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Specification

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Academy Density Exchange Encoding (ADX) and the Spectral Responsivities Defining Academy Printing Density (APD)

The Academy of Motion Picture Arts and Sciences

Science and Technology Council

Image Interchange Framework Subcommittee

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Summary: The Academy Density Exchange Encoding (ADX) is an RGB density encoding of motion picture color negative film image data within the Academy's Image Interchange Framework. Academy Printing Density (APD) is the optical density of the motion picture film material as seen by the material onto which the film material is printed. This document specifies 10-bit integer and 16-bit integer ADX encodings. Also specified are the spectral responsivities that define the APD printing density metric that serves as the basis for the encoding method of the ADX encodings. ADX and APD are designed for use with color negative and internegative film materials, color process control hardware, color film scanners, and film recorders common to the motion picture industry. This specification also describes a method for converting ISO Status M density to APD.

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Revision History

Version	Date	Description
1.0	9/1/2009	Initial Academy Density Exchange Encoding (ADX) and the Spectral responsivities Defining Academy Printing Density (APD) Specification
1.1	10/18/2010	Modification to ADX encoding gain factors Definitions updated to conform to ISO guidelines Revised FLOOR Function Note Updated Figure 1 Updated AMPAS Logo Minor Formatting Modifications

Related A.M.P.A.S. Documents

Document Name	Version	Date	Description
S-2008-001	1.0	08-12-2008	Academy Color Encoding Specification (ACES)

Table of Contents

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Introduction

Academy Density Exchange Encoding (ADX) is the common densitometric encoding of scanned motion picture color negative film images used within the Academy's Image Interchange Framework (IIF). Academy Printing Density (APD) specifies a printing density definition appropriate for use with motion picture negative and internegative films and serves as the basis for the density encoding method of ADX. ADX values may encode densitometric imagery in a form suitable for transformation into Academy Color Encoding Specification (ACES) values for creative manipulation. Later points in the image processing chain provide forms suitable for critical viewing (Figure 1).

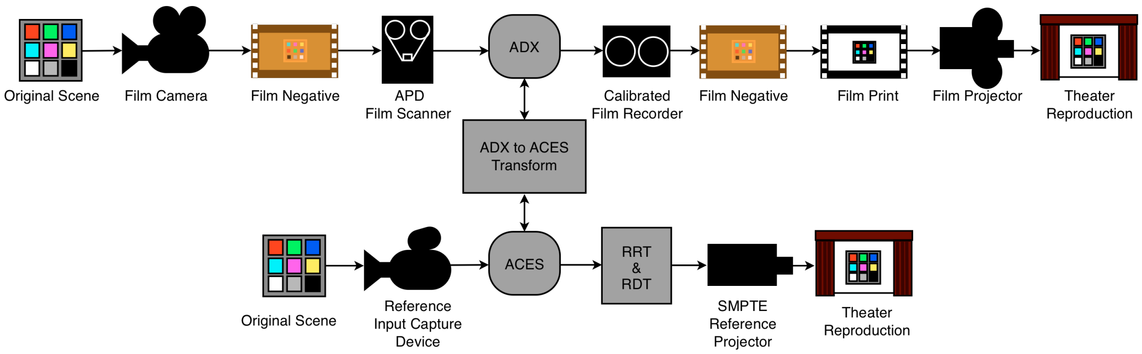

Figure 1 – Abridged IIF Image Processing Diagram

The spectral responsivities that define APD, known as Π_{APD} and provided in Annex A, are based on the spectral sensitivities of contemporary motion picture print films such as those of the Kodak Vision family, of the Fujifilm Eterna family, and of Fujifilm F-CP. Its definition is also based on the spectral power distribution of a Bell & Howell Model C printer lamp house with dichroic filters and the spectral transmission of an Eastman Kodak Wratten Filter No. 2B. As such, the spectral responsivities Π_{APD} are capable of interpreting the optical densities of motion picture color negative and internegative films as the film manufacturers intended those densities to be interpreted.

Π_{APD} are the appropriate spectral responsivities for scanning devices digitizing motion picture color negative and internegative film imagery for use with the Image Interchange Framework. Its greater currency and unambiguous specification make Π_{APD} a better set of spectral responsivities for a scanning device than the spectral responsivities given in SMPTE RP-180-1999 (Archived 2006) or the unpublished spectral responsivities that were the basis of Eastman Kodak Cineon Printing Density (CPD). APD is directly compatible with contemporary color negative and internegative film stocks, as well as any legacy motion picture color negative and internegative film stocks capable of being printed onto contemporary print films with reasonable results. When appropriately encoded, APD is also compatible with scan-only color negative films, such as Kodak Vision2 HD Color Scan Film (Kodak 5299), even though color negative film stocks of this type are not intended to be directly printable. APD is not appropriate for scanning of color print film material.

The spectral responsivities Π_{APD} provided as part of this specification serves as a reference against which scanning device behaviors can be compared. When a scanning device with spectral responsivities other than Π_{APD} is used to scan a motion picture color negative or internegative film, a stock-specific Input Device Transform (IDT) converts the resulting scanner density values into the APD density values a scanning device with the Π_{APD} spectral responsivities would have produced from that same color negative film (Figure 2).

The purpose of the spectral responsivities Π_{APD} is to provide a well-documented metric for measuring color negative film density values, allowing the unambiguous encoding of those densities in ADX. The encoding of density images in ADX within the Academy Image Interchange Framework allows for the development and use of a universal (i.e. non-stock-specific) transform to convert images encoded in ADX into ACES images.

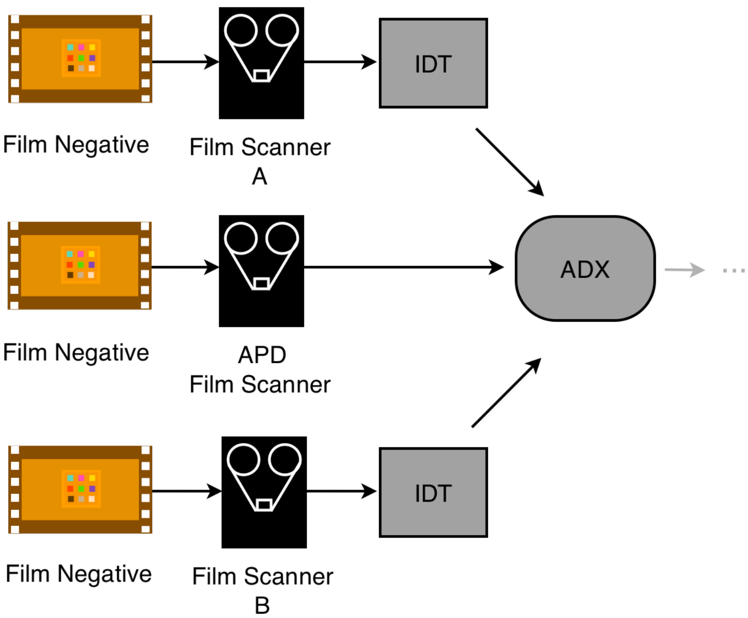

Figure 2 – Film Scanner Image Processing Diagram

1 Scope

This document specifies ADX, a common RGB density encoding used with the Academy's Image Interchange Framework, and the spectral responsivities used to calculate Academy Printing Density (APD), a common printing density definition which serves as the basis for the encoding method of ADX.

2 References

The following standards, specifications, articles, presentations, and texts are referenced in this text:

Academy of Motion Picture Arts and Sciences (A.M.P.A.S.) Specification S-2008-001, Academy Color Encoding Specification (ACES)

SMPTE Recommended Practice RP 180-1999 (Archived 2006), Spectral Conditions Defining Printing Density in Motion-Picture Negative and Intermediate Films

SMPTE Recommended Practice RP 431-2-2007, D-Cinema Quality - Reference Projector and Environment

ISO 5-1:1984, Photography– Density Measurements – Part 1: Terms, symbols, and notations, First Edition, March 1, 1984

ISO 5-2:2001(E), Photography – Density Measurements – Part 2: Geometric conditions for transmission density, Fourth Edition, June 15, 2001

ISO 5-3:1995, Photography – Density Measurements – Part 3: Spectral Conditions, Second Edition, November 15, 1995

Patterson, Richard, Evaluating Density Metrics for Scanning Motion Picture Negatives, *SMPTE Motion Imaging Journal,* Vol. 117 No.4 pg.31, May/June 2008

Dumont, Christopher, Maier, Thomas O., Printing Density*, SMPTE Technical Conference Proceedings,* October 24-27, 2007

James, T.H., *The Theory of the Photographic Process*, 4th Edition, The Macmillan Company, New York, New York, 1977.

Hunt, R.W.G., *The Reproduction of Colour*, 6th Edition, John Wiley & Sons Ltd, West Sussex, England, 2004.

3 Terms and Definitions

The following terms and definitions are used in this document:

3.1 Academy Color Encoding Specification (ACES)

RGB color encoding for exchange of image data that have not been color rendered, between and throughout production and postproduction, within the Academy's Image Interchange Framework.

3.2 Academy Density Exchange Encoding (ADX)

encoding of motion picture film color negative and internegative image data as APD values within the Academy's Image Interchange Framework.

3.3 Academy Printing Density (APD)

printing densities defined by the spectral responsivities Π_{APD}. The spectral responsivities Π_{APD} are defined for use with motion picture color negative and internegative films. APD serves as the basis for the encoding method of ADX, the common densitometric encoding used within the Image Interchange Framework.

3.4 APD film scanner

motion picture film scanning device with spectral responsivities equal to Π_{APD}. An APD film scanner will typically produce ADX encoded image files, as the steps required for encoding are usually accounted for in the scanning process.

3.5 CIE Standard Illuminant A

Planckian radiation at a temperature of about 2,856 K as defined by the Commission Internationale de l'Eclairage (CIE)

3.6 contemporary color negative film

negative color photographic film designed to be printed on Kodak Vision family, Fujifilm Eterna family, and Fujifilm F-CP print films.

3.7 densitometer

device for directly measuring transmission or reflection optical densities. For meaningful color measurements, the illumination and collection geometries and the spectral responses of the densitometer must be specified.

3.8 densitometry

the measurement of optical density.

3.9 D_{min}

optical density of an area of a chemically processed photographic medium that has received zero exposure. D_{min} corresponds to the optical density of film base and non-image density due to factors other than exposure to light.

3.10 equivalent neutral (visual) density (END)

density value used to express the relative amount of subtractive-medium colorants. The END value for a given amount of colorant is the visual density that would result if appropriate amounts of the other colorants of the medium were added such that a colorimetric neutral is formed based on a defined viewing illuminant.

3.11 equivalent neutral printing density (ENPD)

printing density value used to express the relative amount of subtractive-medium colorants. The ENPD value for a given amount of colorant is the printing density that would result if appropriate amounts of the other colorants of the medium were added such that the component printing densities are equal.

3.12 influx spectrum

spectrum of the radiant flux incident on the specimen surface or sampling aperture. It is a function of the energy source and the optical system on the source side of the specimen.

3.13 Input Device Transform (IDT)

color signal-processing transform that maps a device's representation of an image to a common input color encoding specification. ADX is the densitometric input encoding used within the Image Interchange Framework. ACES is the colorimetric input encoding used within the Image Interchange Framework.

3.14 legacy color negative film

negative photographic film designed to be printed on any color print medium other than Kodak Vision family, Fujifilm Eterna family, and Fujifilm F-CP print films.

3.15 negative

photographic medium that forms a reversed image (i.e. higher exposure levels result in the formation of greater optical density during development).

3.16 optical density

negative logarithm to the base 10 of the ratio of the integration of the spectral responsivities of a detection system and the spectral transmittance or reflectance of the sample under examination and the integration of the spectral responsivities of the detection system alone.

3.17 Output Device Transform (ODT)

color signal-processing transform that maps an image represented in a common output color encoding to a representation on a reference device of a particular type.

3.18 print

photographic medium onto which a negative is printed to form a positive image intended for final viewing.

3.19 printing density

optical density measured according to effective spectral responsivities defined by the spectral power distribution of a printer, including the light source, the spectral transmission, reflection and absorbance of its optical components, and the spectral sensitivity of a print medium.

3.20 relative exposure values

relative responses to light of an image capture system determined by the integrated spectral responsivities of its color channels and the irradiances at the focal plane of the image capture system.

3.21 scan-only color negative film

negative color photographic film primarily designed to be scanned by a motion picture film scanning device rather than printed on any photographic print medium.

3.22 scanner density

logarithm to the base 10 of the ratio of the integration of the spectral responsivities of a scanner and the spectral transmittance of the sample under examination and the integration of the spectral responsivities of the scanner alone.

3.23 silver criterion

principle that each stage of a photographic system shall be maintain equivalent neutral densities or equivalent neutral printing densities for equal red, green, and blue relative exposure values.

3.24 source

physically realizable light, the spectral power distribution of which can be experimentally determined.

3.25 spectral density

optical densities of a medium as measured as a function of wavelength.

3.26 spectral power distribution

power, or relative power, of electromagnetic radiation as a function of wavelength.

3.27 spectral product

wavelength-by-wavelength product of two or more spectral power distributions, spectral sensitivities, spectral responsivities, or spectral transmittances.

3.28 spectral responsivities

responses of a detection system, such as a scanner or a densitometer, as a function of wavelength. Spectral responsivities are determined by the spectral power distribution of the illumination, the spectral filtration effects of various optical components, and the spectral sensitivity of the detector.

3.29 spectral sensitivity

response of a detector to monochromatic stimuli of equal radiant power.

3.30 spectral transmittance

fraction of the incident power transmitted as a function of wavelength.

3.31 transmittance factor

ratio of the measured flux transmitted by a specimen to the measured flux when the specimen is removed from the sampling aperture of the measuring device.

4 Specification

4.1 Academy Printing Density (APD)

The spectral responsivities associated with any printing density metric are the product of the spectral power distribution of a printer light source, the spectral transmission, reflection, and absorbance of the optical components of the printer, and the spectral sensitivities of the print medium onto which the sample is to be printed. The spectral responsivities used to calculate Academy Printing Density (APD) include the effect of the light source spectral power distribution and the spectral transmission, reflection, absorbance of the optical components of a Bell & Howell Model C printer lamp house, and the spectral transmission of an Eastman Kodak Wratten Filter No. 2B. The spectral sensitivities of the print medium are representative of the spectral sensitivities of contemporary motion picture print films such as those of the Kodak Vision family, of the Fujifilm Eterna family, and of Fujifilm F-CP. The spectral responsivities used to calculate APD, known as Π_{APD}, are illustrated in Figure 3 below.

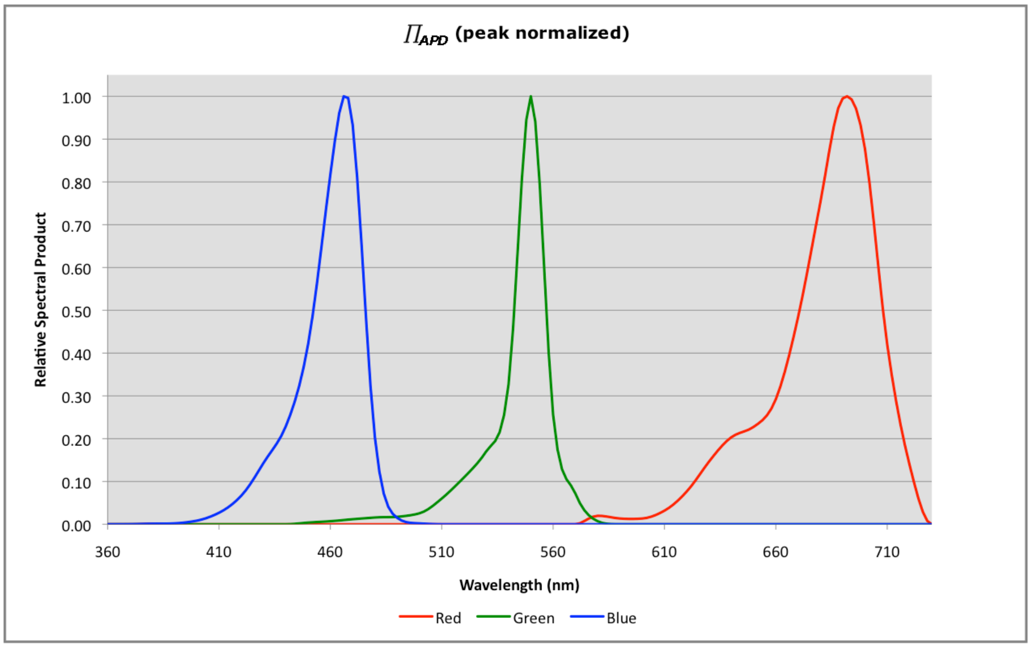

Figure 3 – The spectral responsivities Π_{APD}

NOTE Tabulated values of the spectral responsivities Π_{APD}, can be found in Annex A.

4.1.1 Reference Measurement Device

To completely specify a density metric it is necessary to also specify the conditions in which the density measurements shall be made.

NOTE The specifications in this section are intended to eliminate ambiguity in the determination of the APD values of a film sample. The specifications in this section should not be misconstrued to be specifications for conditions under which films must be scanned. For instance, section 4.1.1.2 specifies that device geometry shall conform to the ISO standard diffuse transmission density. In practice, due to the very low scattering properties of conventionally processed color negative and internegative films, little variation would be expected between scans obtained using a scanner with ISO standard diffuse transmission density geometry and a scanner with ISO standard projection transmission density geometry. Variations that might occur could be compensated for in an IDT.

4.1.1.1 Spectral Responsivities

The reference measurement device shall have spectral responsivities equal to the spectral responsivities $\Pi_{APD.}$

4.1.1.2 Measurement Geometry

The reference measurement device geometry shall conform to the ISO standard diffuse transmission density specification found in ISO 5-2:2001(E).

4.1.1.3 Sample Conditions

Color negative and internegative films to be measured shall be at 23°C ± 2°C (73.4°F ± 3.6°F) and 50% (±5%) relative humidity, consistent with the sample conditions specification for density measurements found in ISO 5-3:1995(E).

4.2 Academy Density Exchange Encoding (ADX)

The Academy Density Exchange Encoding (ADX) encodes densitometric images within the Image Interchange Framework. The ADX equations specified below provide conversions from APD values to digital code values as 10-bit or 16-bit integer color components. ADX images are transformable into ACES using the universal ADX-to-ACES transform. Conversely, ACES images are transformable into ADX images using the universal ACES-to-ADX transform. The universal ADX-to-ACES transform and universal ACES-to-ADX transform are described in other documents detailing the Image Interchange Framework.

4.2.1 Encoding Method

ADX values encode image data as the Academy Printing Density values of a color negative film designed to be printed on Kodak Vision family, Fujifilm Eterna family, and Fujifilm F-CP color print films.

NOTE Most color negative and internegative films require no transformation in order to be compatible with the ADX encoding method, because most color negative and internegative films can be printed onto contemporary color print films with reasonable results. Color interpositive films are also compatible with the ADX encoding method as they are part of the negative reproduction chain. Some film stocks, such as scan-only color negative film (e.g. Kodak 5299) and color print films, were not designed to be printed onto color print films. Printing a scan-only negative or color print film onto a contemporary color print film is not likely to yield a result that would be considered "good-looking." Scanned density values from these materials require additional transformation in order to achieve compatibility with the ADX encoding method. A custom conversion from scanner density values to ADX must be designed for materials that were not designed to be printed onto color print films.

4.2.1.1 Achieving Encoding Method Compatibility

In order to achieve compatibility with the Image Interchange Framework, color films not capable of being printed onto contemporary color print films with reasonable results shall be scanned temporarily into a set of scanner density values and transformed into a set of ACES values using a film specific transform provided by the film manufacturer. If desired, those ACES values can be transformed into a set of ADX values using the universal ACES-to-ADX transform. The transforms listed above shall be implemented with an Input Device Transform.

4.2.2 Encoding Metric

The encoding data metric for the ADX is based on D_{min} offset Academy Printing Density values. In many cases the D_{min} offset adjustment is accomplished during the setup of the scanning device. In the equations given below APD_{R_Dmin}, APD_{G_Dmin}, and APD_{B_Dmin} represent the red, green, and blue APD values respectively of the assumed or measured D_{min} of the sample.

Two component value encodings are provided. ADX_{16} in which the R, G, and B printing density values are each stored as 16-bit unsigned integers, and ADX_{10} in which the R, G, and B printing density values are each stored as 10-bit unsigned integers.

The exposure of a spectrally nonselective (i.e. neutral color) object by a source for which the film has been balanced, followed by nominal laboratory processing, would ideally produce a negative having equal Red, Green, and Blue printing densities. This ideal behavior, historically present in systems that comply with the silver criterion, is not a characteristic of contemporary motion picture negative films stocks. Encoding gain factors of 1.00, 0.92 and 0.95 in the encoding equations below attempt to produce equality in ADX values for the abovementioned exposure. These gain factors were computed as a weighted average of gain factors for commonly used motion picture films, and will produce ADX values whose corresponding Status M densities are compatible with the capabilities of modern film recorders recording onto intermediate stocks.

NOTE Printing density values are always non-negative, as a value of 0 represents 100% transmission.

4.2.2.1 ADX_{16} – The 16-bit Component Value Encoding Metric

The ADX 16-bit component value encoding metric shall be known as ADX_{16} or ADX16 where the use of subscripted text is not possible.

The value range for ADX_{16} is [0, 65535].

ADX_{16} code values shall be 16-bit unsigned integer values. An encoding gain of 8000 code values allows for the encoding of a density range of 8.191875 with the density difference between adjacent code values equal to 0.000125. An encoding offset of 1520 code values allows for a density range of 0.190000 below the measured D_{min} to be encoded.

ADX_{16} code values shall be transformed from APD values using Equation (1)..

$$ADX_{16\_R} = \mathrm{INT}\left[1.00 \times \left(APD_R - APD_{R\_Dmin}\right) \times 8000 + 1520\right]$$
$$ADX_{16\_G} = \mathrm{INT}\left[0.92 \times \left(APD_G - APD_{G\_Dmin}\right) \times 8000 + 1520\right]$$
$$ADX_{16\_B} = \mathrm{INT}\left[0.95 \times \left(APD_B - APD_{B\_Dmin}\right) \times 8000 + 1520\right]$$

Equation (1)

NOTE The INT operator returns the value of 0 for fractional parts in the range of 0 to .4999… and +1 for fractional parts in the range .5 to .9999…, i.e. it rounds up fractions equal to or greater than 0.5.

NOTE 2 The quantity ($APD - APD_{Dmin}$) may produce negative values as the D_{min} value of each color layer can vary throughout a scanned roll. The offset quantity, 1520, provides a target value for the scanned D_{min}, and allows “footroom” so that densities lower than APD_{Dmin} will be encoded.

4.2.2.2 ADX_{10} – The 10-bit Component Value Encoding Metric

The 10-bit component value encoding metric is specified to provide compatibility with existing hardware and file format specifications. Some modern motion picture color negative and internegative film products are capable of producing density ranges that exceed the density range capable of being encoded by the 10-bit component value encoding metric. For this reason, whenever possible the 16-bit component value encoding metric shall be used.

The ADX 10-bit component value encoding metric shall be known as ADX_{10} or ADX10 where the use of subscripted text is not possible.

The value range for ADX_{10} is [0, 1023].

ADX_{10} code values shall be 10-bit unsigned integer values. An encoding gain of 500 code values allows for the encoding of a density range of 2.046000 with the density difference between adjacent code values equal to 0.002000. An encoding offset of 95 code values allows for a density range of 0.190000 below the measured D_{min} to be encoded. ADX_{10} code values shall be transformed from APD values using Equation (2).

$$ADX_{10\_R} = \mathrm{INT}\left[1.00 \times \left(APD_R - APD_{R\_Dmin}\right) \times 500 + 95\right]$$
$$ADX_{10\_G} = \mathrm{INT}\left[0.92 \times \left(APD_G - APD_{G\_Dmin}\right) \times 500 + 95\right]$$
$$ADX_{10\_B} = \mathrm{INT}\left[0.95 \times \left(APD_B - APD_{B\_Dmin}\right) \times 500 + 95\right]$$

Equation (2)

NOTE The INT operator returns the value of 0 for fractional parts in the range of 0 to .4999… and +1 for fractional parts in the range .5 to .9999…, i.e. it rounds up fractions equal to or greater than 0.5.

NOTE 2 The quantity ($APD - APD_{Dmin}$) may produce negative values as the D_{min} value of each color layer can vary throughout a scanned roll. The offset quantity, 95, provides a target value for the scanned D_{min}, and allows 'footroom' so that densities lower than APD_{Dmin} will be encoded.

4.2.2.3 Converting between the 16-bit and 10-bit Component Value Encoding Metrics

The 16-bit Component Value Encoding Metric (i.e. ADX_{16}) shall allocate 2 bits of additional range and 4 bits of additional precision as compared to the 10-bit Component Value Encoding Metric (i.e. ADX_{10}). The 2 bits of additional range shall be allocated in the most significant bits. The 4 bits of additional precision shall be allocated in the least significant bits. Figure 4 illustrates the allocation of the additional bits in the 16-bit Component Value Encoding Metric as compared to the 10-bit Component Value Encoding Metric.

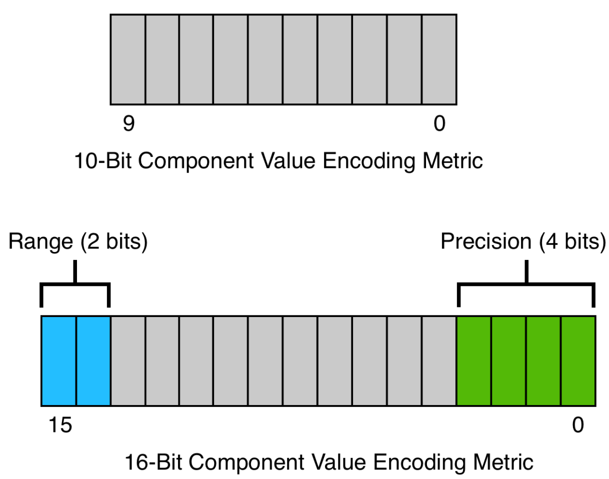

Figure 4 – Bit allocations of ADX_{10} and ADX_{16}

Equation (3) shall be used to convert APD printing density values encoded using the 10-bit Component Value Encoding Metric to the APD printing density values encoded using the 16-bit Component Value Encoding Metric.

$$ADX_{16} = ADX_{10} \times 16$$

Equation (3)

Equation (4) shall be used to convert APD printing density values encoded using the 16-bit Component Value Encoding Metric to APD printing density values encoded using the 10-bit Component Value Encoding Metric.

$$\text{if FLOOR}[ADX_{16} \div 16] \text{ is even}$$

$$ADX_{10} = \left(ADX_{16} + 7\right) \div 16$$

$$\text{if FLOOR}[ADX_{16} \div 16] \text{ is odd}$$

$$ADX_{10} = \left(ADX_{16} + 8\right) \div 16$$

Equation (4)

NOTE The value of FLOOR[x] is the largest integer that is not greater than x.

The following is an example C programming language code fragment to convert APD printing density values encoded using the 16-bit Component Value Encoding Metric to APD printing density values encoded using the 10-bit Component Value Encoding Metric.

```
int ADX16 = …;
int ADX10 = (ADX16 + 7 + ((ADX16 >> 4) & 1)) >> 4;
```

5 Usage

5.1 Derivation of Π_{APD}

The spectral responsivities defined in this specification are specified as spectral products rather than discrete spectral components. The spectral product for any densitometric specification, film scanner, or densitometer may be denoted using Equation (5).

$$\Pi = S(\lambda)s(\lambda)$$

Equation (5)

where:

$S(\lambda)$ is the relative spectral power distribution of the influx.

$s(\lambda)$ is the relative spectral sensitivity of the receiver, which includes the photodetector and all intervening components between it and the plane of the sample to be measured.

The subscript Π_{APD} shall be used to denote the spectral product representing the spectral responsivities used to calculate APD. Π_{APD_R}, Π_{APD_G}, and Π_{APD_B} shall be used to denote the spectral responsivities of the red, green, and blue components of APD respectively.

The subscript S_{APD} shall be used to denote the relative spectral power distribution of the influx spectrum used in the calculation of the spectral product Π_{APD}.

5.1.1 Influx Spectrum

The spectral responsivities defining APD incorporate the influx spectrum S_{APD}, which models the lamphouse of a Bell & Howell Model C motion picture printer, filtered by an Eastman Kodak Wratten Filter No. 2B.

NOTE The basic light source for ISO densitometry, as specified in ISO 5-3:1995(E), is CIE Standard Illuminant A. The lamp house of the Bell & Howell Model C motion picture printer uses a tungsten light source that is separated into red, blue, and green components with a set of dichroic mirrors; those components are then modulated by a series of light valves in order to precisely control the ratios of red, green, and blue light, and after modulation are filtered with a Eastman Kodak Wratten Filter No. 2B. Use of S_{APD} in the calculation of the spectral responsivity associated with APD therefore meets the light source requirement of ISO 5-3:1995(E).

NOTE 2 Tabulated values and a graph of the influx spectrum S_{APD} can be found in Annex B.

NOTE 3 The specification of CIE Standard Illuminant A by ISO 5-3:1995(E) is motivated, in part, by the need to manage fluorescence in the sample to be measured.

NOTE 4 Filtration of the light source is permitted and in fact suggested by ISO 5-3:1995(E) in order to protect the sample to be measured and optical elements from the heat of the light source.

5.2 Calculation of APD Values

There are two methods for determining the APD values of color negative and internegative films, as outlined below.

5.2.1 Spectral Calculation

The spectral calculation of Academy Printing Density values requires the measurement of the spectral transmission of the color negative or internegative film using a spectral measurement device. Measured film transmission spectra can be converted into APD values using Equation (6).

$$APD_R = -\log_{10}\left(\int_{360}^{730} T(\lambda)\bar{r}(\lambda)\,d\lambda\right)$$

$$APD_G = -\log_{10}\left(\int_{360}^{730} T(\lambda)\bar{g}(\lambda)\,d\lambda\right)$$

$$APD_B = -\log_{10}\left(\int_{360}^{730} T(\lambda)\bar{b}(\lambda)\,d\lambda\right)$$

Equation (6)

where:

$\bar{r}(\lambda)$, $\bar{g}(\lambda)$, and $\bar{b}(\lambda)$ are Π_{APD_R}, Π_{APD_G}, and Π_{APD_B} normalized such that

$$\int_{360}^{730} \Pi_{APD\_R}(\lambda)\,d\lambda = \int_{360}^{730} \Pi_{APD\_G}(\lambda)\,d\lambda = \int_{360}^{730} \Pi_{APD\_B}(\lambda)\,d\lambda = 1$$

and

$T(\lambda)$ is the spectral transmission of the color negative film or internegative film, or $10^{-density(\lambda)}$

NOTE In practice, it is common to calculate APD values using summations rather than integrals, as common spectral measurement devices typically return transmission data as a series of spectral samples uniformly separated in wavelength rather than as a single continuous analytic function of wavelength.

NOTE 2 A densitometer with spectral responsivities equal to the spectral responsivities of Π_{APD} could measure APD values directly; no such densitometer, however, exists at the time of this writing.

5.2.2 Conversion from Other Density Metric Values

Conversions between other density metric values (i.e. Status M density, scanner density, etc.) and APD values are possible. These transformations are product specific: a separate transformation needs to be determined for each color negative and internegative film product. The ISO Status M to APD matrix conversion transforms and associated residual errors for a variety of motion picture color negative and internegative films listed in Annex C can be particularly useful in process control efforts. When native scanner spectral responsivities are exactly known, these residual errors may be reduced by substitution of a polynomial conversion transform for the appropriate 3x3 matrix shown below, or by the replacement of that 3x3 matrix by a 3D LUT. Compared to a 3x3 matrix, a polynomial conversion transform may reduce the residual error associated with the conversion between density metrics. Assuming the use of a transform with an appropriate number and distribution of nodes, the use of a stock specific 3D LUT, particularly when used in conjunction with a one or more 1D shaper LUTs, could nearly eliminate the residual errors associated with the transform.

NOTE Individual densitometers may report optical densities that differ significantly from ISO Status M as specified in the ISO 5 standards. Care should be taken to ensure measurement devices are properly calibrated and report ISO Status M density values for a known sample. For instance, the density values of the transmission tablet used to calibrate the X-Rite® 310 transmission densitometer are reported as densities that conform to ANSI PH2.19-1976 rather than ANSI PH2.19-1986 and ISO 5. Instructions are included with the calibration tablet in order to calibrate the device to ISO Status M rather than ANSI PH2.19-1976 and care should be take to ensure the device is calibrated to the ISO Status M standard.

NOTE 2 Film scanners typically are not manufactured with spectral responsivities that either match, or are a linear combination of ISO Status M. However, if a film scanner exhibits spectral responsivities that match ISO Status M, the transforms in Annex C may be used to transform the scanner density values into APD. If a film scanner exhibits spectral responsivities that are a linear combination of ISO Status M responsivities, a 3x3 transform may be used to convert the scanner density values into ISO Status M before using the transforms in Annex C. If a film scanner does not exhibit spectral responsivities that either match, or are a linear combination of ISO Status M responsivities, either a more complex transform to convert scanner density values to ISO Status M density values must be used before the transforms in Annex C, or the transforms in Annex C are not appropriate for conversion of those scanner density values into APD and a different set of stock-specific scanner density to APD IDTs must be calculated. Procedures for characterizing a scanner with spectral responsivities other than those of ISO Status M or a linear combination of ISO Status M responsivities, and the calculation of appropriate IDTs, are described in other documents detailing the Image Interchange Framework.

Annex A

(normative)

Spectral Responsivities Π_{APD}

The spectral responsivities used to determine Academy Printing Density are the spectral product (Π_{APD}) of the relative spectral power distribution of the influx (S_{APD}) and the relative spectral response of the receiver (s), which includes the photodetector and all intervening components between it and the plane of the sample to be measured.

Wavelength λ, (nm)	Red	Green	Blue
360	0.0000	0.0000	0.0000
362	0.0000	0.0000	0.0000
364	0.0000	0.0000	0.0000
366	0.0000	0.0000	0.0000
368	0.0000	0.0000	0.0001
370	0.0000	0.0000	0.0001
372	0.0000	0.0001	0.0003
374	0.0002	0.0001	0.0005
376	0.0005	0.0002	0.0007
378	0.0009	0.0002	0.0010
380	0.0013	0.0002	0.0012
382	0.0013	0.0002	0.0013
384	0.0010	0.0001	0.0013
386	0.0006	0.0001	0.0014
388	0.0002	0.0000	0.0016
390	0.0000	0.0000	0.0020
392	0.0000	0.0000	0.0028
394	0.0000	0.0000	0.0037
396	0.0000	0.0000	0.0050
398	0.0000	0.0000	0.0065
400	0.0000	0.0000	0.0083
402	0.0000	0.0000	0.0107
404	0.0000	0.0000	0.0138
406	0.0000	0.0000	0.0175
408	0.0000	0.0000	0.0219
410	0.0000	0.0000	0.0268

Wavelength λ, (nm)	Red	Green	Blue
412	0.0000	0.0000	0.0325
414	0.0000	0.0000	0.0392
416	0.0000	0.0000	0.0471
418	0.0000	0.0000	0.0562
420	0.0000	0.0000	0.0667
422	0.0000	0.0000	0.0790
424	0.0000	0.0000	0.0935
426	0.0000	0.0000	0.1095
428	0.0000	0.0000	0.1265
430	0.0000	0.0000	0.1434
432	0.0000	0.0000	0.1591
434	0.0000	0.0000	0.1738
436	0.0000	0.0000	0.1891
438	0.0000	0.0000	0.2068
440	0.0000	0.0000	0.2290
442	0.0000	0.0003	0.2557
444	0.0000	0.0010	0.2866
446	0.0000	0.0020	0.3231
448	0.0000	0.0030	0.3670
450	0.0000	0.0039	0.4204
452	0.0000	0.0046	0.4863
454	0.0000	0.0052	0.5635
456	0.0000	0.0058	0.6478
458	0.0000	0.0064	0.7344
460	0.0000	0.0071	0.8174
462	0.0000	0.0079	0.8952

464	0.0000	0.0089	0.9611
466	0.0000	0.0099	1.0000
468	0.0000	0.0108	0.9959
470	0.0000	0.0117	0.9339
472	0.0000	0.0126	0.8125
474	0.0000	0.0134	0.6538
476	0.0000	0.0142	0.4825
478	0.0000	0.0150	0.3240
480	0.0000	0.0158	0.2028
482	0.0000	0.0163	0.1230
484	0.0000	0.0165	0.0710
486	0.0000	0.0166	0.0407
488	0.0000	0.0167	0.0243
490	0.0000	0.0174	0.0150
492	0.0000	0.0184	0.0087
494	0.0000	0.0196	0.0051
496	0.0000	0.0211	0.0033
498	0.0000	0.0230	0.0025
500	0.0000	0.0256	0.0020
502	0.0000	0.0296	0.0014
504	0.0000	0.0356	0.0009
506	0.0000	0.0430	0.0004
508	0.0000	0.0514	0.0001
510	0.0000	0.0600	0.0000
512	0.0000	0.0690	0.0000
514	0.0000	0.0787	0.0000
516	0.0000	0.0888	0.0000
518	0.0000	0.0990	0.0000
520	0.0000	0.1095	0.0000
522	0.0000	0.1201	0.0000
524	0.0000	0.1310	0.0000
526	0.0000	0.1427	0.0000
528	0.0000	0.1556	0.0000
530	0.0000	0.1704	0.0000

532	0.0000	0.1829	0.0000
534	0.0000	0.1944	0.0000
536	0.0000	0.2151	0.0000
538	0.0000	0.2556	0.0000
540	0.0000	0.3269	0.0000
542	0.0000	0.4552	0.0000
544	0.0000	0.6303	0.0000
546	0.0000	0.8082	0.0000
548	0.0000	0.9457	0.0000
550	0.0000	1.0000	0.0000
552	0.0000	0.9408	0.0000
554	0.0000	0.7932	0.0000
556	0.0000	0.5983	0.0000
558	0.0000	0.4023	0.0000
560	0.0000	0.2559	0.0000
562	0.0000	0.1744	0.0000
564	0.0000	0.1285	0.0000
566	0.0000	0.1051	0.0000
568	0.0000	0.0907	0.0000
570	0.0000	0.0718	0.0000
572	0.0023	0.0496	0.0000
574	0.0075	0.0330	0.0000
576	0.0133	0.0211	0.0000
578	0.0177	0.0129	0.0000
580	0.0197	0.0071	0.0000
582	0.0194	0.0033	0.0000
584	0.0181	0.0013	0.0000
586	0.0163	0.0003	0.0000
588	0.0146	0.0000	0.0000
590	0.0135	0.0000	0.0000
592	0.0128	0.0000	0.0000
594	0.0125	0.0000	0.0000
596	0.0125	0.0000	0.0000
598	0.0128	0.0000	0.0000

600	0.0134	0.0000	0.0000
602	0.0149	0.0000	0.0000
604	0.0176	0.0000	0.0000
606	0.0214	0.0000	0.0000
608	0.0262	0.0000	0.0000
610	0.0318	0.0000	0.0000
612	0.0383	0.0000	0.0000
614	0.0461	0.0000	0.0000
616	0.0553	0.0000	0.0000
618	0.0655	0.0000	0.0000
620	0.0766	0.0000	0.0000
622	0.0890	0.0000	0.0000
624	0.1028	0.0000	0.0000
626	0.1175	0.0000	0.0000
628	0.1323	0.0000	0.0000
630	0.1464	0.0000	0.0000
632	0.1597	0.0000	0.0000
634	0.1724	0.0000	0.0000
636	0.1843	0.0000	0.0000
638	0.1947	0.0000	0.0000
640	0.2033	0.0000	0.0000
642	0.2094	0.0000	0.0000
644	0.2138	0.0000	0.0000
646	0.2174	0.0000	0.0000
648	0.2215	0.0000	0.0000
650	0.2275	0.0000	0.0000
652	0.2348	0.0000	0.0000
654	0.2432	0.0000	0.0000
656	0.2544	0.0000	0.0000
658	0.2702	0.0000	0.0000
660	0.2923	0.0000	0.0000
662	0.3213	0.0000	0.0000
664	0.3560	0.0000	0.0000

666	0.3954	0.0000	0.0000
668	0.4386	0.0000	0.0000
670	0.4845	0.0000	0.0000
672	0.5337	0.0000	0.0000
674	0.5867	0.0000	0.0000
676	0.6418	0.0000	0.0000
678	0.6977	0.0000	0.0000
680	0.7527	0.0000	0.0000
682	0.8112	0.0000	0.0000
684	0.8727	0.0000	0.0000
686	0.9289	0.0000	0.0000
688	0.9721	0.0000	0.0000
690	0.9950	0.0000	0.0000
692	1.0000	0.0000	0.0000
694	0.9928	0.0000	0.0000
696	0.9714	0.0000	0.0000
698	0.9336	0.0000	0.0000
700	0.8776	0.0000	0.0000
702	0.7997	0.0000	0.0000
704	0.7045	0.0000	0.0000
706	0.6028	0.0000	0.0000
708	0.5049	0.0000	0.0000
710	0.4203	0.0000	0.0000
712	0.3498	0.0000	0.0000
714	0.2876	0.0000	0.0000
716	0.2324	0.0000	0.0000
718	0.1834	0.0000	0.0000
720	0.1396	0.0000	0.0000
722	0.0984	0.0000	0.0000
724	0.0603	0.0000	0.0000
726	0.0289	0.0000	0.0000
728	0.0077	0.0000	0.0000
730	0.0000	0.0000	0.0000

Annex B

(informative)

Influx Spectrum S_{APD}

Relative spectral power distribution of the influx spectrum S_{APD} normalized to 1.0000 at 560 nm.

Wavelength λ, (nm)	S_{APD}	Wavelength λ, (nm)	S_{APD}	Wavelength λ, (nm)	S_{APD}
360	0.0000	416	0.0560	472	0.1988
362	0.0000	418	0.0614	474	0.1981
364	0.0000	420	0.0669	476	0.1964
366	0.0000	422	0.0724	478	0.1933
368	0.0001	424	0.0779	480	0.1885
370	0.0001	426	0.0834	482	0.1802
372	0.0002	428	0.0889	484	0.1684
374	0.0005	430	0.0944	486	0.1563
376	0.0007	432	0.0998	488	0.1468
378	0.0010	434	0.1052	490	0.1428
380	0.0013	436	0.1106	492	0.1428
382	0.0014	438	0.1159	494	0.1439
384	0.0016	440	0.1211	496	0.1471
386	0.0018	442	0.1261	498	0.1534
388	0.0022	444	0.1309	500	0.1637
390	0.0030	446	0.1357	502	0.1825
392	0.0043	448	0.1406	504	0.2114
394	0.0061	450	0.1456	506	0.2476
396	0.0084	452	0.1508	508	0.2883
398	0.0113	454	0.1562	510	0.3307
400	0.0147	456	0.1616	512	0.3762
402	0.0189	458	0.1671	514	0.4265
404	0.0237	460	0.1725	516	0.4794
406	0.0290	462	0.1787	518	0.5325
408	0.0345	464	0.1856	520	0.5836
410	0.0399	466	0.1921	522	0.6338
412	0.0451	468	0.1969	524	0.6842
414	0.0505	470	0.1989	526	0.7325

528	0.7764
530	0.8137
532	0.8434
534	0.8669
536	0.8852
538	0.8993
540	0.9104
542	0.9179
544	0.9220
546	0.9248
548	0.9285
550	0.9352
552	0.9469
554	0.9621
556	0.9779
558	0.9915
560	1.0000
562	1.0036
564	1.0032
566	0.9969
568	0.9832
570	0.9602
572	0.9235
574	0.8728
576	0.8134
578	0.7502
580	0.6882
582	0.6252
584	0.5589
586	0.4947
588	0.4376
590	0.3930
592	0.3627
594	0.3436

596	0.3334
598	0.3297
600	0.3304
602	0.3467
604	0.3866
606	0.4423
608	0.5062
610	0.5705
612	0.6370
614	0.7101
616	0.7863
618	0.8623
620	0.9345
622	1.0029
624	1.0690
626	1.1317
628	1.1898
630	1.2424
632	1.2890
634	1.3303
636	1.3667
638	1.3985
640	1.4261
642	1.4499
644	1.4700
646	1.4867
648	1.5005
650	1.5118
652	1.5206
654	1.5273
656	1.5320
658	1.5348
660	1.5359
662	1.5355

664	1.5336
666	1.5305
668	1.5263
670	1.5212
672	1.5151
674	1.5079
676	1.4994
678	1.4892
680	1.4771
682	1.4631
684	1.4480
686	1.4332
688	1.4197
690	1.4088
692	1.4015
694	1.3965
696	1.3926
698	1.3880
700	1.3813
702	1.3714
704	1.3590
706	1.3450
708	1.3305
710	1.3163
712	1.3030
714	1.2904
716	1.2781
718	1.2656
720	1.2526
722	1.2387
724	1.2242
726	1.2091
728	1.1937
730	1.1782

The relative spectral power distribution of the influx spectrum S_{APD} is illustrated in Figure 5 below. The influx spectrum is normalized to 1.0 at 560nm.

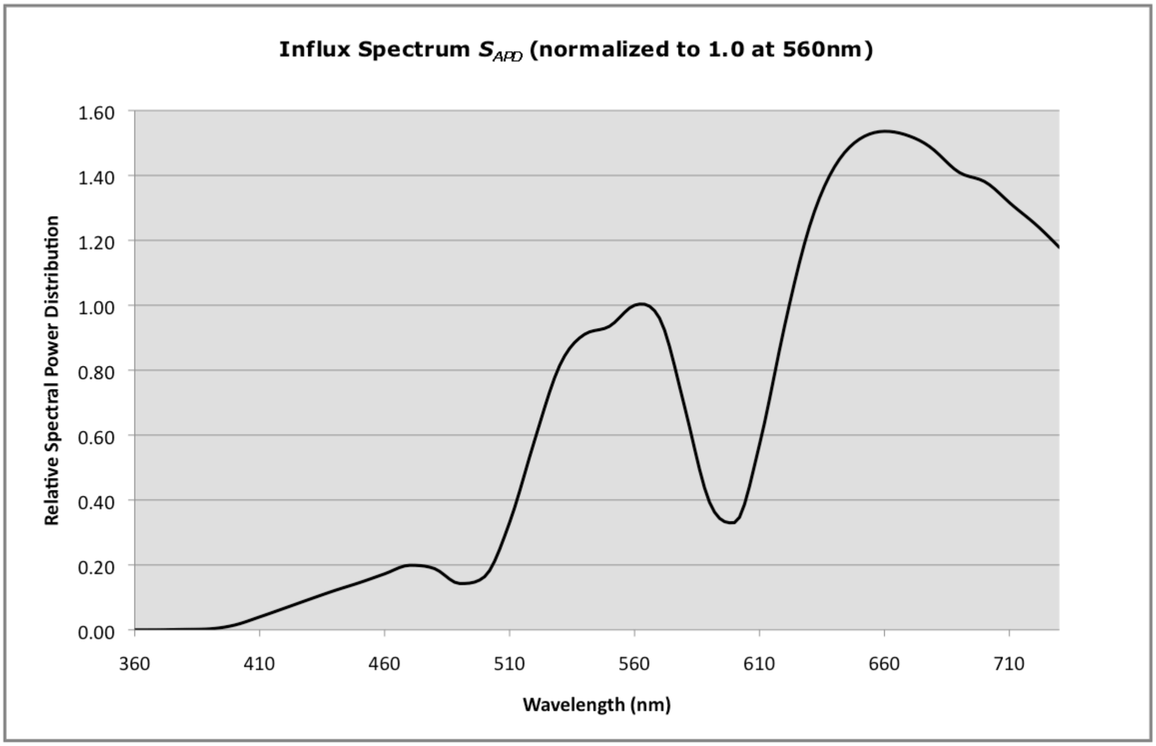

Figure 5 – Influx Spectrum S_{APD}

Annex C

(informative)

Status M to APD Conversion Transforms

Listed below are sample ISO Status M to APD conversion transforms and the associated residual errors for a variety of motion picture color negative and internegative films. The matrix coefficients were computed based on spectral measurements of 31 contemporary camera negative and intermediate film stocks. A set of test patches, consisting of 33 “grays” (a ramp of approximately equal Status M densities in all three dyes) and 64 “colors” (a cube of 4^3 approximately equidistant density combinations), was exposed on each film stock. An ARRILASER film recorder was used to create the test negatives. The resulting 97 patches on each negative were measured with a spectrophotometer in 10 nm increments. The spectral transmission of each measured patch was converted to Status M density and APD, respectively. A least-squares regression was used to calculate the Status M density to APD transforms listed below. The associated residual errors are listed in the table below each transform.

The most likely use for the Status M to APD transforms below is process control. In those circumstances, a density ramp is produced on a negative. The negative is measured with a densitometer and the resulting Status M values are converted to APD. With the exception of the intermediate stocks, the expected errors are all smaller than or equal to 0.02. For the intermediate stocks or in other cases where a higher accuracy of the conversion is desired, a polynomial conversion or a 3D LUT may be calculated.

The following is a description of the residual error statistics calculated and reported in each table.

mean abs error (all)

The arithmetic mean of the absolute differences between the fitted and the measured APD values used in the regression.

max abs error (all)

The maximum of the absolute differences between the fitted and the measured APD values used in the regression.

max abs error (gray)

The maximum of the absolute differences between the fitted and the measured APD values of the “gray” values only. Those errors are considered to be most relevant in applications where the matrices are used for process control.

max abs error (Macbeth)

The maximum of the absolute differences between the fitted and the measured APD values for an independent set of 18 colors similar to the ones used in the Macbeth ColorChecker.

max abs error (large)

The maximum of the absolute differences between the fitted and the measured APD values for a large set of patches consisting of 33 “grays” and an independent set of 216 “colors”. This test was done to ensure that the calculated transformations are not too dependent on the regression samples.

NOTE The transforms given below were calculated from the spectral transmission measurements of a particular set of patches using a particular regression methodology to calculate the transform coefficients. If a different set of patches or a different regression routine were used, the transform coefficients and residual errors calculated would be slightly different than those given above. For details contact the Academy at councilinfo@oscars.org.

Eastman Kodak 5201

$$\begin{bmatrix} APD_R \\ APD_G \\ APD_B \end{bmatrix} = \begin{bmatrix} 1.101296 & -0.032969 & -0.000005 \\ -0.006654 & 1.026220 & 0.006813 \\ -0.007217 & 0.028168 & 0.955982 \end{bmatrix} \begin{bmatrix} StM_R \\ StM_G \\ StM_B \end{bmatrix} + \begin{bmatrix} -0.009850 \\ -0.025275 \\ 0.008601 \end{bmatrix}$$

Residual Errors	**APD$_R$**	**APD$_G$**	**APD$_B$**
mean abs error (all)	0.002	0.005	0.002
max abs error (all)	0.006	0.029	0.008
max abs error (gray)	0.004	0.002	0.002
max abs error (Macbeth)	0.004	0.006	0.002

Eastman Kodak 5205

$$\begin{bmatrix} APD_R \\ APD_G \\ APD_B \end{bmatrix} = \begin{bmatrix} 1.066019 & -0.027482 & -0.002535 \\ -0.014992 & 1.026082 & 0.007485 \\ -0.007457 & 0.030328 & 0.953577 \end{bmatrix} \begin{bmatrix} StM_R \\ StM_G \\ StM_B \end{bmatrix} + \begin{bmatrix} 0.012239 \\ -0.011941 \\ 0.009534 \end{bmatrix}$$

Residual Errors	**APD$_R$**	**APD$_G$**	**APD$_B$**
mean abs error (all)	0.004	0.005	0.002
max abs error (all)	0.011	0.027	0.008
max abs error (gray)	0.006	0.002	0.003
max abs error (Macbeth)	0.006	0.006	0.002

Eastman Kodak 5207

$$\begin{bmatrix} APD_R \\ APD_G \\ APD_B \end{bmatrix} = \begin{bmatrix} 1.087370 & -0.008372 & 0.001454 \\ -0.010327 & 1.022765 & 0.017075 \\ -0.007220 & 0.028536 & 0.955400 \end{bmatrix} \begin{bmatrix} StM_R \\ StM_G \\ StM_B \end{bmatrix} + \begin{bmatrix} -0.015931 \\ -0.032591 \\ 0.012734 \end{bmatrix}$$

Residual Errors	**APD$_R$**	**APD$_G$**	**APD$_B$**
mean abs error (all)	0.004	0.010	0.002
max abs error (all)	0.016	0.053	0.010
max abs error (gray)	0.006	0.005	0.003
max abs error (Macbeth)	0.005	0.011	0.002
max abs error (large)	0.019	0.053	0.009

Eastman Kodak 5212

$$\begin{bmatrix} APD_R \\ APD_G \\ APD_B \end{bmatrix} = \begin{bmatrix} 1.069642 & -0.031255 & 0.001811 \\ -0.013424 & 1.030529 & 0.004713 \\ -0.008880 & 0.026912 & 0.958874 \end{bmatrix} \begin{bmatrix} StM_R \\ StM_G \\ StM_B \end{bmatrix} + \begin{bmatrix} 0.007303 \\ -0.015218 \\ 0.003834 \end{bmatrix}$$

Residual Errors	**APD_R**	**APD_G**	**APD_B**
mean abs error (all)	0.004	0.005	0.003
max abs error (all)	0.009	0.028	0.013
max abs error (gray)	0.006	0.002	0.003
max abs error (Macbeth)	0.008	0.006	0.003

Eastman Kodak 5217

$$\begin{bmatrix} APD_R \\ APD_G \\ APD_B \end{bmatrix} = \begin{bmatrix} 1.069704 & -0.032058 & 0.001695 \\ -0.013846 & 1.030479 & 0.005748 \\ -0.009112 & 0.026934 & 0.959581 \end{bmatrix} \begin{bmatrix} StM_R \\ StM_G \\ StM_B \end{bmatrix} + \begin{bmatrix} 0.007737 \\ -0.017027 \\ 0.002515 \end{bmatrix}$$

Residual Errors	**APD_R**	**APD_G**	**APD_B**
mean abs error (all)	0.004	0.005	0.003
max abs error (all)	0.010	0.031	0.014
max abs error (gray)	0.006	0.002	0.003
max abs error (Macbeth)	0.008	0.006	0.003
max abs error (large)	0.022	0.031	0.018

Eastman Kodak 5218

$$\begin{bmatrix} APD_R \\ APD_G \\ APD_B \end{bmatrix} = \begin{bmatrix} 1.065835 & -0.026713 & 0.000830 \\ -0.007235 & 1.024090 & 0.007475 \\ -0.009174 & 0.032606 & 0.962619 \end{bmatrix} \begin{bmatrix} StM_R \\ StM_G \\ StM_B \end{bmatrix} + \begin{bmatrix} 0.006082 \\ -0.023898 \\ 0.003488 \end{bmatrix}$$

Residual Errors	**APD_R**	**APD_G**	**APD_B**
mean abs error (all)	0.004	0.005	0.002
max abs error (all)	0.011	0.029	0.008
max abs error (gray)	0.006	0.003	0.003
max abs error (Macbeth)	0.008	0.006	0.002

Eastman Kodak 5219

$$\begin{bmatrix} APD_R \\ APD_G \\ APD_B \end{bmatrix} = \begin{bmatrix} 1.100481 & -0.017433 & -0.000160 \\ -0.005245 & 1.021893 & 0.009767 \\ -0.008288 & 0.028113 & 0.957600 \end{bmatrix} \begin{bmatrix} StM_R \\ StM_G \\ StM_B \end{bmatrix} + \begin{bmatrix} -0.046520 \\ -0.025677 \\ 0.010549 \end{bmatrix}$$

Residual Errors	**APD$_R$**	**APD$_G$**	**APD$_B$**
mean abs error (all)	0.003	0.006	0.002
max abs error (all)	0.013	0.032	0.009
max abs error (gray)	0.006	0.004	0.003
max abs error (Macbeth)	0.005	0.007	0.002
max abs error (large)	0.019	0.048	0.013

Eastman Kodak 5229

$$\begin{bmatrix} APD_R \\ APD_G \\ APD_B \end{bmatrix} = \begin{bmatrix} 1.052718 & -0.026359 & 0.001004 \\ -0.008720 & 1.029220 & 0.006463 \\ -0.007768 & 0.031219 & 0.954600 \end{bmatrix} \begin{bmatrix} StM_R \\ StM_G \\ StM_B \end{bmatrix} + \begin{bmatrix} 0.011119 \\ -0.026719 \\ 0.010776 \end{bmatrix}$$

Residual Errors	**APD$_R$**	**APD$_G$**	**APD$_B$**
mean abs error (all)	0.007	0.005	0.002
max abs error (all)	0.017	0.026	0.008
max abs error (gray)	0.010	0.002	0.003
max abs error (Macbeth)	0.012	0.005	0.002

Eastman Kodak 5242

$$\begin{bmatrix} APD_R \\ APD_G \\ APD_B \end{bmatrix} = \begin{bmatrix} 1.119738 & -0.010526 & -0.010656 \\ -0.010715 & 1.015791 & 0.032838 \\ -0.005212 & 0.023310 & 0.945385 \end{bmatrix} \begin{bmatrix} StM_R \\ StM_G \\ StM_B \end{bmatrix} + \begin{bmatrix} -0.014891 \\ -0.049307 \\ 0.015709 \end{bmatrix}$$

Residual Errors	**APD$_R$**	**APD$_G$**	**APD$_B$**
mean abs error (all)	0.010	0.018	0.005
max abs error (all)	0.049	0.093	0.026
max abs error (gray)	0.013	0.011	0.005
max abs error (Macbeth)	0.016	0.021	0.005
max abs error (large)	0.056	0.199	0.027

Eastman Kodak 5245

$$\begin{bmatrix} APD_R \\ APD_G \\ APD_B \end{bmatrix} = \begin{bmatrix} 1.101702 & -0.035539 & 0.001548 \\ 0.000995 & 1.016569 & 0.007579 \\ -0.006835 & 0.018933 & 0.963635 \end{bmatrix} \begin{bmatrix} StM_R \\ StM_G \\ StM_B \end{bmatrix} + \begin{bmatrix} -0.011186 \\ -0.030343 \\ 0.002572 \end{bmatrix}$$

Residual Errors	**APD_R**	**APD_G**	**APD_B**
mean abs error (all)	0.005	0.006	0.002
max abs error (all)	0.013	0.039	0.009
max abs error (gray)	0.010	0.005	0.002
max abs error (Macbeth)	0.008	0.005	0.002

Eastman Kodak 5246

$$\begin{bmatrix} APD_R \\ APD_G \\ APD_B \end{bmatrix} = \begin{bmatrix} 1.092853 & -0.040243 & -0.001080 \\ -0.001106 & 1.008393 & 0.004645 \\ -0.006896 & 0.025253 & 0.960196 \end{bmatrix} \begin{bmatrix} StM_R \\ StM_G \\ StM_B \end{bmatrix} + \begin{bmatrix} -0.006945 \\ -0.007516 \\ 0.007339 \end{bmatrix}$$

Residual Errors	**APD_R**	**APD_G**	**APD_B**
mean abs error (all)	0.002	0.005	0.001
max abs error (all)	0.008	0.021	0.007
max abs error (gray)	0.004	0.005	0.002
max abs error (Macbeth)	0.002	0.004	0.002

Eastman Kodak 5248

$$\begin{bmatrix} APD_R \\ APD_G \\ APD_B \end{bmatrix} = \begin{bmatrix} 1.082584 & -0.036321 & 0.000167 \\ -0.001970 & 1.021369 & 0.008139 \\ -0.006600 & 0.018432 & 0.954864 \end{bmatrix} \begin{bmatrix} StM_R \\ StM_G \\ StM_B \end{bmatrix} + \begin{bmatrix} -0.001246 \\ -0.035773 \\ 0.013566 \end{bmatrix}$$

Residual Errors	**APD_R**	**APD_G**	**APD_B**
mean abs error (all)	0.003	0.006	0.002
max abs error (all)	0.008	0.049	0.011
max abs error (gray)	0.005	0.004	0.002
max abs error (Macbeth)	0.006	0.005	0.002

Eastman Kodak 5260

$$\begin{bmatrix} APD_R \\ APD_G \\ APD_B \end{bmatrix} = \begin{bmatrix} 1.081063 & -0.016746 & 0.002187 \\ -0.009016 & 1.027180 & 0.012147 \\ -0.006843 & 0.025106 & 0.957405 \end{bmatrix} \begin{bmatrix} StM_R \\ StM_G \\ StM_B \end{bmatrix} + \begin{bmatrix} -0.023288 \\ -0.030115 \\ 0.010275 \end{bmatrix}$$

Residual Errors	**APD_R**	**APD_G**	**APD_B**
mean abs error (all)	0.007	0.009	0.004
max abs error (all)	0.020	0.050	0.017
max abs error (gray)	0.011	0.005	0.004
max abs error (Macbeth)	0.012	0.012	0.003
max abs error (large)	0.020	0.049	0.016

Eastman Kodak 5274

$$\begin{bmatrix} APD_R \\ APD_G \\ APD_B \end{bmatrix} = \begin{bmatrix} 1.097576 & -0.035788 & 0.002337 \\ -0.000444 & 1.006740 & 0.006519 \\ -0.007421 & 0.023325 & 0.962592 \end{bmatrix} \begin{bmatrix} StM_R \\ StM_G \\ StM_B \end{bmatrix} + \begin{bmatrix} -0.009561 \\ -0.009950 \\ -0.002281 \end{bmatrix}$$

Residual Errors	**APD_R**	**APD_G**	**APD_B**
mean abs error (all)	0.005	0.006	0.003
max abs error (all)	0.019	0.032	0.012
max abs error (gray)	0.005	0.005	0.003
max abs error (Macbeth)	0.006	0.005	0.002

Eastman Kodak 5277

$$\begin{bmatrix} APD_R \\ APD_G \\ APD_B \end{bmatrix} = \begin{bmatrix} 1.101778 & -0.032309 & -0.002576 \\ -0.003777 & 1.016441 & 0.004321 \\ -0.005778 & 0.024723 & 0.958173 \end{bmatrix} \begin{bmatrix} StM_R \\ StM_G \\ StM_B \end{bmatrix} + \begin{bmatrix} -0.015127 \\ -0.014964 \\ 0.009370 \end{bmatrix}$$

Residual Errors	**APD_R**	**APD_G**	**APD_B**
mean abs error (all)	0.002	0.005	0.002
max abs error (all)	0.009	0.023	0.008
max abs error (gray)	0.005	0.004	0.002
max abs error (Macbeth)	0.003	0.005	0.002

Eastman Kodak 5279

$$\begin{bmatrix} APD_R \\ APD_G \\ APD_B \end{bmatrix} = \begin{bmatrix} 1.091623 & -0.030673 & 0.001958 \\ -0.006285 & 1.018994 & 0.005023 \\ -0.005914 & 0.023762 & 0.957924 \end{bmatrix} \begin{bmatrix} StM_R \\ StM_G \\ StM_B \end{bmatrix} + \begin{bmatrix} -0.011469 \\ -0.015863 \\ 0.012219 \end{bmatrix}$$

Residual Errors	**APD_R**	**APD_G**	**APD_B**
mean abs error (all)	0.002	0.005	0.002
max abs error (all)	0.011	0.028	0.011
max abs error (gray)	0.004	0.004	0.003
max abs error (Macbeth)	0.002	0.007	0.003

Eastman Kodak 5299

$$\begin{bmatrix} APD_R \\ APD_G \\ APD_B \end{bmatrix} = \begin{bmatrix} 1.077334 & -0.023919 & -0.000050 \\ -0.004527 & 1.020150 & 0.005350 \\ -0.005810 & 0.031206 & 0.950420 \end{bmatrix} \begin{bmatrix} StM_R \\ StM_G \\ StM_B \end{bmatrix} + \begin{bmatrix} -0.002048 \\ -0.011858 \\ 0.018764 \end{bmatrix}$$

Residual Errors	**APD_R**	**APD_G**	**APD_B**
mean abs error (all)	0.003	0.002	0.001
max abs error (all)	0.009	0.008	0.003
max abs error (gray)	0.006	0.001	0.001
max abs error (Macbeth)	0.006	0.002	0.001

Fujifilm 8502

$$\begin{bmatrix} APD_R \\ APD_G \\ APD_B \end{bmatrix} = \begin{bmatrix} 1.103056 & -0.004308 & 0.004461 \\ -0.012660 & 1.016000 & 0.021615 \\ -0.004584 & 0.018212 & 0.961341 \end{bmatrix} \begin{bmatrix} StM_R \\ StM_G \\ StM_B \end{bmatrix} + \begin{bmatrix} -0.005504 \\ -0.034962 \\ 0.011536 \end{bmatrix}$$

Residual Errors	**APD_R**	**APD_G**	**APD_B**
mean abs error (all)	0.015	0.016	0.007
max abs error (all)	0.053	0.086	0.037
max abs error (gray)	0.015	0.007	0.008
max abs error (Macbeth)	0.020	0.014	0.006

Fujifilm 8511

$$\begin{bmatrix} APD_R \\ APD_G \\ APD_B \end{bmatrix} = \begin{bmatrix} 1.088654 & 0.001173 & 0.001221 \\ -0.010253 & 0.993960 & 0.050069 \\ -0.002240 & 0.008808 & 0.967194 \end{bmatrix} \begin{bmatrix} StM_R \\ StM_G \\ StM_B \end{bmatrix} + \begin{bmatrix} 0.029360 \\ -0.051075 \\ 0.005934 \end{bmatrix}$$

Residual Errors	**APD_R**	**APD_G**	**APD_B**
mean abs error (all)	0.021	0.028	0.012
max abs error (all)	0.080	0.146	0.060
max abs error (gray)	0.024	0.019	0.009
max abs error (Macbeth)	0.027	0.035	0.015
max abs error (large)	0.083	0.143	0.064

Fujifilm 8522

$$\begin{bmatrix} APD_R \\ APD_G \\ APD_B \end{bmatrix} = \begin{bmatrix} 1.120747 & -0.016442 & 0.003391 \\ -0.003807 & 1.023849 & 0.004196 \\ -0.005334 & 0.025377 & 0.965731 \end{bmatrix} \begin{bmatrix} StM_R \\ StM_G \\ StM_B \end{bmatrix} + \begin{bmatrix} -0.101438 \\ -0.016643 \\ -0.001216 \end{bmatrix}$$

Residual Errors	**APD_R**	**APD_G**	**APD_B**
mean abs error (all)	0.006	0.004	0.001
max abs error (all)	0.025	0.019	0.007
max abs error (gray)	0.009	0.003	0.002
max abs error (Macbeth)	0.009	0.003	0.002

Fujifilm 8532

$$\begin{bmatrix} APD_R \\ APD_G \\ APD_B \end{bmatrix} = \begin{bmatrix} 1.120083 & -0.018091 & 0.002768 \\ -0.004167 & 1.022935 & 0.005679 \\ -0.005553 & 0.024758 & 0.964728 \end{bmatrix} \begin{bmatrix} StM_R \\ StM_G \\ StM_B \end{bmatrix} + \begin{bmatrix} -0.100561 \\ -0.017547 \\ 0.000077 \end{bmatrix}$$

Residual Errors	**APD_R**	**APD_G**	**APD_B**
mean abs error (all)	0.005	0.005	0.001
max abs error (all)	0.024	0.022	0.008
max abs error (gray)	0.008	0.002	0.002
max abs error (Macbeth)	0.008	0.003	0.002

Fujifilm 8543

$$\begin{bmatrix} APD_R \\ APD_G \\ APD_B \end{bmatrix} = \begin{bmatrix} 1.100818 & -0.005546 & 0.008210 \\ -0.002098 & 1.004132 & 0.027088 \\ -0.009459 & 0.028099 & 0.960856 \end{bmatrix} \begin{bmatrix} StM_R \\ StM_G \\ StM_B \end{bmatrix} + \begin{bmatrix} -0.089836 \\ -0.021309 \\ 0.004479 \end{bmatrix}$$

Residual Errors	APD_R	APD_G	APD_B
mean abs error (all)	0.006	0.012	0.003
max abs error (all)	0.027	0.058	0.012
max abs error (gray)	0.009	0.010	0.003
max abs error (Macbeth)	0.009	0.012	0.006
max abs error (large)	0.030	0.064	0.020

Fujifilm 8552

$$\begin{bmatrix} APD_R \\ APD_G \\ APD_B \end{bmatrix} = \begin{bmatrix} 1.111265 & -0.001654 & 0.005046 \\ -0.000486 & 1.015521 & 0.013800 \\ -0.010030 & 0.025085 & 0.964599 \end{bmatrix} \begin{bmatrix} StM_R \\ StM_G \\ StM_B \end{bmatrix} + \begin{bmatrix} -0.091562 \\ -0.029594 \\ 0.005883 \end{bmatrix}$$

Residual Errors	APD_R	APD_G	APD_B
mean abs error (all)	0.008	0.009	0.002
max abs error (all)	0.029	0.042	0.010
max abs error (gray)	0.010	0.006	0.003
max abs error (Macbeth)	0.011	0.008	0.003

Fujifilm 8553

$$\begin{bmatrix} APD_R \\ APD_G \\ APD_B \end{bmatrix} = \begin{bmatrix} 1.102104 & 0.001192 & 0.004893 \\ -0.002092 & 1.011376 & 0.027884 \\ -0.011200 & 0.031622 & 0.959221 \end{bmatrix} \begin{bmatrix} StM_R \\ StM_G \\ StM_B \end{bmatrix} + \begin{bmatrix} -0.106220 \\ -0.030323 \\ 0.005961 \end{bmatrix}$$

Residual Errors	APD_R	APD_G	APD_B
mean abs error (all)	0.010	0.012	0.003
max abs error (all)	0.031	0.067	0.013
max abs error (gray)	0.019	0.009	0.003
max abs error (Macbeth)	0.019	0.013	0.005

Fujifilm 8562

$$\begin{bmatrix} APD_R \\ APD_G \\ APD_B \end{bmatrix} = \begin{bmatrix} 1.118347 & 0.001297 & 0.009660 \\ -0.001586 & 1.011502 & 0.017415 \\ -0.008897 & 0.026010 & 0.963635 \end{bmatrix} \begin{bmatrix} StM_R \\ StM_G \\ StM_B \end{bmatrix} + \begin{bmatrix} -0.100944 \\ -0.028342 \\ 0.004148 \end{bmatrix}$$

Residual Errors	**APD_R**	**APD_G**	**APD_B**
mean abs error (all)	0.008	0.009	0.002
max abs error (all)	0.032	0.046	0.008
max abs error (gray)	0.010	0.007	0.002
max abs error (Macbeth)	0.013	0.009	0.003

Fujifilm 8563

$$\begin{bmatrix} APD_R \\ APD_G \\ APD_B \end{bmatrix} = \begin{bmatrix} 1.098024 & 0.002330 & 0.005770 \\ -0.001853 & 1.007534 & 0.029294 \\ -0.010695 & 0.032361 & 0.956680 \end{bmatrix} \begin{bmatrix} StM_R \\ StM_G \\ StM_B \end{bmatrix} + \begin{bmatrix} -0.106860 \\ -0.028211 \\ 0.008003 \end{bmatrix}$$

Residual Errors	**APD_R**	**APD_G**	**APD_B**
mean abs error (all)	0.010	0.013	0.003
max abs error (all)	0.032	0.072	0.013
max abs error (gray)	0.021	0.009	0.005
max abs error (Macbeth)	0.019	0.014	0.007

Fujifilm 8572

$$\begin{bmatrix} APD_R \\ APD_G \\ APD_B \end{bmatrix} = \begin{bmatrix} 1.106989 & 0.000226 & 0.006250 \\ -0.002558 & 1.018617 & 0.011564 \\ -0.009550 & 0.023414 & 0.966451 \end{bmatrix} \begin{bmatrix} StM_R \\ StM_G \\ StM_B \end{bmatrix} + \begin{bmatrix} -0.091657 \\ -0.028476 \\ 0.004428 \end{bmatrix}$$

Residual Errors	**APD_R**	**APD_G**	**APD_B**
mean abs error (all)	0.007	0.009	0.003
max abs error (all)	0.024	0.044	0.014
max abs error (gray)	0.009	0.006	0.004
max abs error (Macbeth)	0.010	0.007	0.004

Fujifilm 8573

$$\begin{bmatrix} APD_R \\ APD_G \\ APD_B \end{bmatrix} = \begin{bmatrix} 1.093298 & 0.000128 & 0.004496 \\ -0.002634 & 1.011719 & 0.027227 \\ -0.010229 & 0.031026 & 0.964333 \end{bmatrix} \begin{bmatrix} StM_R \\ StM_G \\ StM_B \end{bmatrix} + \begin{bmatrix} -0.102170 \\ -0.029137 \\ -0.000866 \end{bmatrix}$$

Residual Errors	**APD_R**	**APD_G**	**APD_B**
mean abs error (all)	0.008	0.012	0.003
max abs error (all)	0.026	0.063	0.012
max abs error (gray)	0.016	0.010	0.003
max abs error (Macbeth)	0.016	0.013	0.004
max abs error (large)	0.038	0.062	0.017

Fujifilm 8582

$$\begin{bmatrix} APD_R \\ APD_G \\ APD_B \end{bmatrix} = \begin{bmatrix} 1.101857 & -0.001503 & 0.004398 \\ -0.004096 & 1.023786 & 0.006595 \\ -0.006307 & 0.023172 & 0.965481 \end{bmatrix} \begin{bmatrix} StM_R \\ StM_G \\ StM_B \end{bmatrix} + \begin{bmatrix} -0.087699 \\ -0.021568 \\ 0.000691 \end{bmatrix}$$

Residual Errors	**APD_R**	**APD_G**	**APD_B**
mean abs error (all)	0.006	0.005	0.002
max abs error (all)	0.017	0.021	0.006
max abs error (gray)	0.007	0.004	0.003
max abs error (Macbeth)	0.010	0.005	0.003

Fujifilm 8583

$$\begin{bmatrix} APD_R \\ APD_G \\ APD_B \end{bmatrix} = \begin{bmatrix} 1.109298 & -0.002422 & 0.007211 \\ -0.003434 & 1.015036 & 0.019227 \\ -0.007370 & 0.028686 & 0.963984 \end{bmatrix} \begin{bmatrix} StM_R \\ StM_G \\ StM_B \end{bmatrix} + \begin{bmatrix} -0.089070 \\ -0.019563 \\ -0.001995 \end{bmatrix}$$

Residual Errors	**APD_R**	**APD_G**	**APD_B**
mean abs error (all)	0.008	0.008	0.002
max abs error (all)	0.025	0.038	0.008
max abs error (gray)	0.013	0.006	0.002
max abs error (Macbeth)	0.013	0.008	0.003

Fujifilm 8592

$$\begin{bmatrix} APD_R \\ APD_G \\ APD_B \end{bmatrix} = \begin{bmatrix} 1.114327 & -0.008608 & 0.010124 \\ 0.000406 & 1.017948 & 0.012473 \\ -0.011736 & 0.024071 & 0.964933 \end{bmatrix} \begin{bmatrix} StM_R \\ StM_G \\ StM_B \end{bmatrix} + \begin{bmatrix} -0.097471 \\ -0.022842 \\ 0.001180 \end{bmatrix}$$

Residual Errors	**APD_R**	**APD_G**	**APD_B**
mean abs error (all)	0.006	0.008	0.002
max abs error (all)	0.023	0.038	0.011
max abs error (gray)	0.008	0.007	0.004
max abs error (Macbeth)	0.010	0.007	0.003