# Color Film Exposure in CRT Image Recorders

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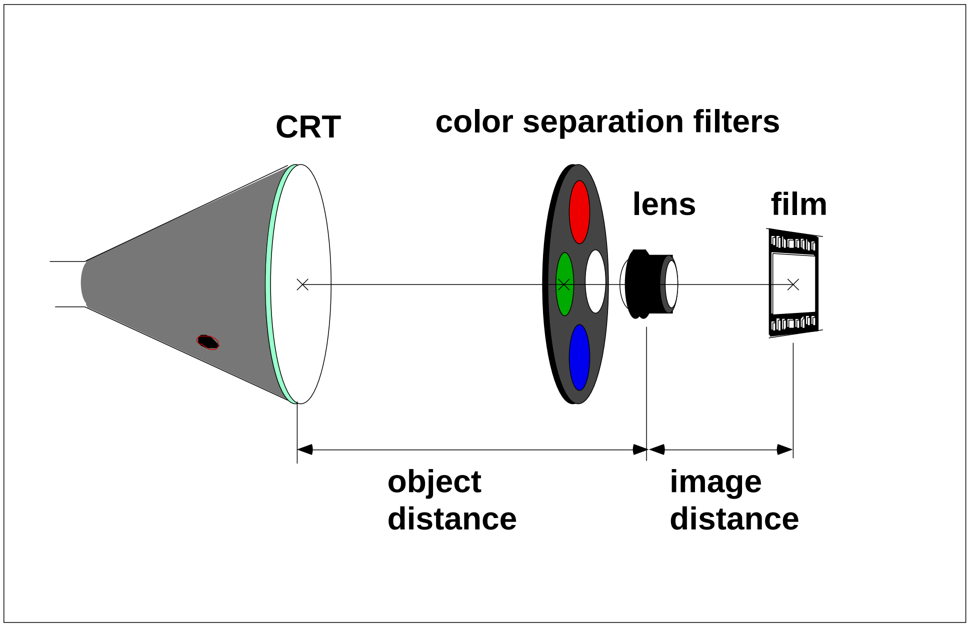
*The process of exposing color film by a CRT recorder is described In particular, the spectral relationships between the CRT light source, its color separation filters, and film characteristics are presented and discussed. Reference spectra of the Solitaire image recorders are used to illustrate the film exposure process.*

The overall process of generating color images with a digital film recorder involves many components, but the film exposure process can be described with just a few. The phosphor coating in the cathode ray tube (CRT), the color filters, and the film itself, are the optical components involved. The lens has an influence on the colors according to how tinted its elements are, and its flare characteristics, but for a good lens these are small effects and will not be considered in this overview. Figure 1 shows schematically the optical path of the film recorder and the relative physical relationships of the components.

*Figure 1. The optical path in a digital CRT film recorder.*

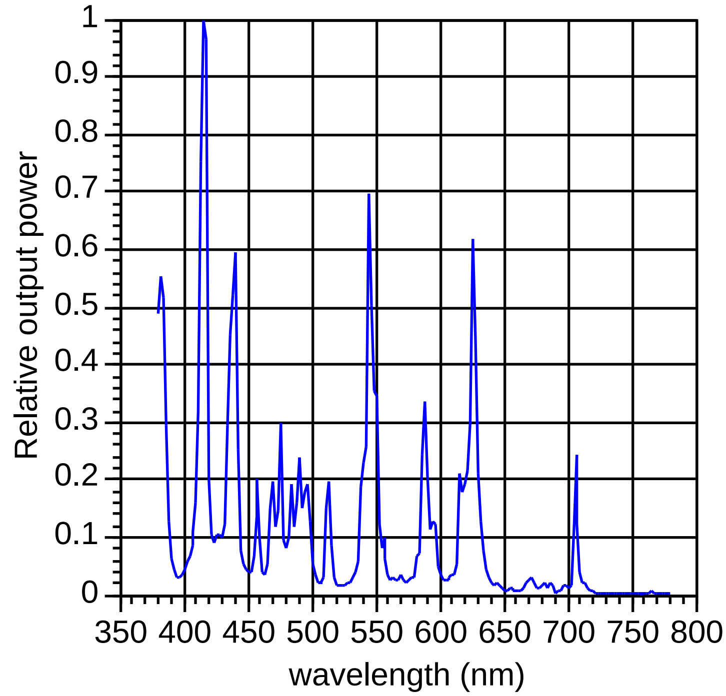


The phosphor used in the CRT generates a bluish-white light, so to create a full color picture, a triple exposure is made, each with a different color filter placed in front of the lens. The first pass lights up the image areas containing the red component of the image while the red filter is in place. The second energizes the green areas of the picture with the green filter in position. Finally the blue components of the image are exposed through the blue filter.

From the film's perspective, it has been exposed by three separate red, green and blue colored images. It acts to integrate the three exposures and when developed, will result in a full color picture. The colors that result are a function of the spectral characteristics of the phosphor, the filters, and the spectral sensitivity and behavior of the film.

The optical energy that ultimately ends up at the film starts out in the phosphor screen in the CRT. Electrons bombard this surface and their energy is converted to light having a spectral distribution that depends on the chemical composition of the phosphor. The spectral output of a Solitaire-16 (also Cine, Sapphire, and Opal) film recorder is shown in figure 2.

*Figure 2.*
*The spectral power output of the Solitaire image recorder phosphor.*

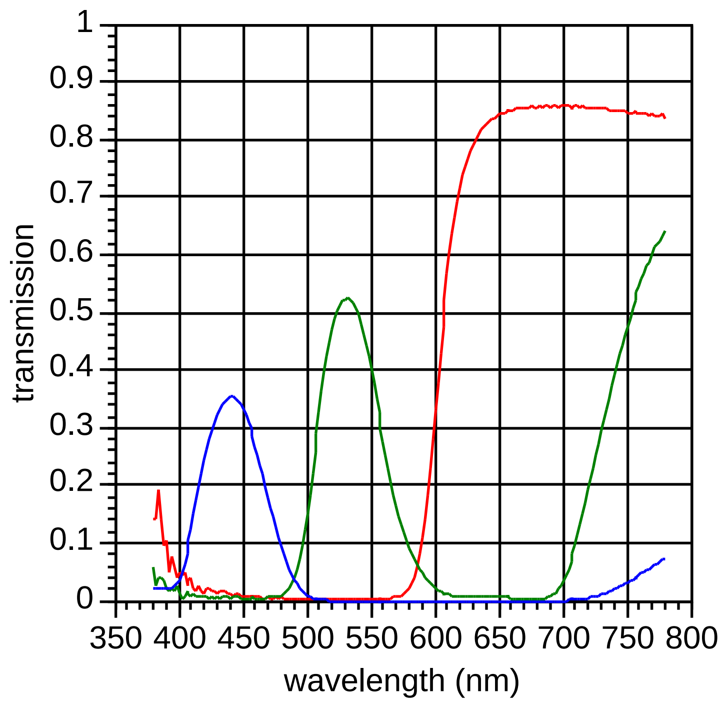



There are several interesting things to note about this spectrum. Unlike the smooth, continuous spectrum of an incandescent light source, the phosphor produces light which is "spiky"; it has high output levels at distinct wavelengths with regions between them which are quite low. This characteristic will be helpful in separating the three distinct color exposures. The largest outputs are at wavelengths of 380 nm (ultraviolet), 420 and 440 nm (perceived as blue), 545 nm (green), and 625 nm (red). The relative strengths of these output spikes and their distribution across the spectrum results in the overall light being perceived as white, with perhaps a hint of a pink or purple tint.

The spectrum shown above is known as a spectral power density function, since it shows the distribution of optical power delivered by the phosphor over a range of wavelengths. An exposure is basically the delivery of an amount of *energy* to the film, it is achieved by maintaining a phosphor power output level for a given time duration. In this discussion it is convenient to think of the exposure time as being constant from pixel to pixel. This results in the delivered energy (the exposure) being proportional to the optical power. We can interpret the spectral power density plots as also representing the delivered spectral energy density for a given exposure time.

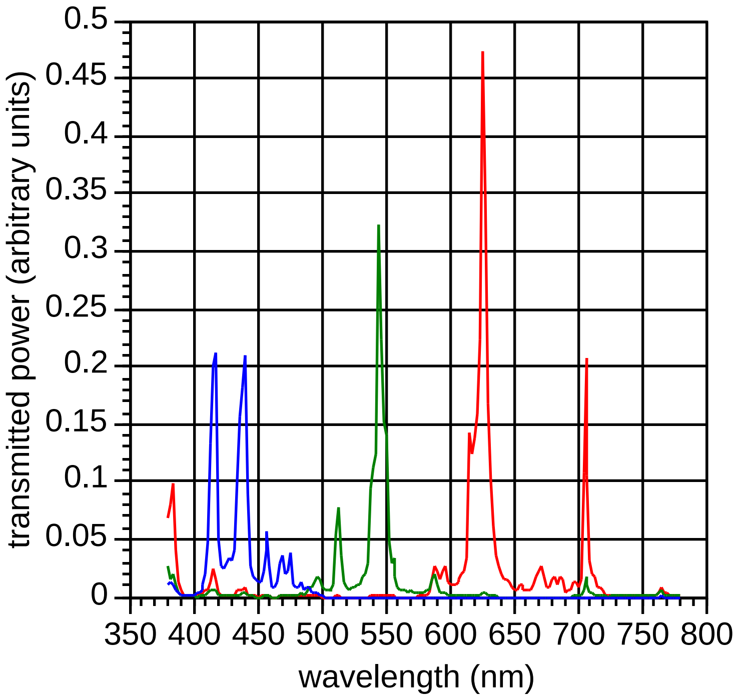
The light generated by the phosphor is filtered before passing through the lens and reaching the film. The filters that are used in Solitaire are designed to isolate the major spikes of the spectrum into three separate color bands, red, green and blue. The filters are similar to three standard color separation filters used widely in the graphic arts industry, the Kodak Wratten filter set #25 (red), #58 (green) and #47B (blue). A plot of their spectral transmission characteristics is shown in figure 3.

*Figure 3. The color separation filter characteristics. These are similar to Wratten filters 25, 58, and 47B.*




When filtered, the spectral spikes of the phosphor are effectively isolated into their respective bands. Figure 4 shows the result of filtering the phosphor spectrum. There are three distinct spectral curves in this plot representing the energy passing through each of the three color separation filters.

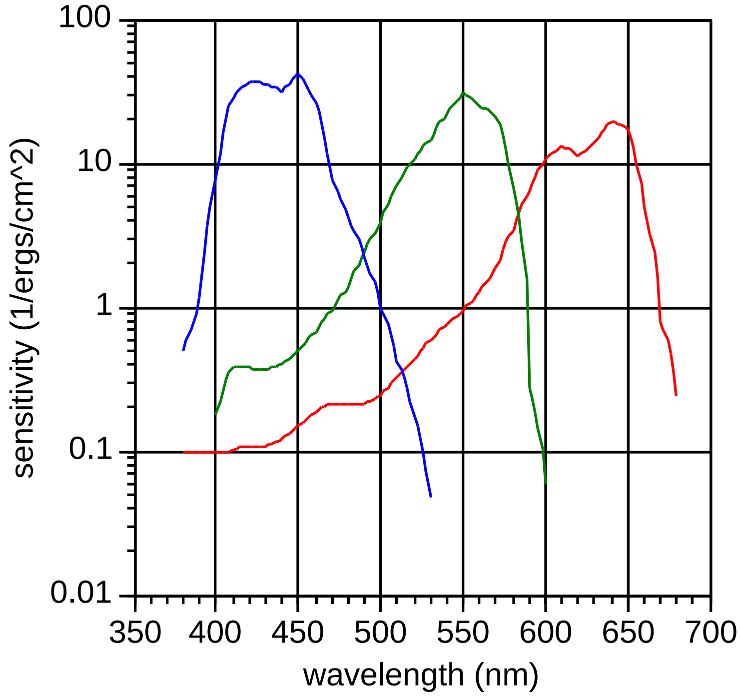
*Figure 4.*
*The filtered phosphor spectra corresponding to the three color pass exposures.*




The effectiveness in exposing color film depends on how well the separated bands of light energy match up with the corresponding film sensitivity curves (figure 5). Each of the curves represents the spectral sensitivity of one of the color layers in the film. The sensitivity can be considered as a film's efficiency at converting the light energy into a dye concentration.

The relative heights of the three curves determine the "color balance" of the film. Daylight balanced film has roughly equal sensitivities while tungsten balanced film has a significantly lower red sensitivity (since incandescant lights deliver so much power in this part of the spectrum).

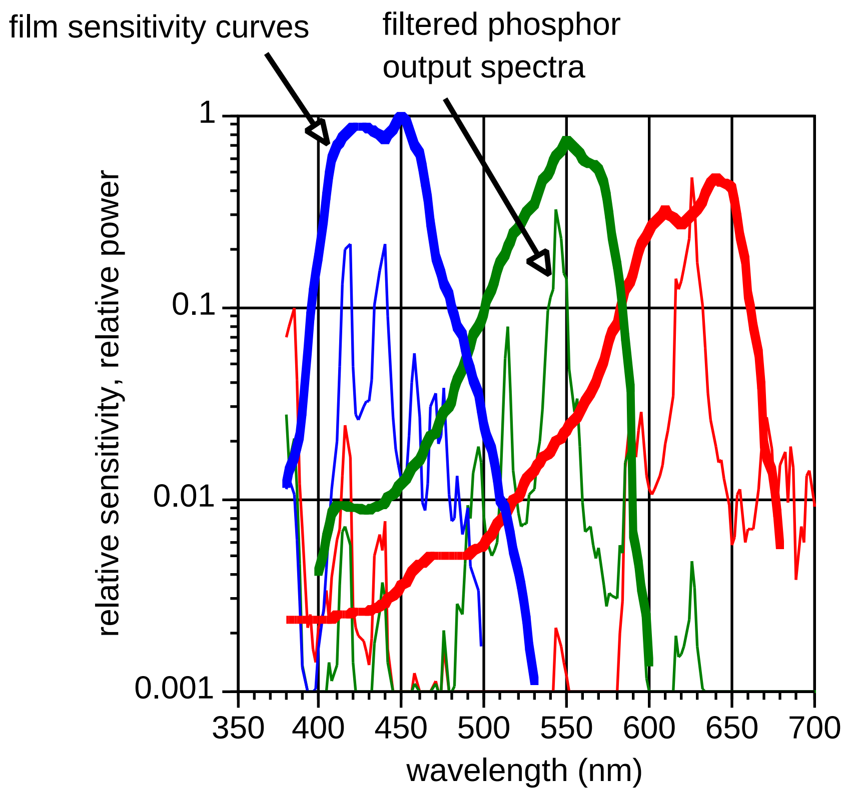
*Figure 5.*
*Film sensitivity curves for EOF, an Ektachrome based color reversal film.*




If the filtered light power spikes land at the peak sensitivity wavelengths of each film layer, and there is very little "out-of-band" energy, good color saturation of the developed film will result. Conversely, if the energy does not land near the peak, but exposes more than a single film layer, it will not be possible to achieve fully saturated colors. Figure 6 shows the relationship between the film sensitivity and the exposure spectra.

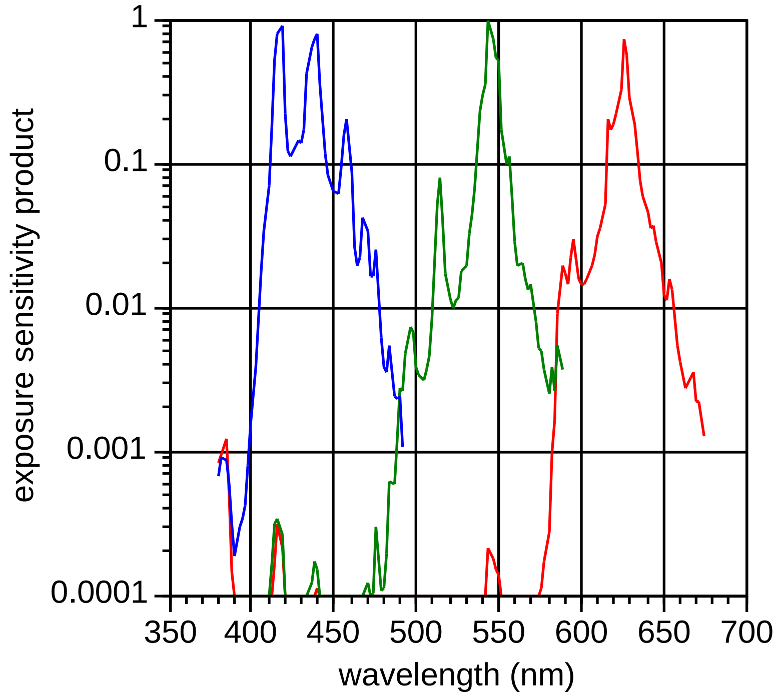
To achieve saturated colors, the film recorder must effectively expose just one of the three layers without exposing the others. Perfect saturation is impossible of course, because the layer sensitivities overlap. There will always be a small amount of exposure to the other layers. Additional unwanted exposure results if the color filters let through light energy in one of the other color bands. This would expose a color layer other than the one intended through that filter.

*Figure 6.*
*Film sensitvity curves overlaying the color separated phosphor spectra.*




The *effective exposure* of the film is the product of the sensitivity curves and the exposure spectra (figure 7). When the CRT is driven at a constant fixed level for each of the three color passes, these exposure-sensitivity product curves represent the effective exposure of the film that results.

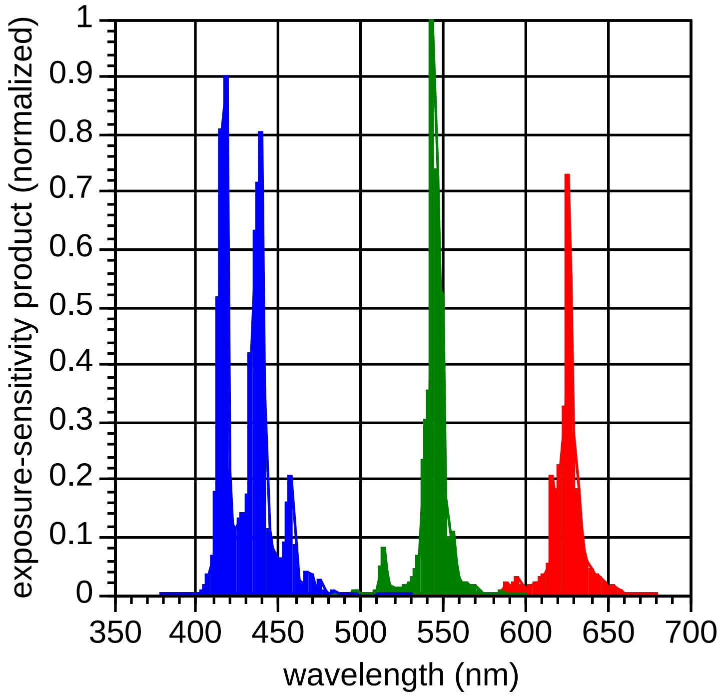
*Figure 7.*
*The exposure-sensitivity product between the film and the filtered light power (log scale).*




It can be seen that the three color exposure passes are successfully isolated. There are slight amounts of cross exposure (where the exposure-sensitivity product is nonzero in one of the other two color bands), but they are restricted to energy densities less than 1% of the peak.

The area under each of the curves represents the total exposure for each color pass. A more accurate visual assessment of these exposures is provided by the linear plot in figure 8.

*Figure 8.*
*The exposure-sensitivity product between the film and the filtered light power (linear scale). The integrated areas under the curves are the net energies utilized by the film.*




In order to result in a neutral color, the integrated total exposures need to be approximately equal. To achieve a neutral gray, the CRT must be driven at slightly different levels for each color pass. This is the job of the lookup table loaded into the film recorder. It contains the CRT drive levels for each of the three color passes so that equal inputs results in equal visual densities of the dye layers in the film, effectively achieving the correct color balance for the filtered CRT light source.

The curves presented here show a particular imaging situation. The phosphor response will be identical for nearly all but the very oldest models of MGI film recorders, but the color separation filters used will differ depending on the camera module. The example here used the filter set found in the medium-format and Cine-class cameras.

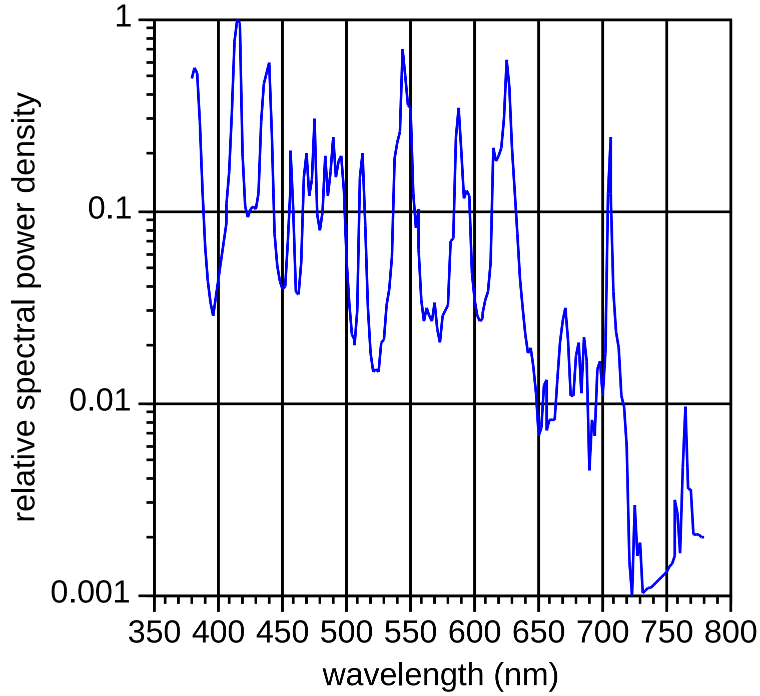
Probably the largest variations are found in the film types. Each has its own particular spectral response according to what that film was designed for. The largest differences are found between daylight and tungsten balanced film, but even the variations in film marketed as "daylight balanced" are considerable. Their behavior and response to the phosphor output spikes could be quite varied from film type to type, and manufacturer to manufacturer.

The behavior of film in response to three successive, fairly lengthy (minutes) color-separated raster-scanned exposures is very complex. The exact colors that result cannot be predicted precisely without further details about the film, but the spectral characteristics shown here are very important in understanding and optimizing the color exposure process. The physics involved at this stage is the first step toward a full model of the digital color imaging process.

**Appendix: Additional plots of phosphor and filter spectra.**

Here are some supplemental plots to document the phosphor and filter responses of Solitaire family of image recorders. The first (figure A1) shows the phosphor response on a log scale.

*Figure A1.*
*The spectral power density of the phosphor screen in Solitaire image recorders (log plot).*



The filter transmission characteristics can also be plotted on log scale. Figure A2 is the filter set used in the following camera modules:

Cine-TG FLX
70mm TG
65mm TG
120/220 TG

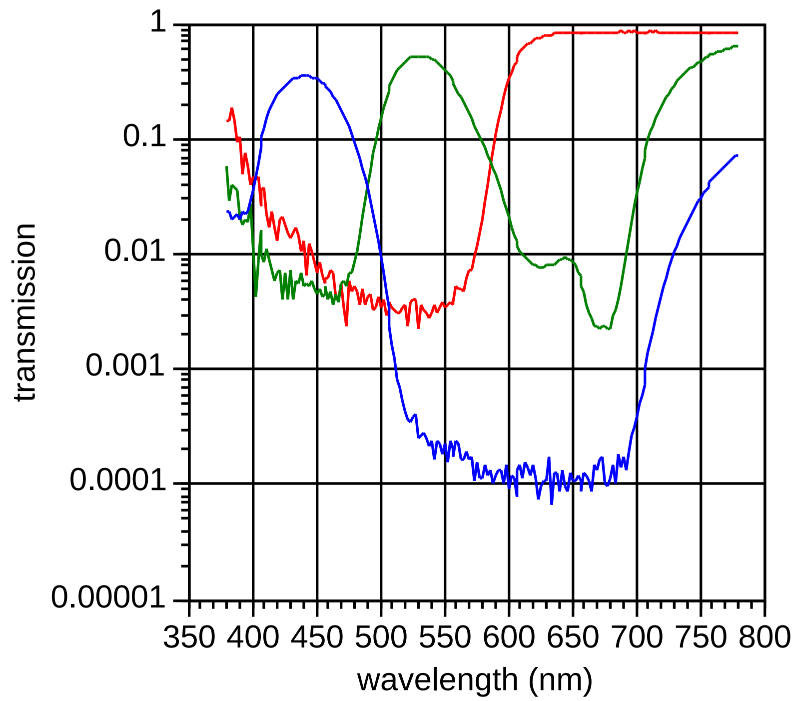



*Figure A2. The transmission characteristics of Cine-TG FLX and other medium format TG camera modules (log plot).*

There is a similar set of filters used in many of the other Solitaire camera modules. The difference is that the blue filter response is attennuated by 15dB. The peak transmission level is reduced from 35% to 25%, a factor of 0.708. This 1/2 stop reduction helps balance the strong blue component of the phosphor against the green and red levels for many film types. The camera modules that use this set of filters include:

120/220
4x5 CP
4x5 TG
8x10 CP

The filters used in the Opal film recorders are of a different technology and have slightly different spectral characteristics. These are shown in figure A3 and A4.

*Figure A3.*
*The transmission characteristics of filters used in the Opal film recorder.*

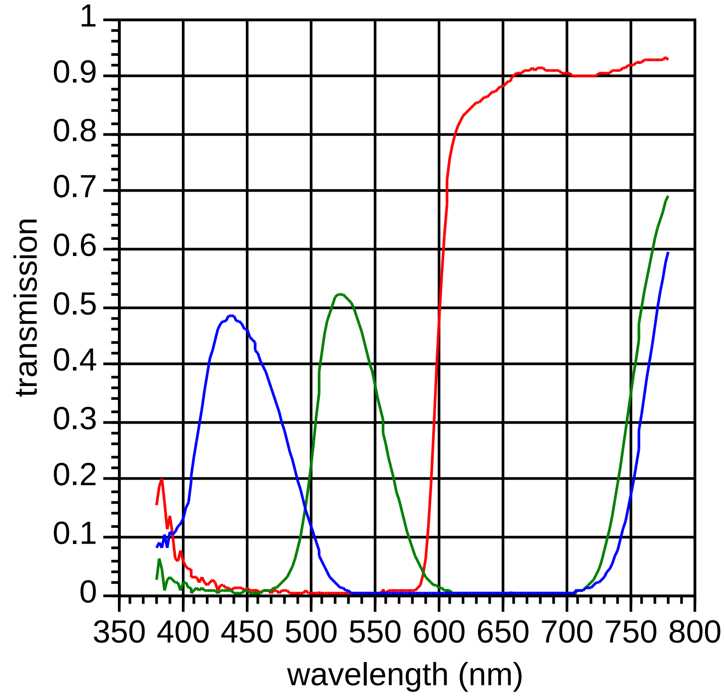



*Figure A4.*
*The transmission characteristics of filters used in the Opal film recorder (log plot).*