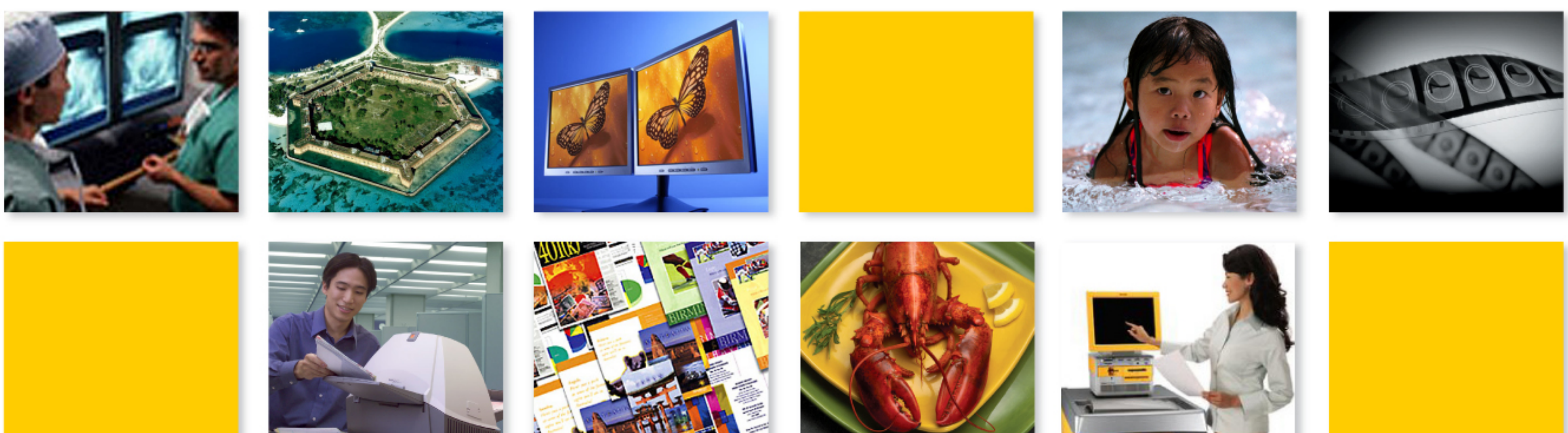
Printing Density

Chris L. DuMont
Thomas O Maier

Kodak



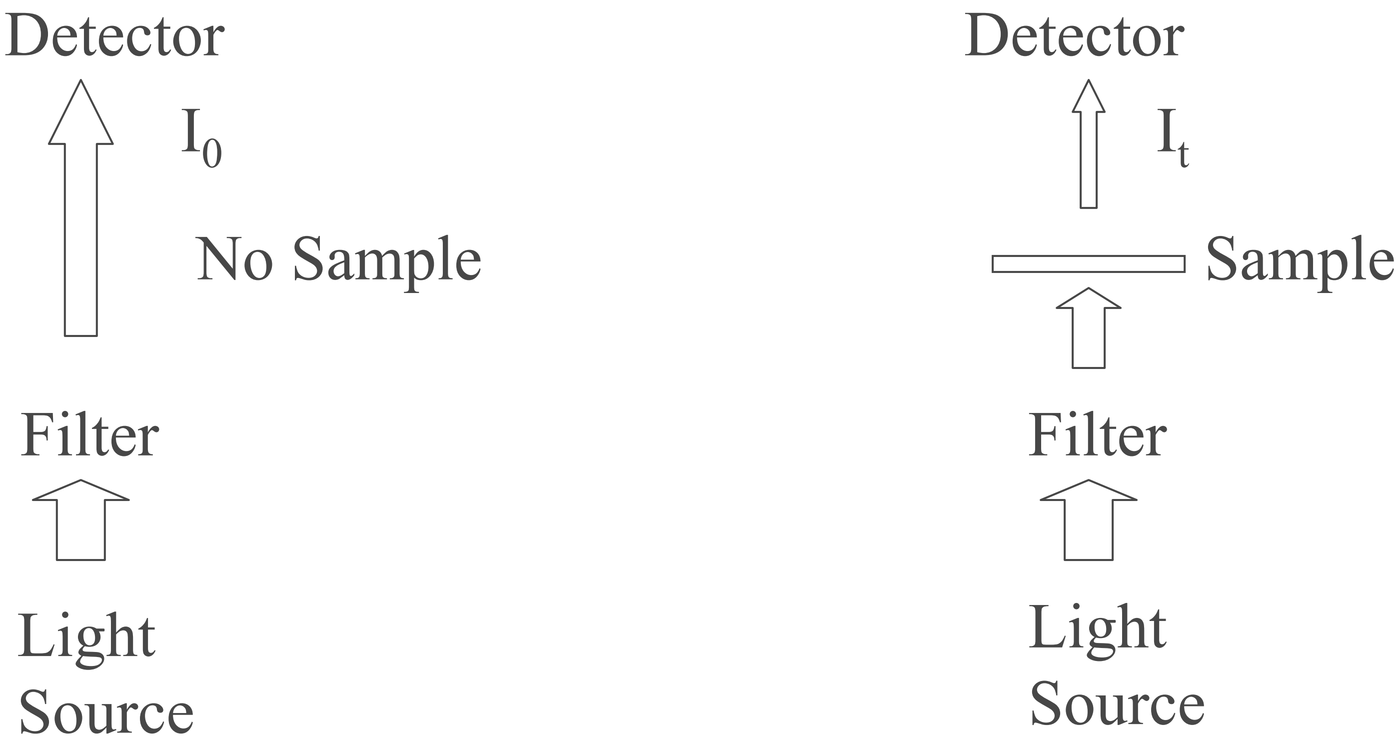
Printing Density

Printing Density is the most efficient encoding of scanned and recorded film information because this is the way that the print film sees the negative. The problem today is that many individuals have their own definition of printing density, and no two agree on the printing density of the same piece of film.

If everyone were calibrated to the same printing density metric, exchanging images would be easier within a facility, as well as between facilities.

Once one can determine the printing density of a patch of film, it is relatively straight forward to calibrate imaging hardware relative to printing density. This presentation will describe an overview of the calibration process overview for various DI post-production applications.

Optical Density



Transmittance Factor, $T = I_t / I_0$

Density, $D = -\log10(T)$

$T = 10 \wedge -D$

Optical Density

Detector – Defined by Spectral Sensitivity

Filter – Defined by Spectral Transmittance Factor

Light Source – Defined by Spectral Energy

Responsivity – The combination of the Detector, the Filter, and the Light Source

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

where λ is the wavelength of the light

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

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

Status M Density

The Status M Responsivity has been standardized and is the combination of the Detector, the Filter, and the Light Source. Any Detector, Filter, and Light Source can be used to measure Status M as long as the Responsivity matches the standard.

Responsivity(λ) = Detector(λ) * Filter(λ) * Light Source(λ)

where λ is the wavelength of the light

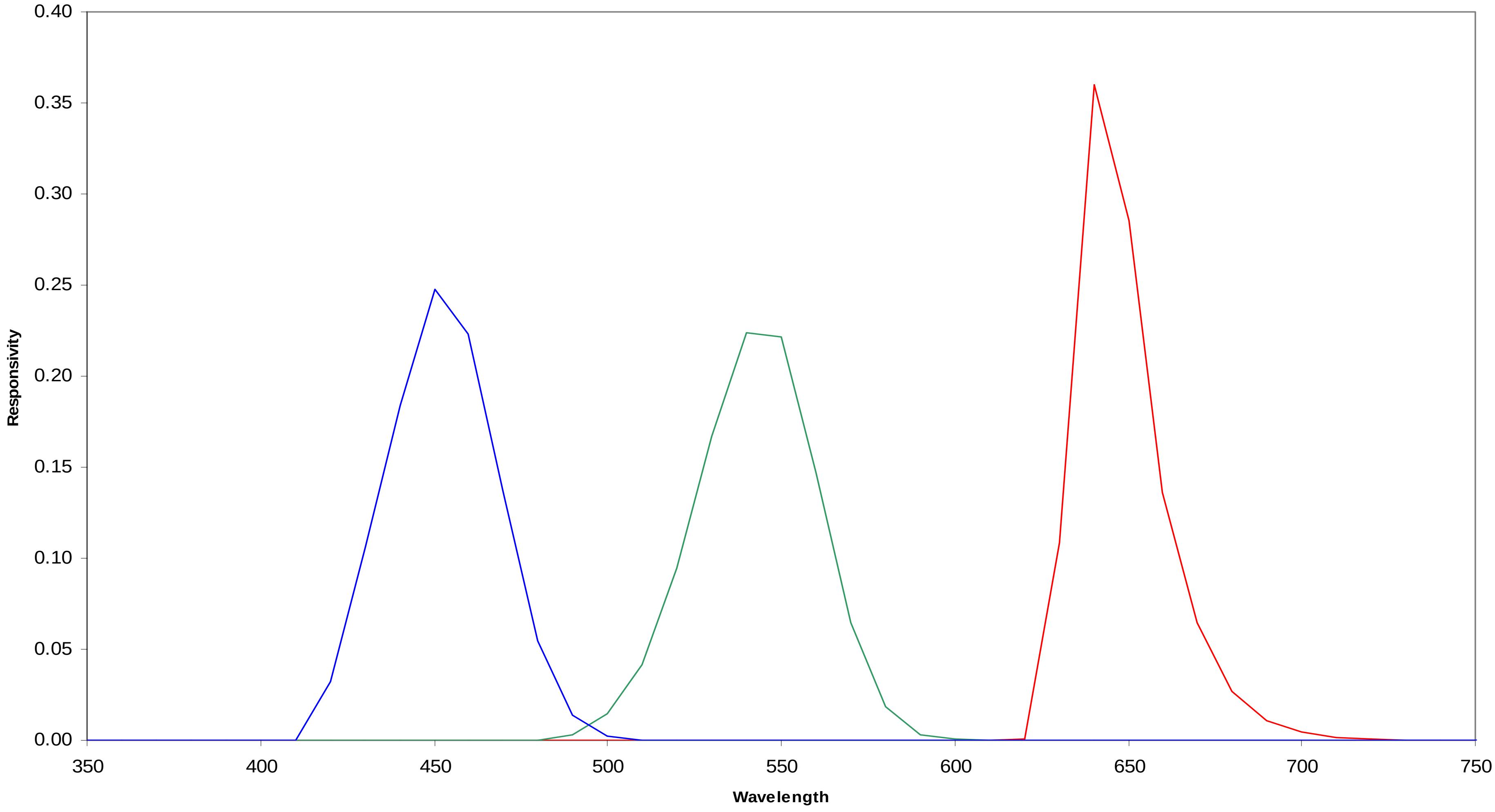
$I_0 = \Sigma_\lambda$ Responsivity(λ)

$I_t = \Sigma_\lambda$ (Responsivity(λ) * Film Transmittance Factor(λ))

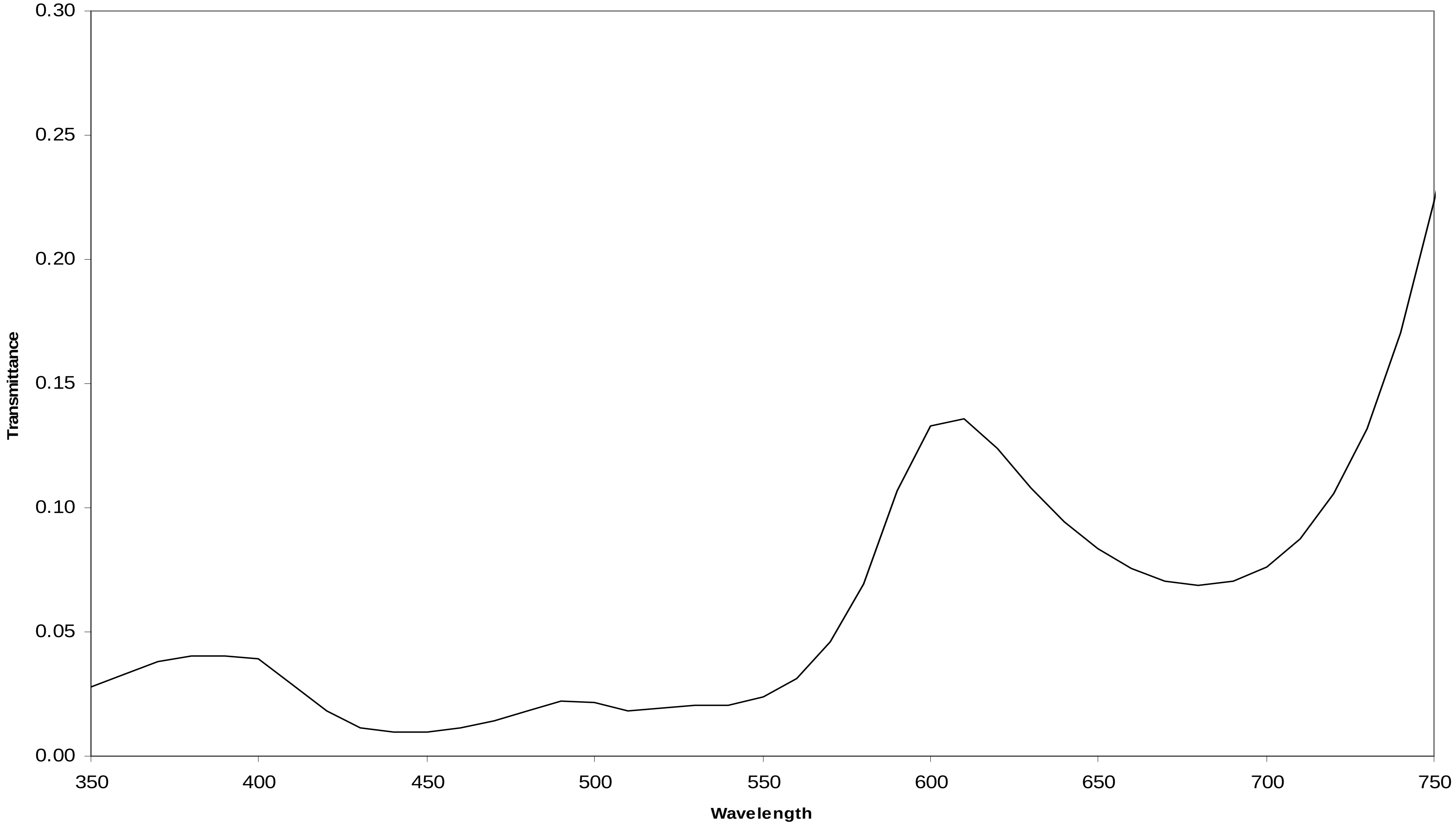
Transmittance Factor, $T = I_t / I_0$

Density, D = -log10(T)　　　T = 10 ^ -D

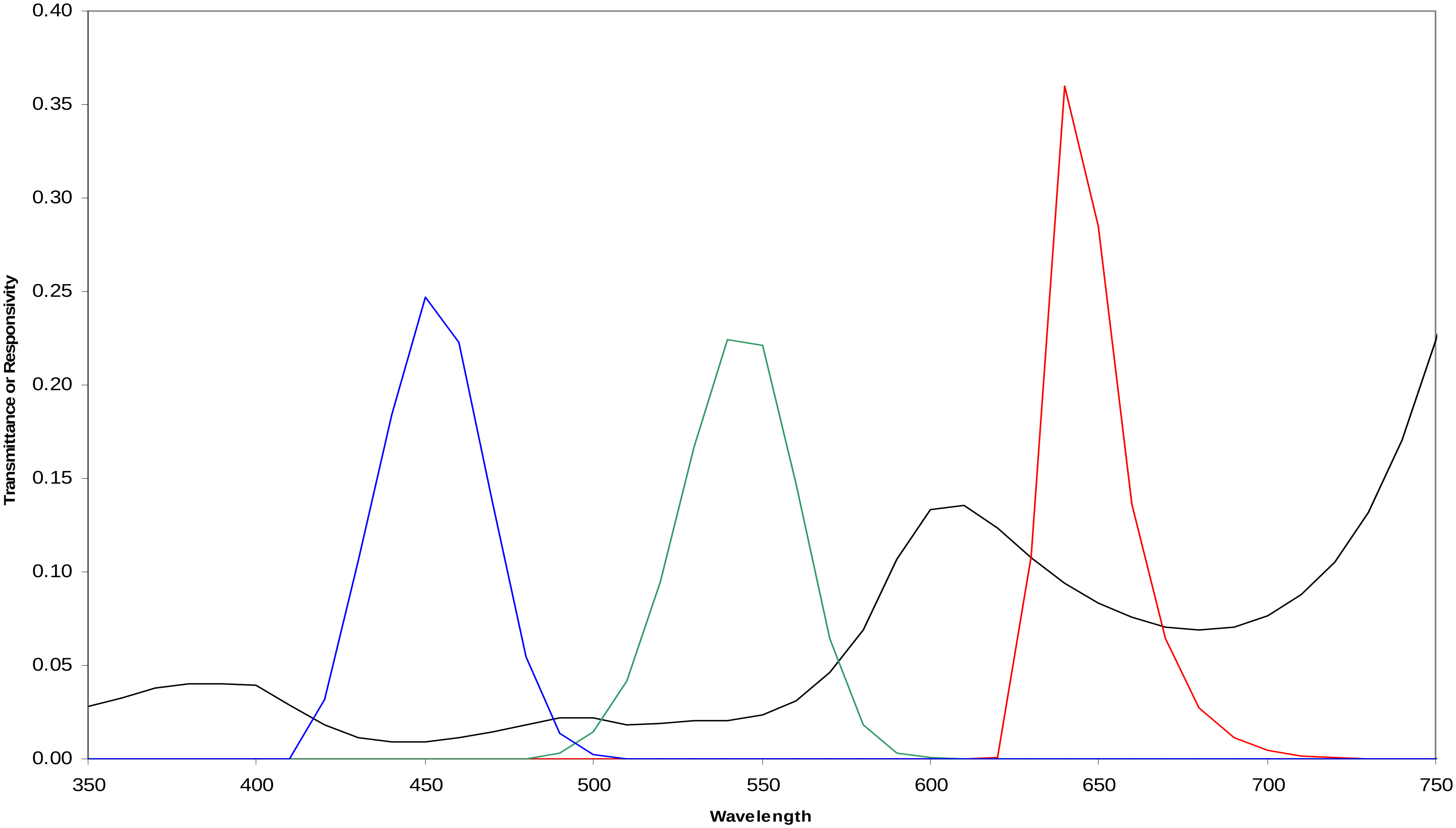
Status M Responsivity



Film Spectral Transmittance



Film and Status M



Calculation of Status M Density

Green Status M Density Only

Wavelength	Status M	Film T	Status M * Film T
400	0	0.0393	0
410	0	0.0291	0
420	0	0.0179	0
430	0	0.0113	0
440	0	0.0094	0
450	0	0.0094	0
460	0	0.0111	0
470	0.00003	0.0143	0
480	0.00036	0.0182	0.00001
490	0.00321	0.0219	0.00007
500	0.01426	0.0216	0.00031
510	0.04188	0.0182	0.00076
520	0.09463	0.0193	0.00183
530	0.16674	0.0205	0.00342
540	0.22389	0.0207	0.00463
550	0.22133	0.0236	0.00522
560	0.14724	0.0314	0.00462
570	0.06427	0.0461	0.00296
580	0.01841	0.0692	0.00127
590	0.00333	0.1067	0.00035
600	0.00039	0.1331	0.00005
			sum = 0.02552
			D = 1.59311

Printing Density

The Printing Density Responsivity is the combination of the Detector, the Filter, and the Light Source. The Detector is the Print Medium Spectral Sensitivity, the Filter and the Light Source are what is in the printer.

The Printing Density Responsivity has been standardized in SMPTE RP 180.

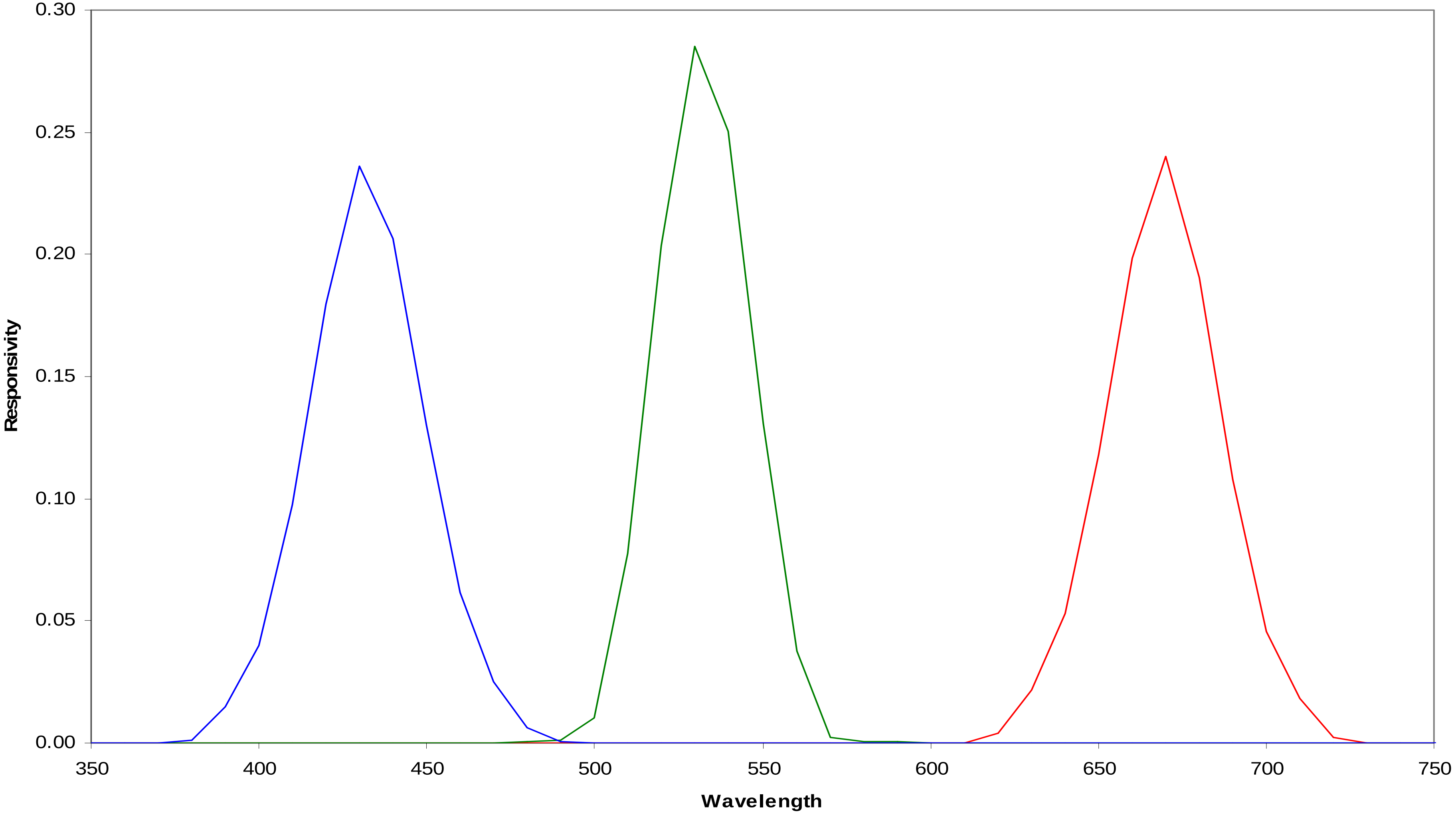
$$I_0 = \Sigma_\lambda \text{ Responsivity}(\lambda)$$

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

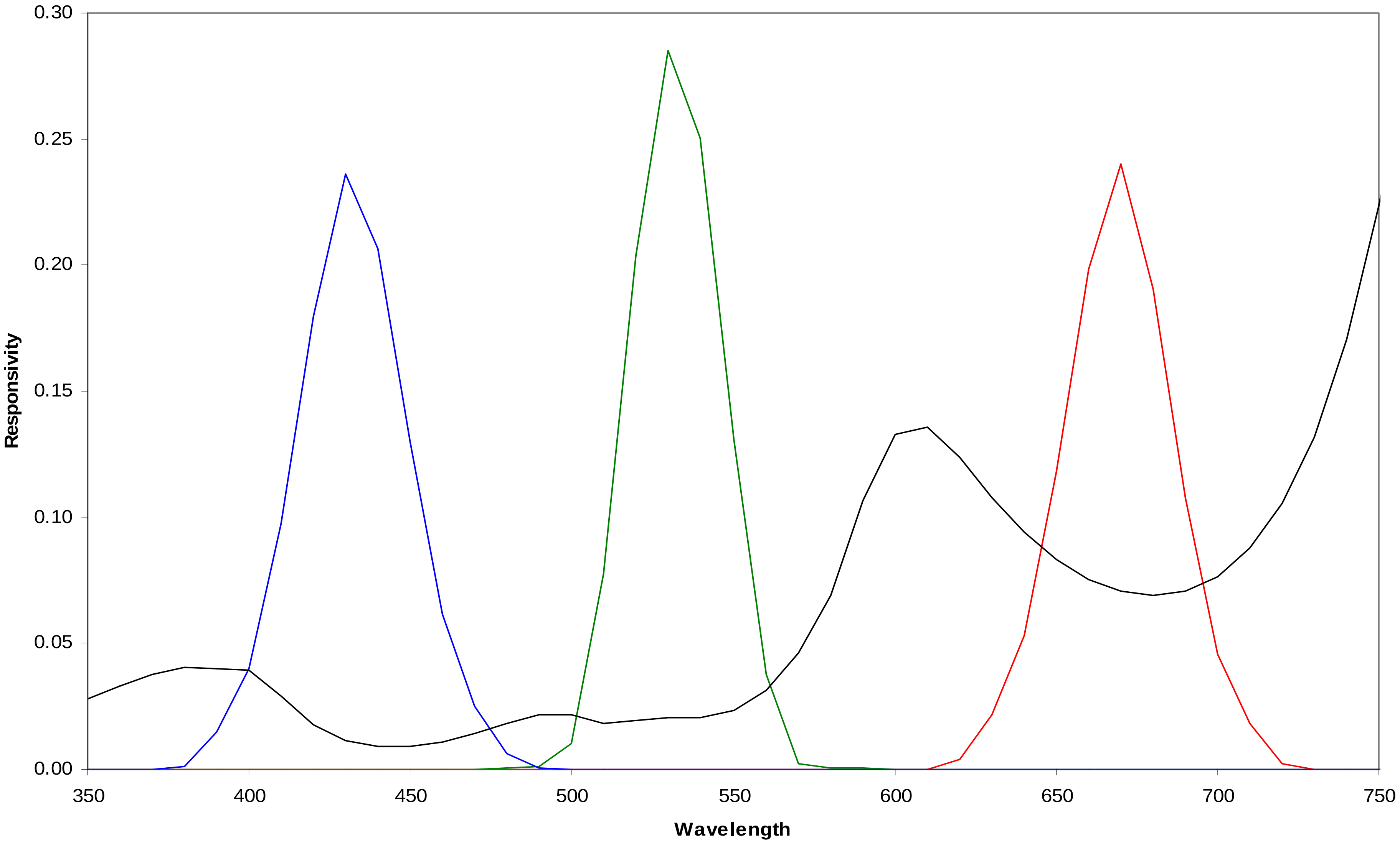
$$\text{Transmittance Factor, } T = I_t / I_0$$

$$\text{Density, } D = -\log10(T) \qquad T = 10 \wedge -D$$

RP 180 Printing Density Responsivity



Film and RP 180



Calculation of Printing Density

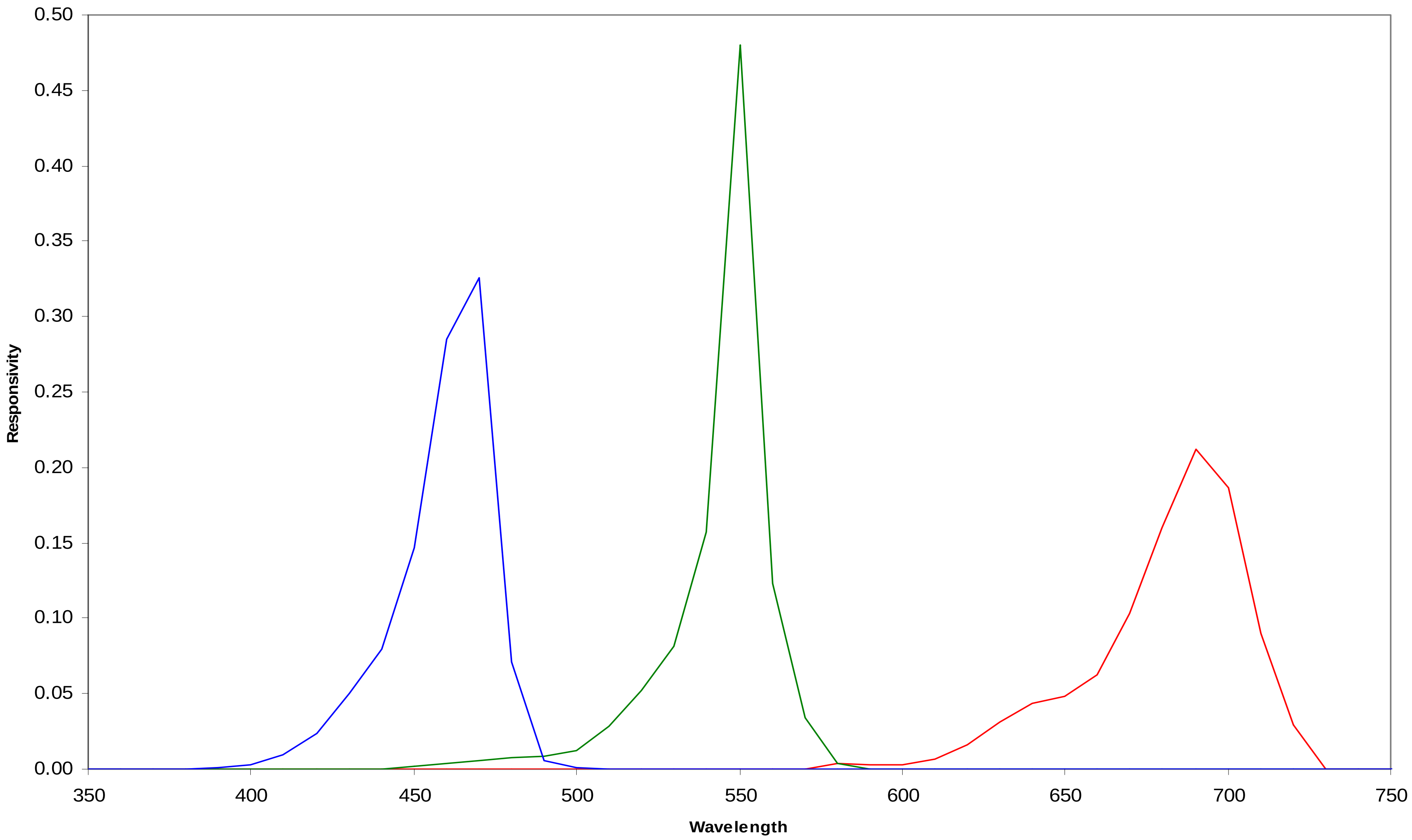
Green Printing Density Only

Wavelength	RP180	Film T	RP180 * Film T
400	0	0.0393	0
410	0	0.0291	0
420	0	0.0179	0
430	0	0.0113	0
440	0	0.0094	0
450	0	0.0094	0
460	0	0.0111	0
470	0.00014	0.0143	0
480	0.00034	0.0182	0.00001
490	0.00140	0.0219	0.00003
500	0.01043	0.0216	0.00023
510	0.07733	0.0182	0.00141
520	0.20379	0.0193	0.00393
530	0.28494	0.0205	0.00584
540	0.25015	0.0207	0.00518
550	0.13062	0.0236	0.00308
560	0.03753	0.0314	0.00118
570	0.00225	0.0461	0.00010
580	0.00071	0.0692	0.00005
590	0.00037	0.1067	0.00004
600	0	0.1331	0
			sum = 0.02108
			pd = 1.67618

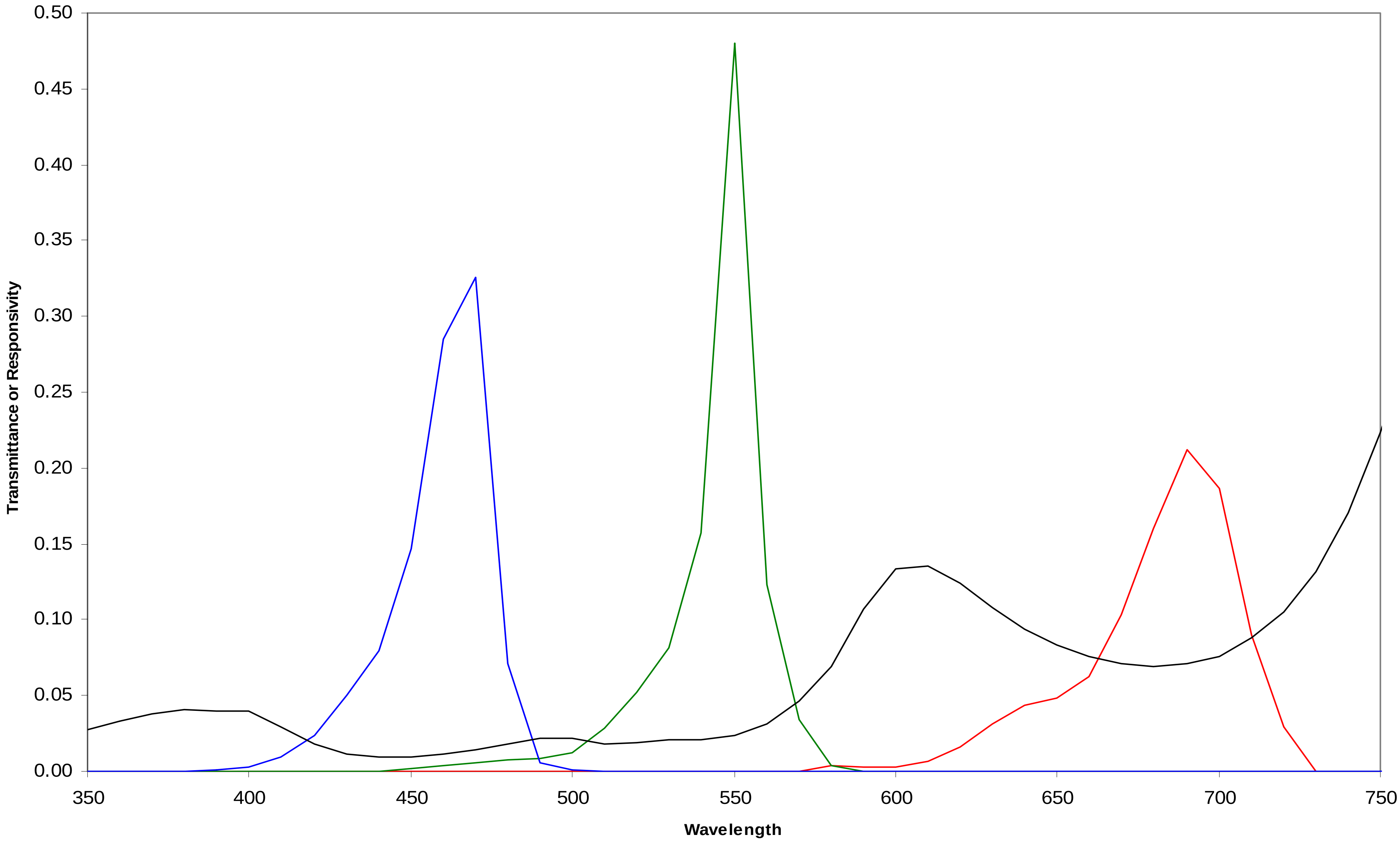
Calculation of Printing Density

However, if we calculate the Responsivity of a Print Film using more current data, we find some differences between RP 180 and the more current data in the calculation of Printing Density.

Current Printing Density Responsivity



Film and Current Responsivity



Calculation of Printing Density

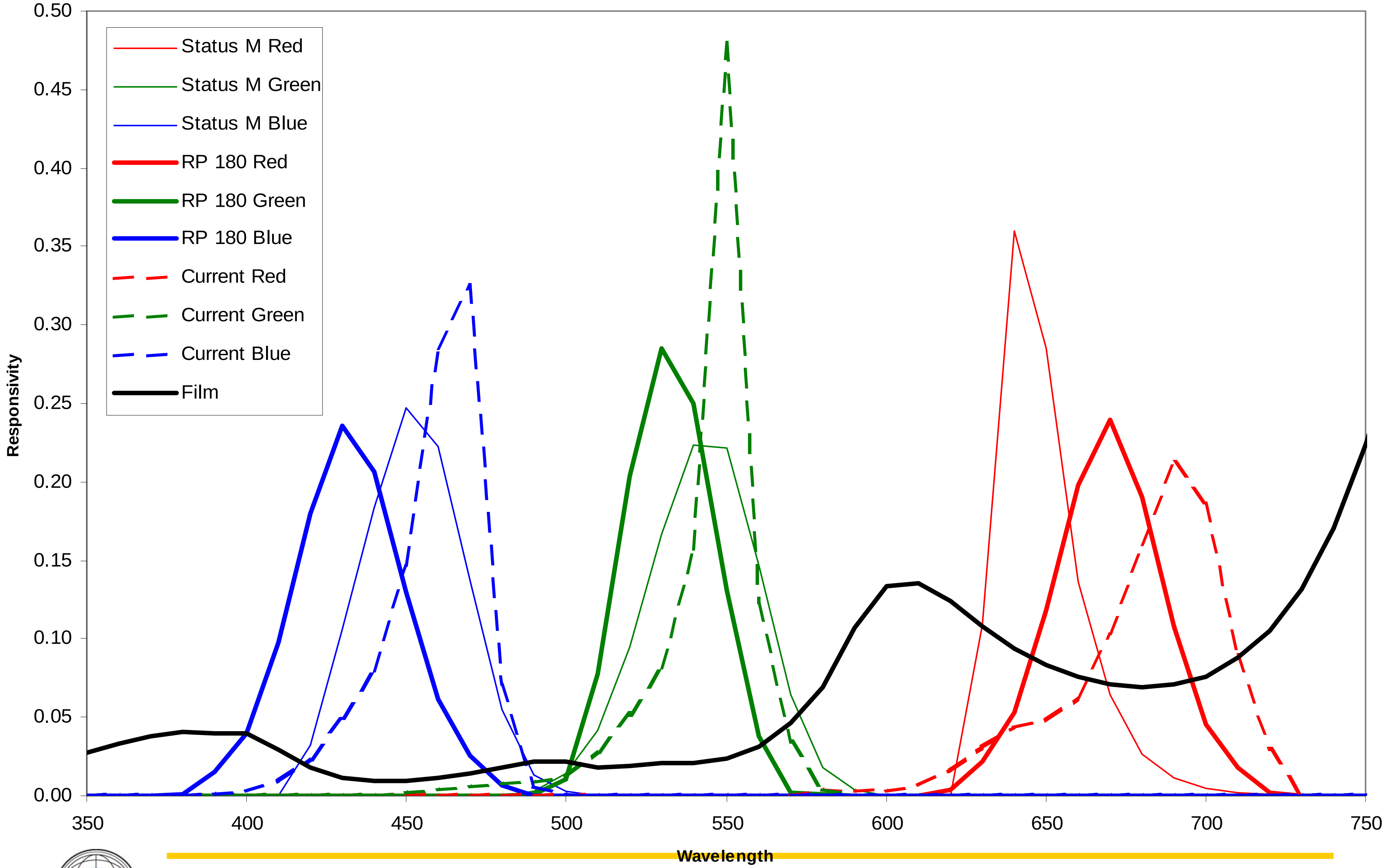
Green Printing Density Only

Wavelength	Current	T	T * Current
400	0	0.0393	0
410	0	0.0291	0
420	0	0.0179	0
430	0	0.0113	0
440	0	0.0094	0
450	0.00188	0.0094	0.00002
460	0.00342	0.0111	0.00004
470	0.00564	0.0143	0.00008
480	0.00757	0.0182	0.00014
490	0.00834	0.0219	0.00018
500	0.01228	0.0216	0.00027
510	0.02882	0.0182	0.00052
520	0.05255	0.0193	0.00101
530	0.08181	0.0205	0.00168
540	0.15690	0.0207	0.00325
550	0.47994	0.0236	0.01133
560	0.12284	0.0314	0.00386
570	0.03446	0.0461	0.00159
580	0.00343	0.0692	0.00024
590	0	0.1067	0
600	0	0.1331	0
			sum = 0.02420
			pd = 1.61618

Summary of the Calculations

Calculation	Red	Green	Blue
Status M	1.058	1.593	1.935
RP 180	1.121	1.676	1.816
Current	1.104	1.616	1.894

Combined Plots



Comments about Printing Density

- With black-and-white film, there is only one spectral sensitivity and one printing density.

- With a color film, there are commonly three spectral sensitivities that produce three printing densities.

- The camera negative transmittance is always greater than 0 and less than 1. Thus the minimum Printing Density is 0. The maximum Printing Density, although unlimited by theory, is practically about 5.

- A film patch has a fixed set of Status M and Status A densities because the Responsivity of Status M and Status A are defined by standards.

Comments about Printing Density

- A film patch does not have a fixed set of Printing Densities because that film patch can be printed onto different print media. Different print media most likely have different spectral sensitivities and are printed using different sets of lights and filters.

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

Measurement of Printing Density

- There is no Printing Density densitometer as there are Status M or Status A densitometers. Therefore, it is not easy to measure Printing Density.

- There are three methods by which the Printing Density is determined:

1. Calculations from spectral measurements

2. Calculations from Status M density measurements (or other standard density measurements

3. Photographic Photometry

Calculation from Spectral Measurements

This is the basis of the calculations already shown.

The measurements are relatively slow and the patch size needs to be relatively large.

The spectral sensitivities of the print media are very difficult to measure and probably only come from the film manufacturer.

The printer spectral power distribution including any filters must be measured. This measurement is not too difficult, but does require special equipment.

Calculation from Status M Density Measurements

This requires the Status M densities and an equation to convert them to Printing Densities.

The equation is calculated from a set of Status M densities and a set of Printing Densities from the same film. This means at some time the Printing Densities must have been measured for one set of film patches.

The equation can be a simple 3x3 matrix equation or a more complex polynomial.

Once the equation is known, the process is relatively fast and easy.

Photographic Photometry

This can be the most accurate measurement of Printing Density, requires equipment that exist in most labs or post-houses, but is a time-consuming process.

This method is based on the fact that the Status M, Status A, and Printing Densities of a material that is spectrally flat, which means has the same film transmittance at all wavelengths, are all the same.

Black & White film is not normally spectrally flat, but a carbon tablet is spectrally flat. The problem is that the carbon tablets are not supplied in 35 mm format with perforations along the edges.

Photographic Photometry

Because of the complex set of measurements and calculations that must be performed, Photographic Photometry will not be explained in detail, but a general overview will be given.

Film Patch → Print onto a print medium → Process → Measure the densities on the print medium

Spectrally Flat Patches → Print onto the same print medium → Process → Measure the densities on the print medium

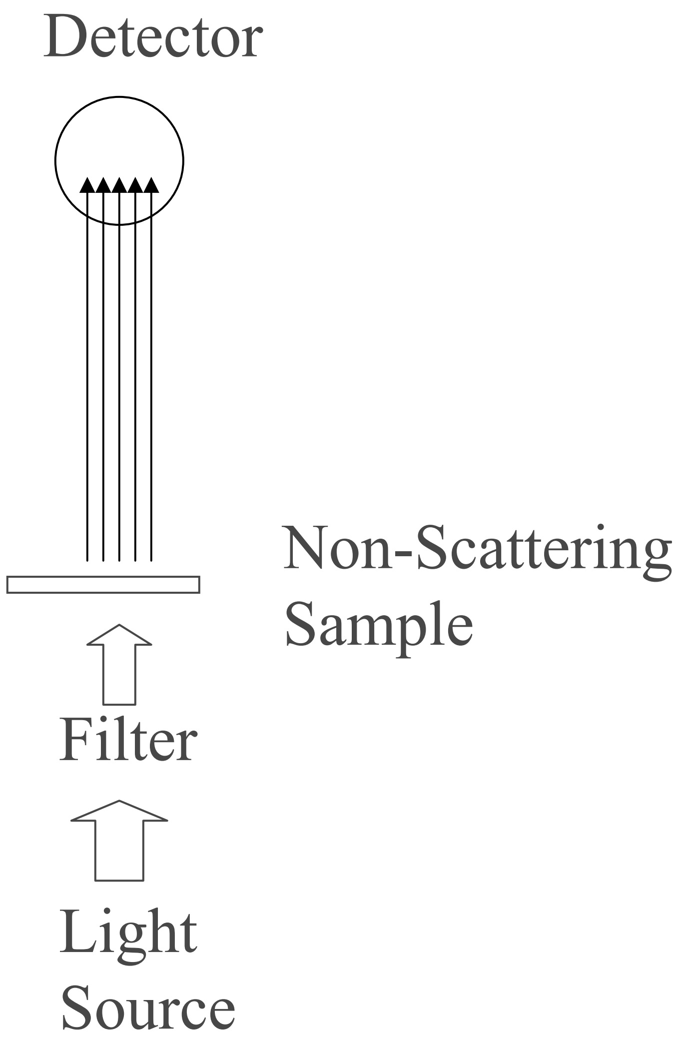
Measure the densities of the patches on the spectrally flat material. These are the printing densities of the spectrally flat material.

Photographic Photometry

Construct a table of the measured densities of the spectrally flat material (the printing densities of this material) and the measured densities of the print medium.

Using this table and interpolating if necessary, the print media densities of the patch that came from printing the film patch are converted to printing densities. This is a simple table look up operation. Those printing densities are the printing densities of the patch on the film.

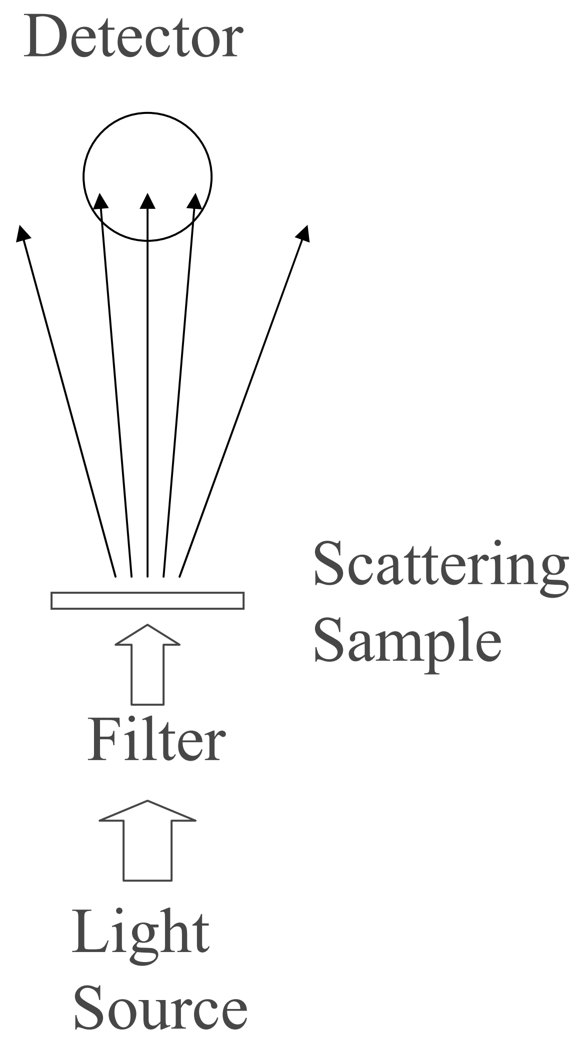
Optical Considerations



With a non-scattering material, the detector will detect the same I_t independent of the distance between the sample and the detector.

Optical Considerations

With a scattering material the detector will detect a larger I_t when the distance is small and a smaller I_t when the distance is larger.



Spectral Curves Change

There are a number of reasons the spectral curves that determine the Printing Density of a material may change

The spectral sensitivities of different print media are most likely different – for example intermediate film vs print film.

Two printers may have different filters, for example a printer with a 2B filter and a printer with a 2E filter.

The original film may change over time due to either thermal effects due to heating in the film gate or due to fading of the film dyes due to repeated exposure of the same film frame.

Standard Materials

Standard materials for printing density do not exist. Even if they did exist, they would have a standard printing density for only one printer set-up printing onto one print medium.

If it did exist, the standard material would be useful because, in most cases, there would be a simple mathematical transform between the printing densities in one condition and the printing densities in another condition.

A spectrally flat material, such as a carbon tablet, is the closest material to a standard material that we currently have.

Closed System Calibration

It is possible to do a closed system calibration in a facility

DPX_1 ➔ Record ➔ Film ➔ Scan ➔ DPX_2

If DPX_1 matches DPX_2, a facility has a closed system calibration, but that does not mean the DPX values are proportional to Printing Densities. This can work for one facility. But if the DPX values are sent from the first facility to another facility, that second facility may not produce the same film from the Record step as the first facility produced if the two facilities are not calibrated to Printing Density. Likewise the two facilities may not produce the same set of DPX values from the scan of the same film material if they are not both calibrated to printing density.

Closed System Calibration

With closed system calibration, a facility can operate quite efficiently because the scanned material and the recorded material can match. However, to calibrate a scanner to printing density without calibrating the recorder to printing density may give poorer results than having neither the scanner nor the recorder calibrated to printing density if the system is calibrated.

Printing Density Calibration

The advantage of printing density calibration is that multiple devices within a facility or even different devices across facilities will all be calibrated to the same metric. Because the metric is directly related to how the print material sees the film used to make the print, the use of data in that metric makes the system most compatible with the film system.

Kodak