Can 2/3-Inch Broadcast Field Lenses Really Portray 4K UHD ?

Emergence of 2/3-inch 4K UHD Lens-Camera Systems

In less than 18 months, in rapid succession, no less than four prominent professional equipment manufacturers introduced 2/3-inch broadcast cameras meeting 4K UHD performance specifications. All four use prism optics with three utilizing traditional tri-imager sampling and one manufacturer using a four-imager system. The broadcast industry was initially somewhat skeptical that this small image format system could possibly produce motion imaging having four times more spatial samples than contemporary HDTV. Perhaps the higher level of incredulity centered about the requisite lens performance possibilities. After all, the impetus lying behind the sudden emergence of these cameras lay in the rapidly growing desire to exploit the superb imaging capabilities of 4K UHD to offer a totally new sports coverage viewing experience. Deep depth of field and very long zoom lenses were imperatives here.

The story behind the unprecedented rapidity of such 4K UHD lenses actually materializing is one of close collaborative efforts between these camera manufacturers and the major optical manufacturers in establishing credible performance benchmarks for the lenses. This paper will outline the achievements to date. We will start by establishing the benchmark of resolution of a 4K UHD 2/3-inch lens in picture center.

A First Benchmark – 4K UHD Super 35mm Lens Resolution at Picture Center

The early 4K UHD camera were largely centered on the Super 35mm image format size. It is useful to start our analysis by examining the resolution requirements of the S35mm lens. The required lens resolution is fundamentally defined by the spatial sampling lattice of the 4K UHD image sensor system in the related camera. This entails 3840 horizontal samples and 2160 vertical samples – for a total of 8,847,360 spatial samples. In sampling theory it has been long-established that a given spatial sampling frequency can only faithfully reproduce spatial frequencies that are half that number. The limit of such spatial reproduction is known as the Nyquist frequency – which is simplistically explained for 4K UHD in Figure 1. The calculation shows that the equivalent optical Nyquist frequency for a S35mm lens is 80 line pairs per millimeter (LP/mm) using the acknowledged optical methodology for specifying optical spatial resolution.

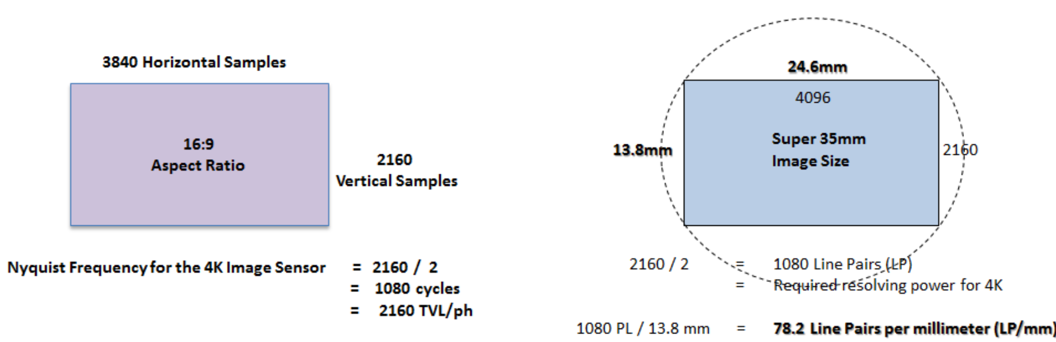

Figure 1 *On the left is the sampling structure of a Super 35mm 4K UHD image sensor and the Nyquist frequency associated with that sampling; the image on the right represents the spatial detail of a 4K Super 35mm lens that can fulfill the resolution capability of that 4K image sensor*

A Second Benchmark – 4K UHD 2/3-inch Lens Resolution at Picture Center

A calculation similar to the above shows that the equivalent optical Nyquist frequency for a 2/3-inch lens is 200 line pairs per millimeter (LP/mm) – as outlined in Figure 2.

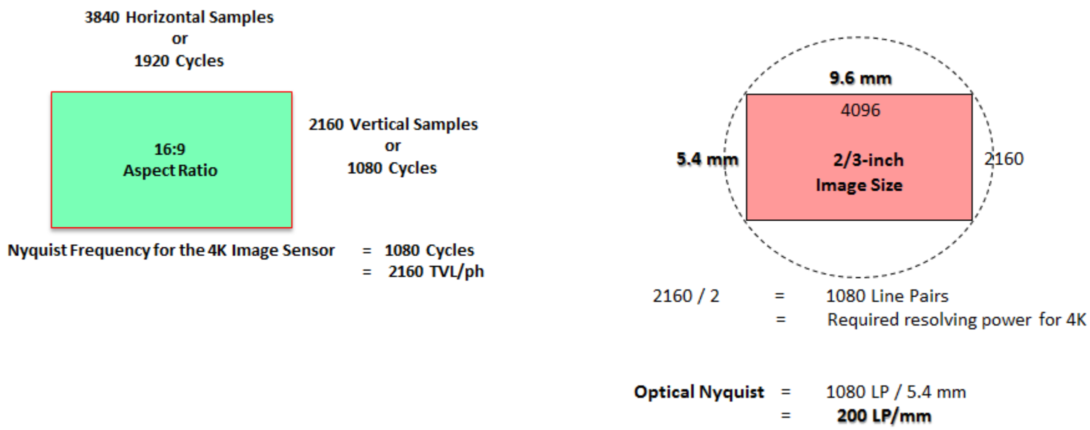

Figure 2 *On the left is the sampling structure of a 2/3-inch 4K UHD image sensor and the Nyquist frequency associated with that sampling; the image on the right represents the spatial detail of a 4K 2/3-inch lens that can fulfill the resolution capability of that 4K image sensor*

The initial benchmarking of a 2/3-inch lens resolution must start with the fundamental limitation imposed by optical diffraction. For all lenses of that image format size the maximum MTF for an aberration-free lens at an F-2.8 aperture setting is as shown in Figure 3.

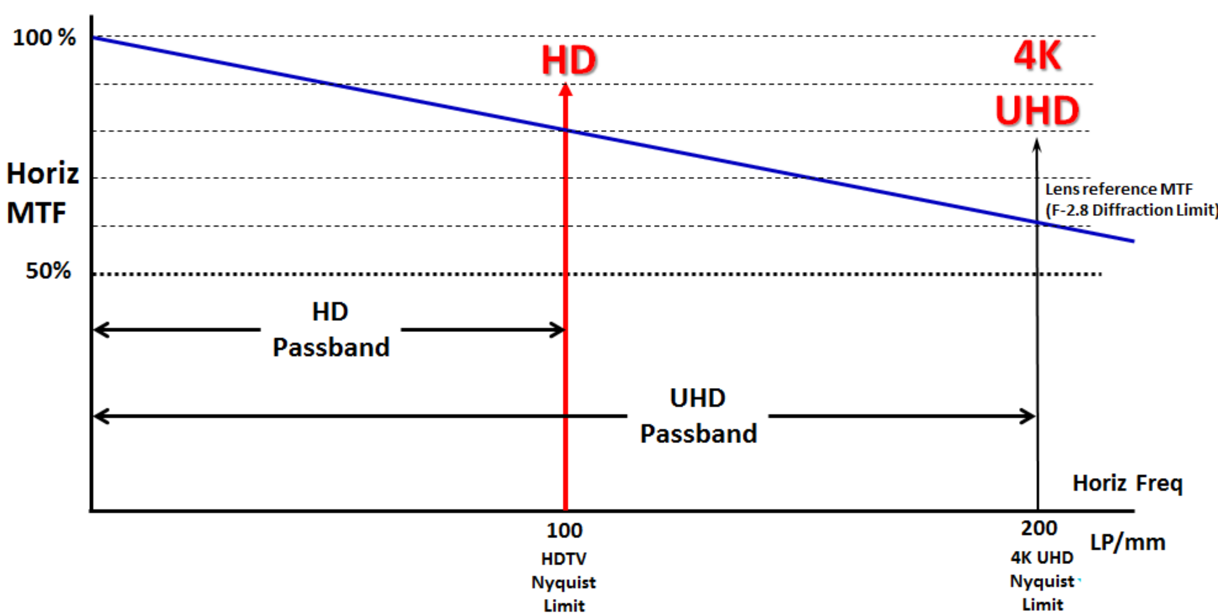

Figure 3 *Showing the limitation on the maximum possible MTF for a 2/3-inch at an aperture setting of F2.8 that is imposed by optical diffraction*

What makes the high-performance 2/3-inch lens viable for 4K UHD motion imaging is the fact that the electronic MTF of the typical 4K UHD camera falls more rapidly than that of the lens – as indicated in Figure 4. This relatively rapid roll-off is primarily due to the aperture of the image sensor (sampling theory) and the optical pre-filter necessitated by the requirement to control aliasing associated with that spatial sampling. The actual camera MTF curves will vary between manufacturers depending upon their individual unique design strategies.

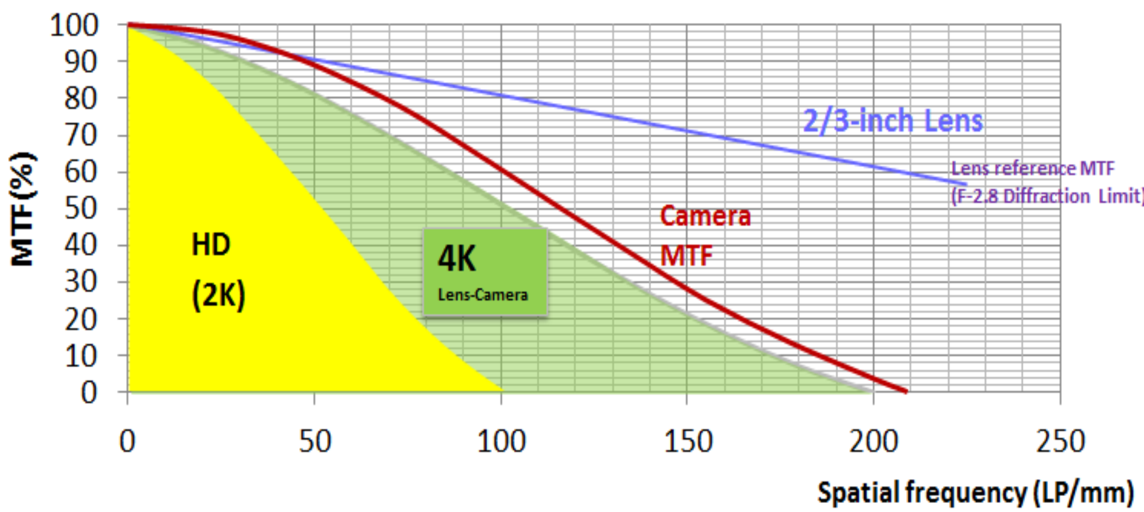

Figure 4 *Showing the relative MTF roll-off of a 2/3-inch 2K and 4K camera and a typical high-end 2/3-inch lens – all at the center of the image*

As the lens aperture is stopped down the lens MTF will progressively lower and this will increasingly curtail the overall 4K UHD lens-camera MTF characteristic. That is a behavior fundamental to all digital motion imaging systems – be they SDTV, HDTV or UHDTV. In the case of 4K UHD, however, the rate of decline of system MTF as the lens aperture is progressively stopped down will be more rapid than the same lens on an HDTV camera.

The Real Challenge of 4K UHD for the Small 2/3-inch Image Format

It is a central struggle in the optical design of multi-element zoom lenses to control the roll-off of MTF across the image plane – that is, from its high level at picture center when moving toward the image extremities. Over many years Canon's optical designers established two specified image zones that guide the multifaceted design strategies for HDTV lenses. Every possible effort is made to limit the MTF fall-off within the Middle Zone – shown in Figure 5.

The area encompassed by that zone was established in concert with many users worldwide as being important to ensure an even sharpness for close-up and medium close-ups of talent. This acquires a particular importance for 4K UHD imagery anticipated to be portrayed on increasingly larger screens. The larger Outer Zone was also identified as being important for wide-angle imagery containing a lot of picture detail. A variety of new optical technologies were mobilized to ensure the tightest control of MTF across the Middle Zone and a carefully controlled fall-off out to the Outer Zone.

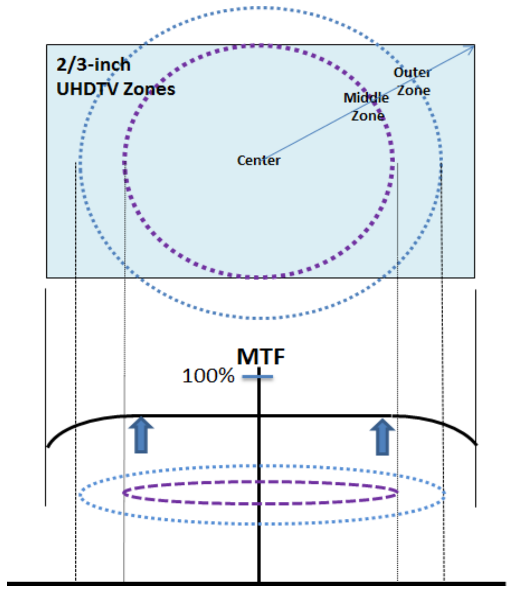

Figure 5 *Showing the two zones traditionally used by Canon to specify levels of MTF across the lens image plane and the idealistic design goal of seeking as flat an MTF as possible across the middle zone*

An additional design priority for the 2/3-inch long zoom lens was to both elevate the MTF curve and even it out as much as possible across the total focal range compared to this behavior in contemporary HDTV long zoom field lenses. In addition, elevating the MTF curve as a function of object distance became a desirable goal.

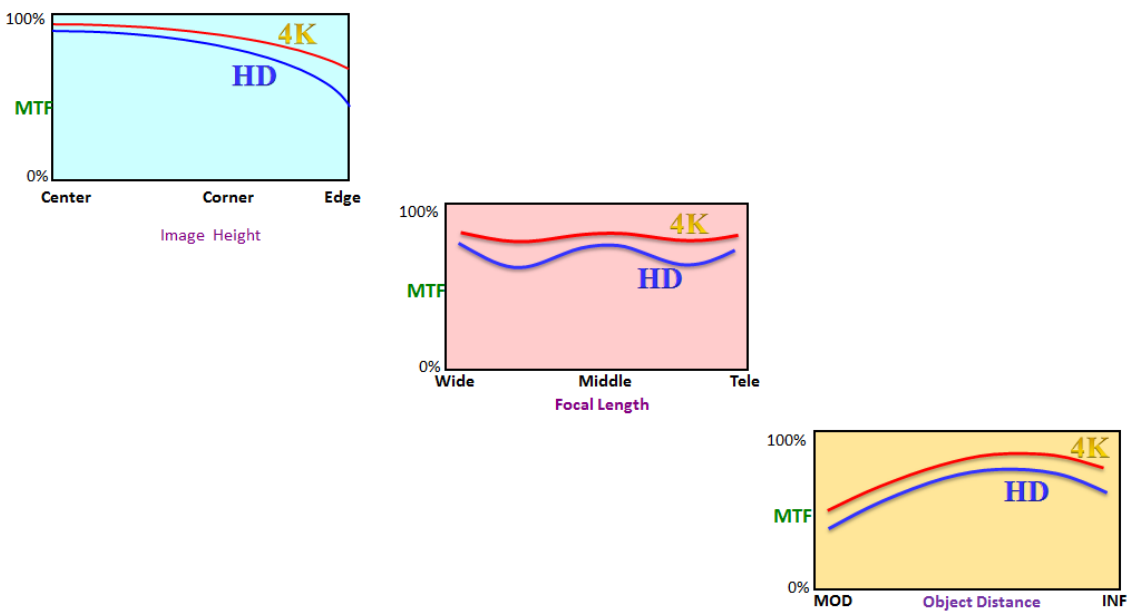

Figure 6 *Showing hypothetical goals for the MTF characteristics of a 4K UHD lens as a function of the two spatial zones, the total focal range, and the object distance from the lens front*

Lens Aberrations

The quest to enhance the overall MTF characteristics of the 2/3-inch 4K UHD lens inherently entailed further minimization of the various optical aberrations (four monochromatic and two chromatic) as they collectively are termed the defocusing distortion that impose another boundary to image sharpness. Separately, high attention was paid to curtailing both the longitudinal and the lateral chromatic aberrations as the higher resolution of the 4K camera allows even a small degree of color fringing to be more visible.

Design Strategies for 2/3-inch 4K UHD Optics

In the new 4K UHD 2/3-inch lenses recently introduced by Canon the following strategies were implemented to achieve the desired performance specifications:

1. Utilization of new glass materials
2. Deployment of large aperture aspheric lens elements
3. Improvements to the optical techniques within the floating focus system
4. New techniques in the design of the variator and compensator groups used for zooming
5. Tighter surface tolerances on all lens elements