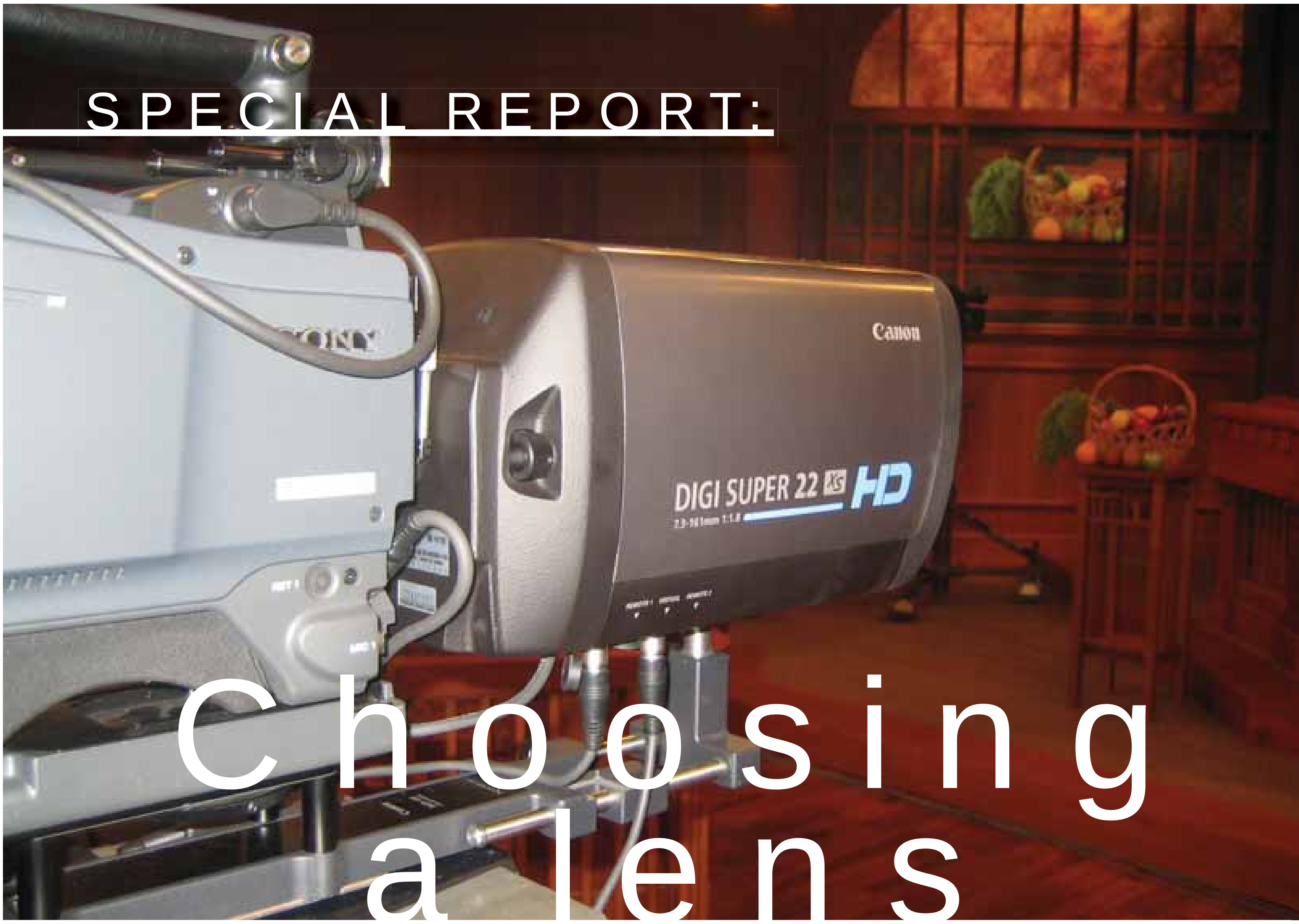

Choosing a lens
for the new HD studio

BY LARRY THORPE AND GORDON TUBBS

As broadcasters across the country turn their attention to incorporating HD news programming as part of their overall DTV services, questions invariably surface with respect to the related cameras, camcorders and associated lenses. Within the studio, capital budget imperatives will entail close examination of those core HD products and associated accessory systems, such as robotics, pedestals and teleprompters.

Deploying portable HD production cameras is increasingly popular because they produce equal picture quality to their larger hard studio camera counterparts at a lower cost. Having committed to such an HD portable camera, many broadcasters naturally ask if an HD portable EFP/ENG lens will suffice. Given the non-trivial cost differential between all HD studio lenses and portable HD lenses, this is a quite understandable question.

The primary difference

Studio lens design criteria are different from those for portable EFP/ENG lenses. The latter has a central imperative of producing a lens that is lightweight and mobile (less than 5lbs being an industry expectation) when coupled with a camcorder or other portable camera. Significantly lowering the size and weight of a lens imposes restrictions on optical optimization (optics is very physical).

The studio lens, on the other hand, typically puts aside issues of size and weight and instead assigns its first priority to achieving the highest overall optical performance. Larger glass elements and more glass elements are central to attaining this higher level of image performance. As a consequence, a typical studio lens will weigh more than 40lbs.

Expectations of overall lens performance

There are many dimensions to HD lens performance, including optical sensitivity, sharpness, contrast ratio and color reproduction. The lens design also seeks to minimize the multiple distortions and aberrations inherent to all optical elements. Formally specifying such imaging parameters involves a great deal of data, and accordingly, all lens manufacturers have shunned publication of this data in product literature. Regrettably, this

Photo: Suppose, for cost reasons, you buy HD portable cameras for your new studios. What are the trade-offs if you use portable HD lenses on them? There are significant quality issues to consider before making this choice.

Picture performance attribute	HD studio lens	HD EFP/ENG lens
Sensitivity	Very high	High
Relative light distribution (Evenness of brightness across image plane)	Very good	Good
Black reproduction	Excellent	Very good
Contrast ratio	Very high	High
Chromatic aberration	Tight control	Controlled
Image sharpness (at picture center)	Very high	High
Image sharpness (at picture corners)	High	Reasonably high
Focus breathing (Change in angle of view as focus is adjusted)	Almost zero	High (with ENG lens) Moderate (with EFP lens)

Table 1. The attributes that produce final image quality in the studio HD lens and the EFP/ENG portable lens

obfuscates the essential performance differences between the HD studio lens and the portable EFP/ENG lens.

Overall lens performance can be distinguished by two primary attributes:

• *Image clarity* — an interrelationship between optical black reproduction, color reproduction, brightness, relative light distribution and contrast ratio.

• *Image sharpness* — an interrelationship between contrast, resolution, defocusing aberrations and chromatic aberrations that are the essence of the high-definition viewing experience.

HD portable EFP/ENG lens design has advanced in recent years, and the performance of these lenses is remarkable, given the severe physical constraints imposed upon them. It is, however, physically impossible for these smaller HD lenses to achieve the same overall image performance as the larger studio HD lenses.

Table 1 offers a comparative summary of those attributes that produce final image quality in the studio HD lens and the EFP/ENG portable lens. No one attribute in isolation constitutes a radical difference between the two lens types. Collectively, however, they amount to a significant overall performance difference. This difference has important aesthetic consequence for the look of a news studio and the portrayal of anchors and other talent. That look becomes the HDTV signature of the television station in its market.

Optical sensitivity

The large studio lens employs wide diameter glass, which inherently captures more light. A high-end studio camera can have a maximum relative aperture of *f*1.5 in contrast to the more typical *f*1.9 of the portable EFP lens. But, there is an additional and important aspect to lens sensitivity, known as relative light distribution.

Relative light distribution

This refers to a fundamental optical phenomenon whereby the transmitted light through each lens element is at maximum at the center and falls off toward the extremities of the image plane. Thus, effective lens sensitivity varies across the image plane, dropping from the center to the extremities. This effect is typically greatest at the lowest aperture number (when the iris has its greatest opening) and at the telephoto end of the focal range. It reduces as the lens is stopped down. (See Figure 1.)

Various optical compensating techniques can reduce this effect at the more open iris settings, but only to a limited degree. These techniques are, however, more readily implemented

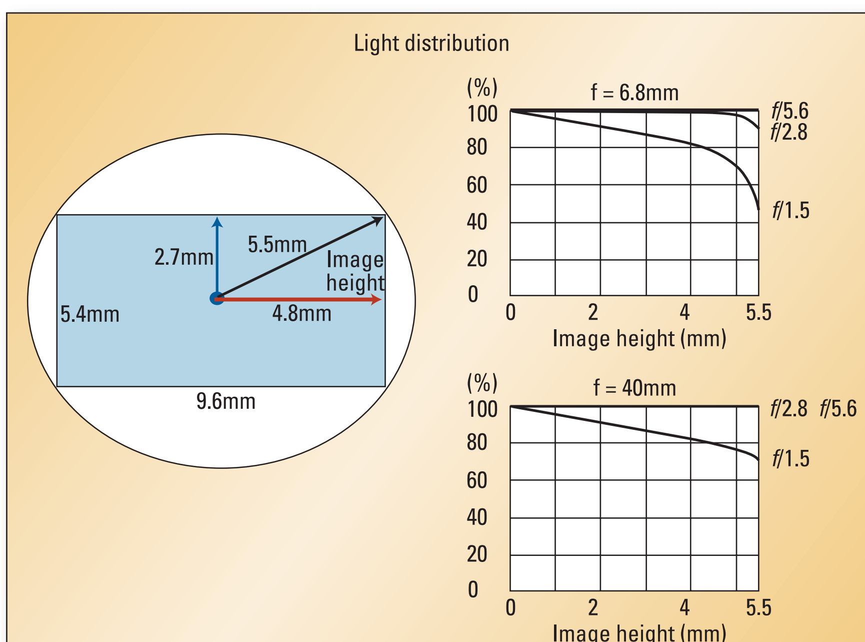

Figure 1. A typical relative light distribution characteristic for an HD studio lens. At a wide angle focal length setting, the light falloff is well controlled when the lens is stopped down to f2.8 or greater. It is even better at longer focal lengths.

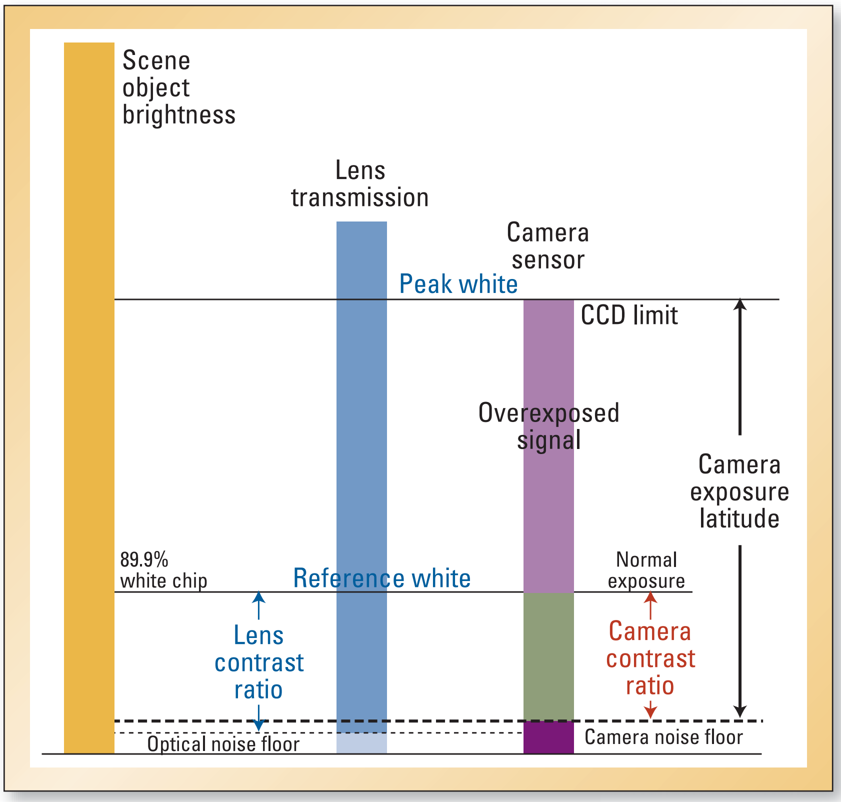

Figure 2. An illustration of an HD studio lens with a contrast ratio greater than that of the HD camera to maximize the overall system contrast ratio

with the larger (and additional number of) glass elements of the studio lens. The typical large HD studio lens will be 30 percent to 40 percent better than an HD portable EFP/ENG lens over the *f*2.8 to *f*5.6 aperture range. This has consequences for the evenness of the lens' contrast ratio across the image plane.

Contrast ratio

This is a measure of the contrast range of the lens from reference white level (the 89.9 percent white chip on the gray scale chart) to a super black in the scene. (See Figure 2.) This range is heavily dependent upon achieving excellent black reproduction, which, in turn, is a measure of how effectively flare, veiling glare and reflections (the combination of which define an effective optical noise floor for a given lens) are reduced.

It is important that this optical noise floor be lower than the electronic noise floor of the associated HD camera. It is equally important that the brightness of the reference white level be as even as possible over the entire 16:9 image, hence the importance of a well-controlled relative light distribution characteristic.

All lenses must deal with reflections at every glass-to-air surface within the multi-element lens. Each untreated glass element can exhibit 8 percent to 9 percent reflectance. In a multi-element lens, this accumulates to considerably contaminate black reproduction through the lens. HD studio lenses incorporate highly specialized multi-layer coatings on each lens element to lower these reflections.

Controlling the thickness and density of the various materials can significantly decrease reflectivity and elevate transmitivity. Managing the reflections of all light wavelengths of interest (approximately 400nm to 700nm) requires many layers. Depending on the material used, they can be deposited on the lens element using vacuum deposition or plasma sputtering techniques.

A contemporary HD studio lens will achieve contrast ratios well in excess of 1000:1 using these techniques. These add significantly to the cost of the lens. To control costs, the typical HD portable EFP/ENG lens will not resort to the same degree of sophistication in such coatings.

Lens image sharpness

Two fundamental optical phenomena impose limits to the resolution of all lenses: defocusing aberrations and

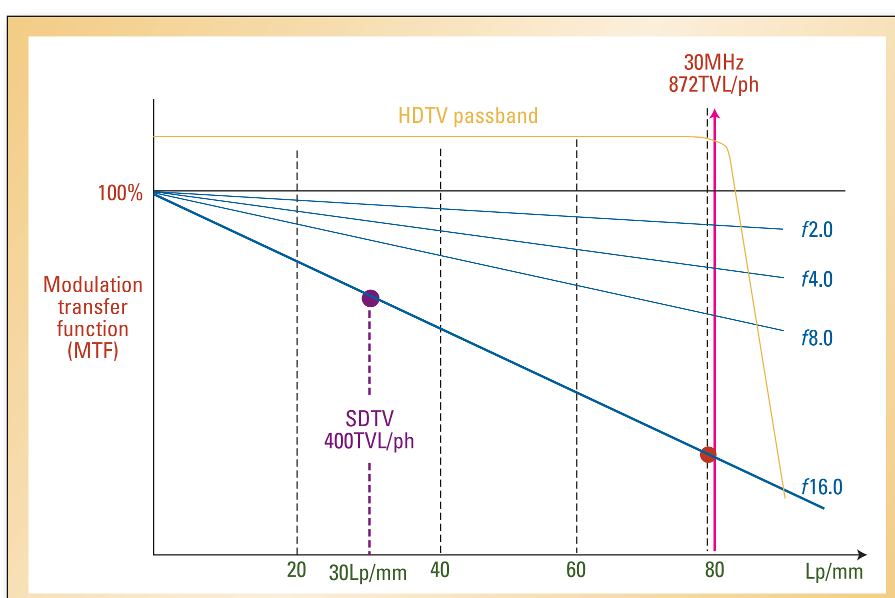

Figure 3. The effects of lens diffraction on a 2/3in hypothetical HDTV lens that is "perfect" in having zero defocusing aberrations

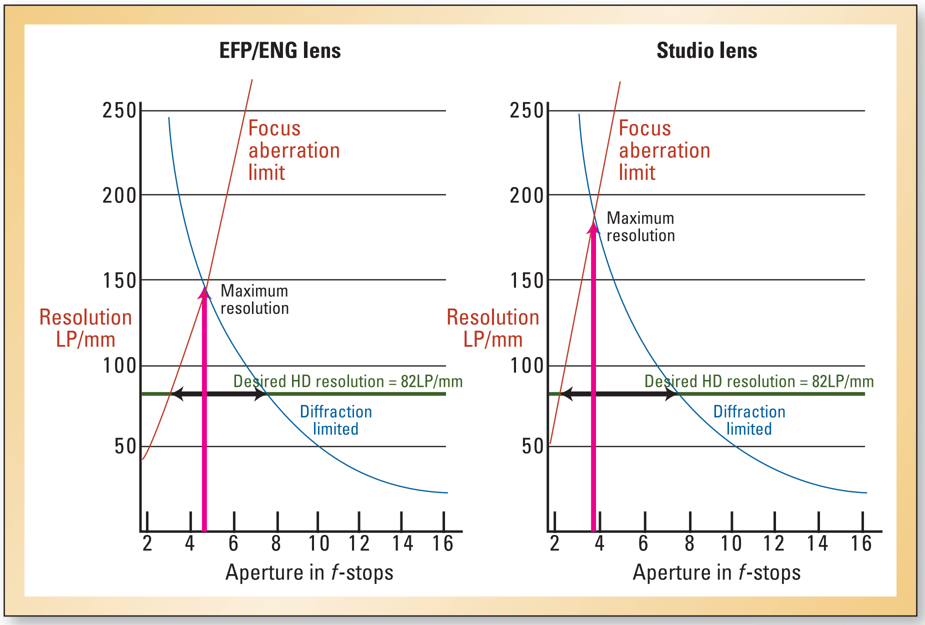

Figure 4. Illustrates the two constraints that dictate the MTF behavior of a lens: the intractable physical limitation of diffraction that worsens as the lens is stopped down and the limitation imposed by the inherent defocusing aberrations (becoming more significant at wide aperture settings). This concept of portrayal is courtesy of Edmund Optics [1].

defraction. They affect the ultimate resolving power of the lens and its MTF characteristic.

Defocusing aberrations are the collective of the four classic monochromatic aberrations common to all lens elements. These errors are at a maximum at low-aperture settings (lens iris near maximum opening), and they generally decrease as the lens is stopped down.

There are many optical design strategies to combat the effects of these aberrations, involving combinations of specially designed elements to implement compensating strategies. The more lens elements that can be mobilized, the more effective the control over these defocusing impairments. Studio lens design involves many more elements than the more compact EFP/ENG lens and consequently has far greater degrees of freedom to counter these aberrations.

Diffraction is an optical behavior related to the wave properties of light. It imposes a limit on how small an optical image spot size can be. This imposes an ultimate limit to the ability of all lenses to transfer contrast at high spatial frequencies. Diffraction effects increase as the lens is stopped down. For the same image size, the resolution of studio and EFP/ENG lenses are both rigidly limited to the same degree by diffraction.

If a hypothetical "perfect" lens could be made — that is, one having zero defocusing aberrations — then diffraction would be the ultimate dictator in defining the resolution limits of a lens. Figure 3 shows that such a perfect lens exhibits a linear MTF roll-off across the optical passband for a given iris setting. As the aperture is decreased (the lens is stopped down), the effects of diffraction become increasingly aggressive. While diffraction certainly has a non-trivial effect on an SDTV lens, it becomes a much more serious issue in HDTV.

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The resolution boundary for the 1920 (H) x 1080 (V) HDTV standard is 875TVL/ph, which equates to 82 Line pairs per millimeter (LP/mm) in the optical domain. Clearly, diffraction is becoming a serious limitation after *f*8.0.

All real lenses, however, must contend with the implacable realities of the defocusing aberrations and diffraction conspiring to define a final limiting resolving power and an attenuation of contrast reproduction (lowering MTF) across the optical passband. The separate dynamics of the two is graphically outlined in Figure 4, which portrays the combined effects of aberrations and diffraction on the resolving power of a 2/3in EFP/ENG and a 2/3in studio lens over the full range of aperture settings. (These are generic curves for illustration purposes and do not refer to any specific lens.) The diffraction limit is shown by the blue curves (same for both lenses) and the defocusing aberrations by the red curves (smaller for the studio lens).

The desired HDTV boundary resolution of 82LP/mm is shown as the green line in Figure 4. For most lenses, resolution improves when it is closed down from wide-open aperture (a consequence of the lessening effects of the defocusing aberrations). Then there is the "sweet range" over which the lens delivers resolution higher than the needed 82LP/mm, followed by the onset of diffraction at the higher aperture settings that progressively lowers the resolution. As indicated, the lower defocusing aberrations of the HD studio lens elevate the maximum or limiting resolution of the lens and broaden the sweet range of aperture settings.

In addition to these fundamental physical limitations, the other resolution-related dynamics within all HD lenses include:

- maximum MTF at image center;
- falloff in MTF at image extremities; and
- significant variations in MTF as the operational controls of zoom, iris and focus are exercised.

The studio lens design specifically seeks to control these overall sharpness gyrations to the highest degree possible. This entails larger glass elements, more elements, special materials and multi-element groupings. As a consequence, size, weight and costs are higher than those of the portable HD lens. The portable lenses are severely constrained in size and weight and accordingly cannot achieve the same degree of compensation of these distortions as is possible in the studio lens. Accordingly, the corner MTF roll-off is consequently greater in the EFP/ENG lens. Over the critical range of *f*2.8 to *f*5.6, this shortfall can be 20 percent to 30 percent greater than for the studio lens.

Chromatic aberration

These aberrations are a consequence of another fundamental of optics, the fact that every transparent element produces a different focus and magnification for each color wavelength. The end result is color blurring and a misregistration in the matrixed luminance video in the HD camera, which further reduces MTF. And again, this can only be dealt with by sophisticated optical design entailing compensating element designs and different element materials within lens element groupings. These aberrations are more tightly controlled in the studio lens than in the portable lens.

Putting it all together

The HD studio lens design pays close attention to overall image optimization across the entire image plane. Larger optical elements contribute to this optimization. Additional elements offer extensive flexibilities in managing all of these parameters and in implementing optical compensating strategies that lower optical distortions and aberrations.

Consequently, lens size, weight and costs are higher than the portable lens. The best HD studio picture performance is achieved with the large studio box HD lenses. The EFP/ENG HD lens is not a good choice for the HD studio camera. BE

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[1] Electronic Imaging Resource Guide, *Section 2: "Image Quality," Edmund Optics.*