution
- Scanner lens MTF
- Scanner lens focus
- Film track stability
- Image processing level

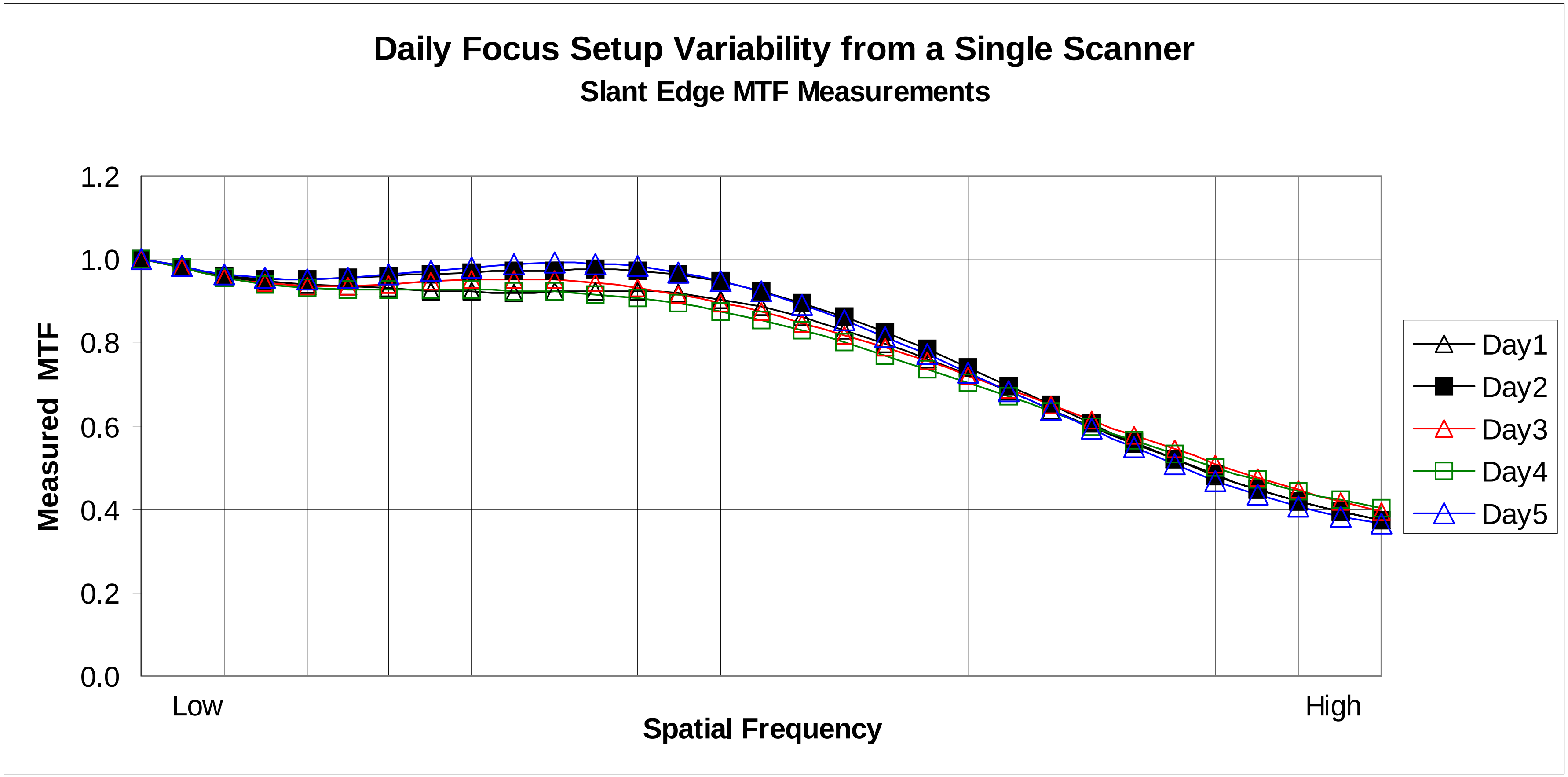
Scanner Slanted Edge MTF Target



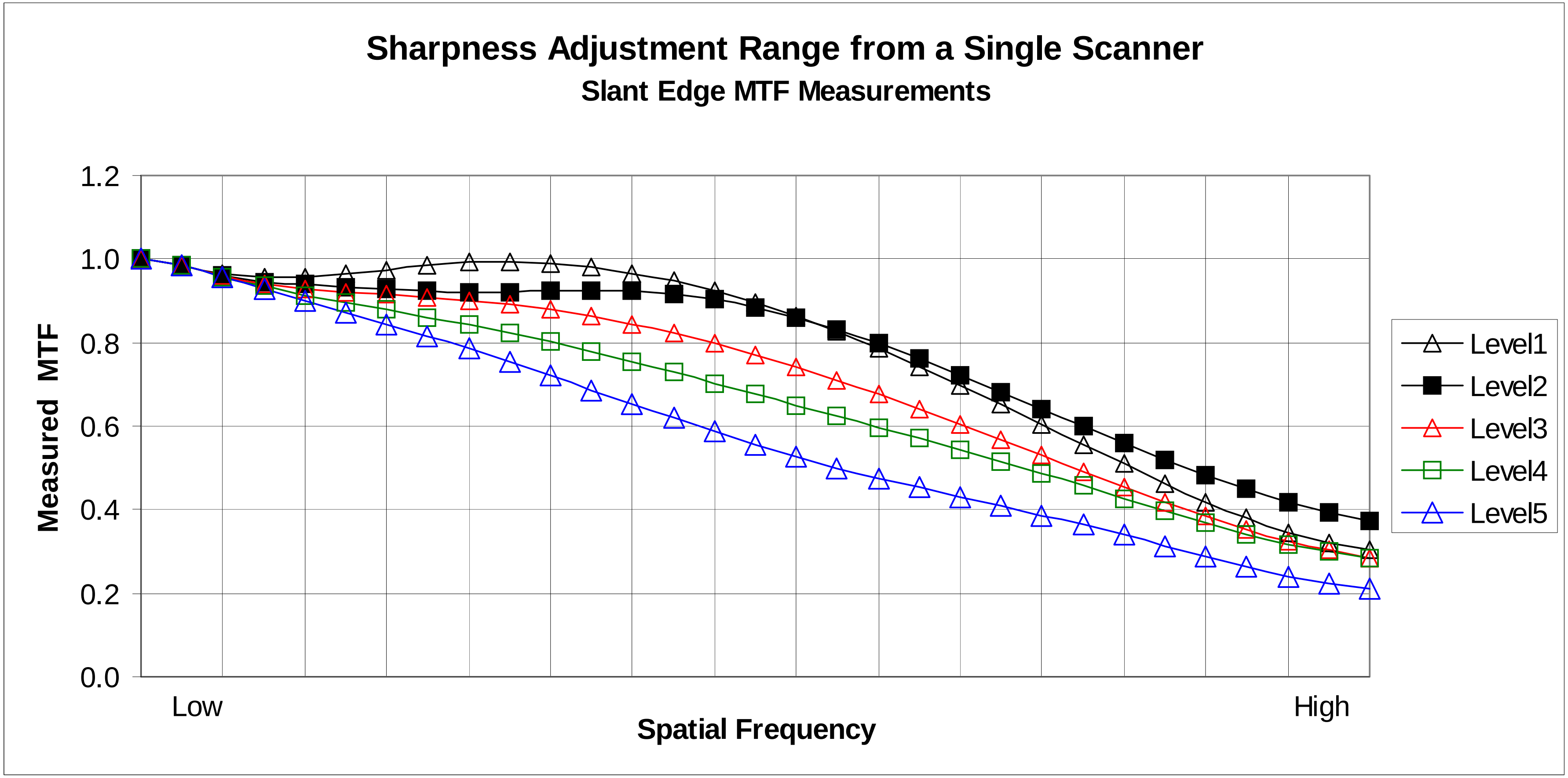
Comparison of Scanner Models



Scanner Focus Variability



Scanner Image Processing Variability



Scanner Linear Sharpening
(Unsharp masking to offset scanner MTF losses)

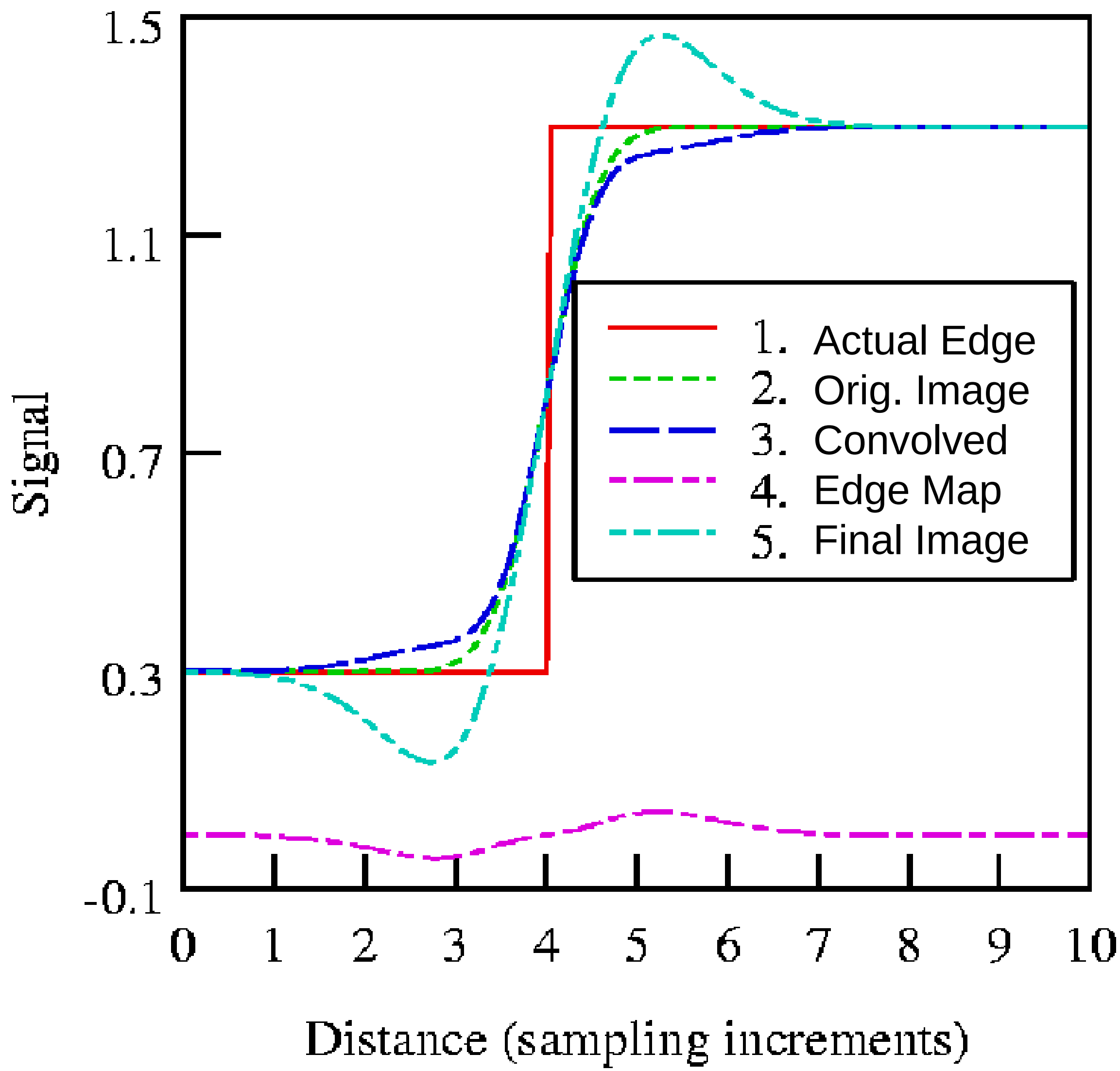
- Original image (2) of actual edge (1) is convolved with a spatial filter to create a lowpass filtered image (3).
- Lowpass filtered image is subtracted from original image to produce an edge map (4).
- Edge map is scaled by a gain factor (boosted), which increases edge contrast.
- Boosted edge map is added to original image to yield a final image (5) having higher apparent sharpness.

However,

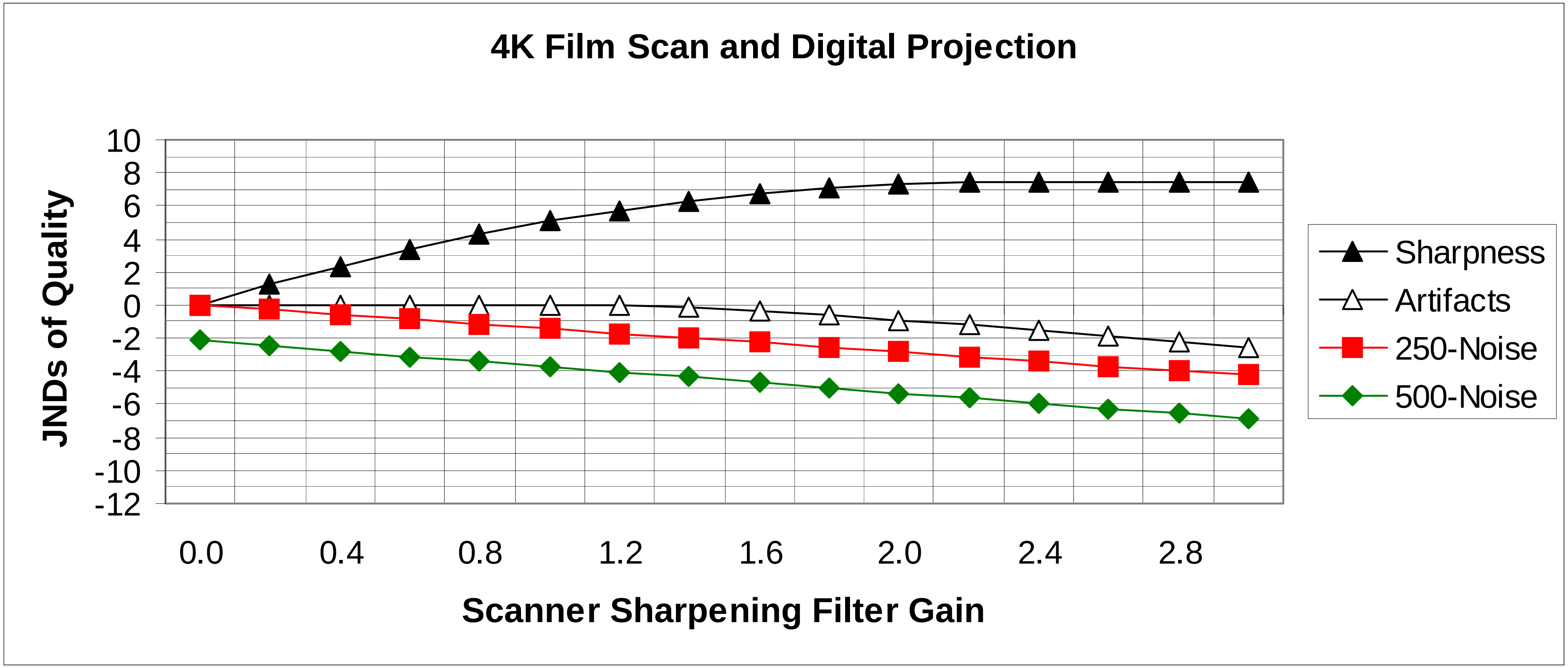
Excessive boosting causes edge fringing (oversharpening) and increases the visibility of grain and other artifacts.

Image Structure auto-calibration mode

- Grain/Noise growth caused by scanner sharpening is quantified (grain statistics measured – i.e. standard deviation profiles) at various scanner sharpening levels to generate grain reference tables
- Grain can then be reduced accordingly to achieve original film image grain level for any increase in sharpness applied that compensates for scanner MTF losses


1.5
1.1
0.7
0.3
-0.1
Signal
0
1
2
3
4
5
6
7
8
9
10
Distance (sampling increments)
1. Actual Edge
2. Orig. Image
3. Convolved
4. Edge Map
5. Final Image

Impact of Gain on Image Quality



Summary

This presentation outlined a system and method for automatically creating scanner-specific calibration functions that convert color, tone, and image structure into the common printing density exchange space.

This approach improves workflow and facilitates visually seamless intercutting of source material.

Acknowledgments

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