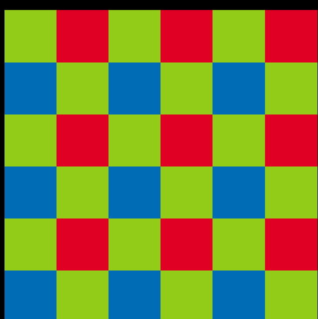
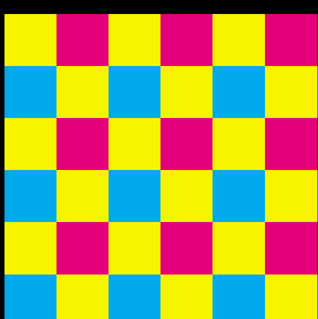
Better COLOR through CMY filters



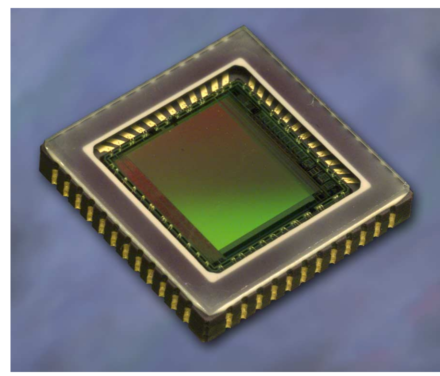
RGB (Red-Green-Blue)



CMY (Cyan-Magenta-Yellow)

One of the most popular patterns for the color filter arrays (CFAs) used in image sensors is the three-color checkerboard pattern invented by Dr. Bryce E. Bayer[1], an Eastman Kodak scientist, more than twenty-five years ago. In his original patent, Dr. Bayer suggested that either of two color schemes could be employed for capturing multi-color information with a camera's sensor: RGB (Red-Green-Blue) or CMY (Cyan-Magenta-Yellow).

Until recently, however, only the RGB pattern has been employed due to issues with color fidelity and sensor manufacturing, although the CMY pattern has much better quantum efficiency and spectral response. CMY-based patterns have, in fact, been used in the video world for years. Now, though, due to groundbreaking advancements in sensor design and a better understanding of system noise sources, CMY deployment has become possible, bringing important advantages to the camera designer.



The major advantage of the CMY-based filter array is sensitivity. In photographic terms, this sensitivity results in superior performance across a wide range of light exposures (ISO ratings). The improvement is the result of two main attributes of the CMY CFA: better light transmission and a stronger color signal.

The CMY-based CFA owes its superior transmission to less light absorption by the color dyes than with an RGB-based scheme. In an RGB CFA system, each color is created by applying two layers of dye: one layer of yellow and one layer of magenta for red; one layer of yellow and one layer of cyan for green; and one layer of magenta and one layer of cyan for blue. In a CMY CFA system, there is only one dye color required for each basic color.

Color filter dyes are not 100-percent efficient. Ideally, they would let the light of one particular color pass through and completely absorb the light of the other colors. But in reality, they have a tendency to also absorb some of the color they are intended to pass. Since RGB colors are made up of dyes of two colors, the unwanted absorption effect is additive, reducing the amount of light passing through to the sensor compared to a CMY system.

The stronger color signal and improved signal-to-noise ratio (SNR) of the CMY-based sensor system is a bit more complicated. First, a few sensor basics-

The photoactive area of an image sensor is made up of "pixels" (picture elements), which are regions that convert light to electrical charge. This charge is proportional to the amount of light striking the pixel. During sensor readout, the charge is converted into a proportional voltage signal, which is subsequently sampled by an analog-to-digital converter (ADC).

When a camera shutter "takes a picture," each pixel is presented with an amount of light that originated in the scene being photographed. Each color in the scene is made up of different amounts of energy at particular wavelengths of light. When a pixel has a color filter placed above it, it responds more strongly to the wavelength of that particular color. The signal developed at the pixel, though, represents an "integration" (averaging togeth-

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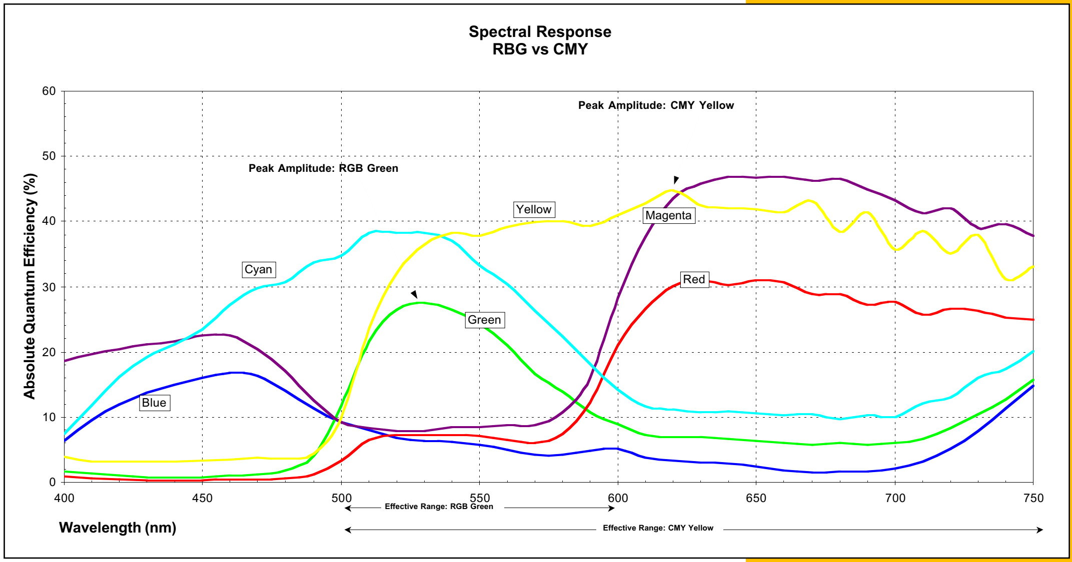
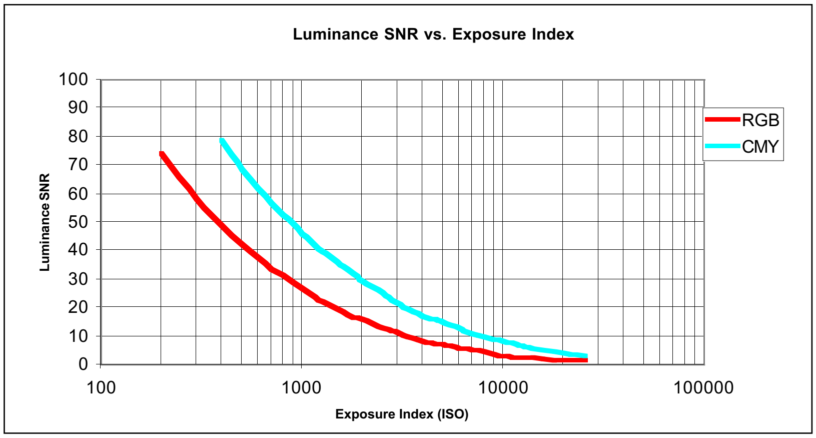
er) of all the wavelengths of light striking the pixel. For example, the green pixels in a sensor with an RGB CFA pattern respond more to green scene content, but the total green signal integrates all the energies in the entire 400- to 700-nm wavelength band.

The Spectral Response chart below compares the efficiency and operating range of sensors using RGB and CMY schemes. Two issues become evident when comparing, for example, the green response of an RGB system with the yellow response of a CMY system. First, the yellow signal has a much higher amplitude (Y axis) than the green signal: approximately 45% vs about 28% for green. This occurs because of the reduction in unwanted absorption. Second, the yellow in a CMY system is responsive to a much broader range of wavelengths (X axis) than the green in an RGB system. It provides better than 10% efficiency, for example, from a 500-nm wavelength to beyond 750-nm, while green has a far narrower 500- to 600-nm range.



If you were to shine a light source with constant energy at all wavelengths onto a sensor, the yellow signal of a CMY system would be about twice as large as the green signal of an RGB system, providing higher effective ISO. That is, it can successfully image over a wider range of exposure levels. Since the noise in the underlying sensor is constant for either type of CFA system, the CMY technique provides larger SNR which, in turn, increases the sensor's ISO range.

That's not to say that there's no downside to the CMY approach to color filter arrays, however. The color correction matrix required to convert CMY data to the RGB data required for printing or display on a monitor adds more noise than the correction matrix for RGB data. But from a total system perspective, the CMY scheme still has the advantage. Despite the additional matrix noise, because a CMY system collects light so much more efficiently than an RGB system, the total system SNR is much higher. In the Luminance SNR vs Exposure chart below, for any given Elexposure, CMY provides a higher SNR. This makes more photospace accessible than is available to RGB systems.



Footnote:
[1]The CFA Bayer pattern was filed Mar. 5, 1975, US patent number 3,971,065 and was granted July 20, 1976.

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