



SPECIAL REPORT:

HDTV lens design: Management of light transmission

By Larry Thorpe and Gordon Tubbs

Broadcast engineers have a comfortable familiarity with electronic transmission. They understand related issues of channel transmission losses, interferences, reflections, ghosts and other aberrations. The optical lens system, meanwhile, is in some sense a microcosm of the larger electronic transmission system, with many direct parallels. The optical system caters to a much higher frequency portion of the electromagnetic spectrum than does its radio/television cousin.

The multi-element lens is all about light transmission. As outlined in previous papers, skillful management of

Modulation Transfer Function (MTF) is an inherent part of contemporary lens design. So too, management of light transmission through two dozen or more optical elements is an equally

from the output optical port of the lens is a measure of the sensitivity (or optical speed) of the lens in question.

- The shaping of the spectral response of that light in its passage

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complex task. In that context, two aspects of that transmission system are of primary importance:

- The amount of light that emanates

through the many elements comprising the lens system has a direct bearing on the color gamut reproduction capability of the lens/camera system.



Challenges in HDTV studio lens design

In the management of the light flux passing through the lens optical system that forms the final image for presentation to the camera sensors, there are four core issues relating to light transmission that are inextricably

4) *Spectral transmittance* of the lens — the shaping of the light transmission between the blue and red wavelength extremities, a significant contributor to the colorimetric performance of the lens/camera system.

We will begin with the efficiency of the light transmission through the

of those elements contribute to this efficiency of light transmission.

A traditional optical measure that defines image brightness at the center of the lens output optical port is derived from the ratio of the lens' effective aperture (D) to the focal length (f). This quotient D/f is called the aperture ratio.

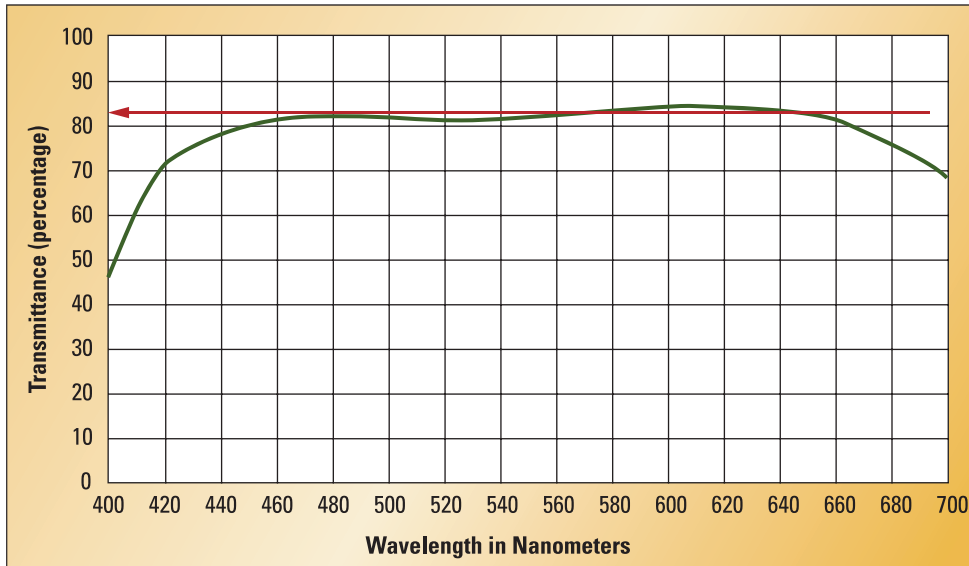


Figure 1. Spectral transmittance of a typical HD studio lens, showing both the amount of light that reaches the output port and the attendant careful shaping of the spectral response

intertwined. They are:

1) *Transmittance* of the lens — the maximum amount of light the lens can transmit.

2) *Aperture control* — the calibrated iris mechanism to precisely control the degree of light passed by the lens.

3) *Relative light distribution* — the

complex multi-element optical system that constitutes the studio lens.

The characteristic shown in Figure 1 is a typical HD studio lens specification. It shows the spectral transmittance characteristic of an HD lens that exhibits an average transmittance of 82 percent. For a lens comprising in excess

of the light transmitted by the lens to the HD camera image sensors. This, in turn, facilitates the management of the lens/camera dynamic range when imaging scenes that have enormous contrast ranges.

In the traditional television or video world, these calibration steps are termed F-numbers, and the nature of this control is known as a geometric aperture system. The actual value of the F-number is the inverse of the aperture ratio — in other words, f/D .

The true merit of the F-number calibration is its accurate depiction of *changes in light level* for a given lens system.

inescapable limitation of an optical system. It curtails the degree of light transmitted at the peripheries of the image relative to that at the center of the lens optical system.

of 30 separate optical elements, this is an impressively high number. Powerful computer-aided design, advanced optical element materials and exotic multilayer optical coatings on each

Geometric aperture

The F-number expresses the optical speed of the lens on the assumption that 100 percent of the incident white light is transmitted through the lens. This is impossible in the real world of lens design, as indicated in Figure 1.

Aperture: Both geometric and photometric

The studio lens has a built-in mechanical iris system that facilitates remote control of the amount of light transmitted by the lens. This is a mechanically variable opening, or aperture, that alters the diameter of the group of light rays passing through the lens. It allows a known degree of control over the brightness of the image being formed at the lens output port. This important operational control is calibrated to facilitate the precise management

For video shooting, this is of no great importance. The true merit of the F-number calibration is its accurate depiction of *changes* in light level for a given lens system. F-number values are expressed as a geometrical series starting at one with a common ratio of square root of two as follows:

1.0, 1.4, 2.0, 2.8, 4.0, 5.6, 8.0, 16.0, 22.0, 32.0

Each doubling of the number indicates a precise halving of the previous

light passed by the lens, and lenses for film cameras have long employed an alternate calibration system known as photometric aperture. The new cine lenses for digital cinematography cameras also employ this method of calibration — one that is described by T-numbers. T-number values take into account the reality that 100 percent of the incident light is not passed through the lens. The values carefully factor in the transmission efficiency percentage of the lens. Therefore, any two lenses having the same T-number *will* have

built. The amount of this fall-off is proportional to the cosine of the angle (at which the light rays are entering with respect to the optical axis of the lens) raised to the fourth power.

Vignetting is caused by the physical fact that the lens mechanical barrel eclipses part of the peripheral light, which causes a 360-degree darkening of the edges of the optical image. This can be eliminated if the diameter of the lens optics is sufficiently increased. Accordingly, it is less a challenge with the larger studio lens than it might be with the necessarily smaller diameter portable EFP/ENG lenses. Vignetting also decreases as the lens is stopped down. This also improves the relative light distribution problem.

T-number values take into account the reality that 100 percent of the incident light is not passed through the lens.

amount of light exiting the lens-output port. This relationship has long served the broadcast studio operation well. It is important to remember, however, that given that the spectral transmittance of lenses made by different lens manufactures invariably will *not* be the same, any two lenses having the same F-number may actually have different optical speeds. This needs to be carefully accounted for in side-by-side tests between different lenses using appropriate light meters.

Photometric aperture

The moviemaking world has always been cognizant of the true amount of

identical optical speed. A later paper will explain this calibration in cine lenses for digital motion picture cameras.

Relative light distribution

Relative light distribution is a familiar term to optical designers, and it refers to a physical phenomenon that is sometimes called peripheral illumination. The specified lens F-number indicates the brightness of a lens at the center of the optical axis. The brightness at the edge of the image is invariably less (due to the unavoidable vagaries of optical physics) and is expressed as a percentage of the center illumination. This peripheral illumination is affected by (a) the Cosine 4th Power Law and (b) optical vignetting.

The Cosine 4th Power Law, familiar to optical designers, states that the rate of light fall-off in peripheral areas of the image (peripheral illumination) increases as the angle of view increases. This is true even for a perfect lens, if such could be

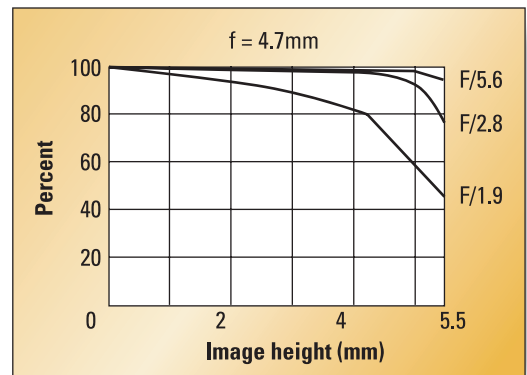


Figure 3. The relative light distribution behavior for a typical HDTV studio lens at one specific focal length

Relative light distribution is expressed as a percentage ratio between the center image brightness and that of off-axis points. This is traditionally specified along the radial termed image height, as shown in Figure 2. A typical published specification for this optical brightness distribution is shown in Figure 3.

As is clear from Figure 3, the light-distribution shortfall is more acute when the lens operates at maximum aperture (with iris wide open). The light distribution characteristic will alter when the focal length is changed, and the effect will increase toward the wide-angle setting.

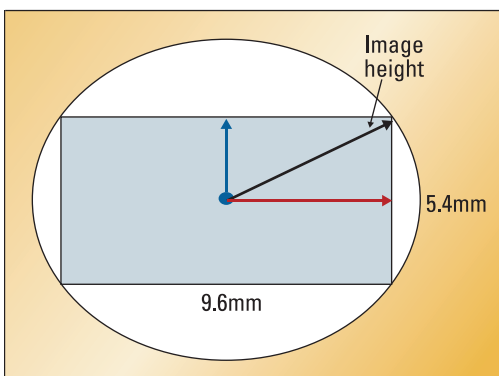


Figure 2. Shows how the light distribution is measured relative to the light level at picture center on a 2/3in HDTV optical image



Spectral response and color reproduction

The goal of the lens-design team is to achieve a lens design that transmits the maximum amount of light, or, in other words, to minimize the attenuation of the amount of light entering the front port of the lens as this flux passes through all 30-plus optical elements. At the same time, those many elements that comprise the lens system must be optimized so that they work in concert to shape the spectral response of the output light flux, predetermining the color reproduction of the system. It does this by closely correlating with the separately specified spectral response of the camera prism beam splitter and the spectral response of the camera's CCD (or CMOS) imager.

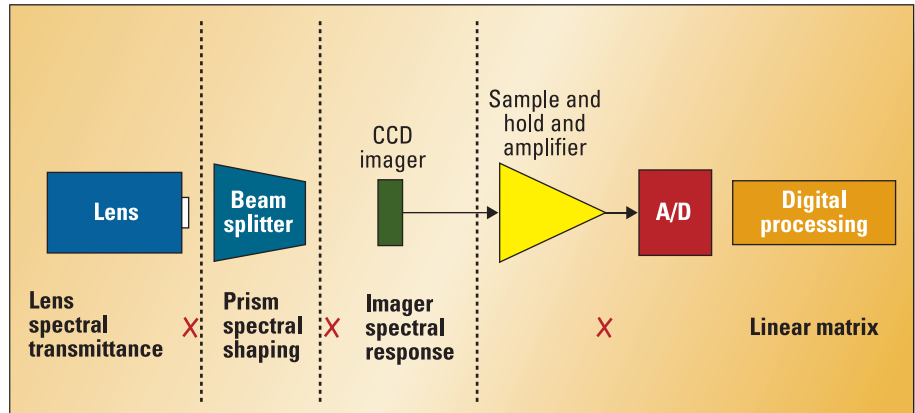


Figure 4. The four core elements of the HD lens/camera system that determine the colorimetry prescribed in the ITU-709 and SMPTE 274M/296M HDTV production standards

be reproduced by the lens/camera imaging system. The proprietary design techniques used by each optical manufacturer will invariably produce variances in this color gamut capabil-

being wrought by different associated camera makers.

But, the challenge does not end there. We'll see in the next paper, while managing all of these design variables, the designer must simultaneously wrestle with an extensive list of optical aberrations and distortions that also vary — sometimes in a quite contrary manner — when the lens operational controls are exercised.

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The lens spectral transmittance curve is designed in close collaboration with the major camera manufacturers because it must accommodate subtle variations in their respective shaping of their camera optical beam-splitter characteristics, the spectral response of their individual CCD (or CMOS) imagers (and associated IR cutoff filters), and the final design of their respective linear matrix circuits, which ensures that the overall lens/camera system colorimetric response meets the published standards of SMPTE 274M/296M and ITU 709 — as outlined in Figure 4.

While attempting to meet the nominal specifications contained in the standards, which, incidentally, have no published tolerances, the lens designer also seeks to implement a spectral characteristic that will maximize the total range of colors that can

ity — and this can only be evaluated by careful subjective testing (a topic of a later paper).

Summary

As stated in our second paper in this series, the contemporary lens is an engineering marvel. Our previous papers exposed the challenge posed to the optical designer in the all-important domain of preserving high image sharpness while the camera operator is exercising zoom, iris, and focus operational controls.

At the same time, as these factors are being optimized, the designer is preoccupied with eking out every degree of transmission efficiency possible to raise the optical sensitivity of the lens. And, at the same time, the careful shaping of that spectral transmission characteristic must be crafted in sync with the separate design optimizations

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