

HDTV lens design: Technology and costs

BY LARRY THORPE AND GORDON TUBBS



A Sony XDCAM HD PDW-F350 camcorder with a Canon HDgc wide angle zoom lens covered the Iditarod dog sled race in Alaska in March 2006.

Amazing advances are taking place in HDTV program-origination equipment. The internationally standardized 2/3in format HD camera continues to raise the bar in image performance, moving from 10-bit digital to 12-bit and now to 14-bit, with up to 30-bit nonlinear calculations. All the while, these cameras continue to pack increasingly powerful HD video processing and extend creative flexibility. HD CCD and CMOS imagers are constantly being refined. Associated HD digital recording has elevated tape capabilities to near-1Gb/s real-time performance and to uncompressed baseband recording on tapeless media.

At another extreme, HD camcorders have splintered into new, cost-effective 2/3in systems and even lower-cost 1/2in- and 1/3in-based systems. These have simultaneously branched into using a variety of tapeless media that are revolutionizing HD production workflow.

Meanwhile, the HD lens continues a steady advance, with each new gen-

eration exhibiting incremental performance improvements. Over the past decade, prices of such lenses have dropped, but very slowly. Today it is possible to acquire an HD camcorder that is lower in price than the lens that accompanies it. This has sparked widespread industry discussion with

respect to the perceived high costs of such lenses.

Contributing costs of professional lenses

All professional lens categories share three major subsystems that, in combination, make up the

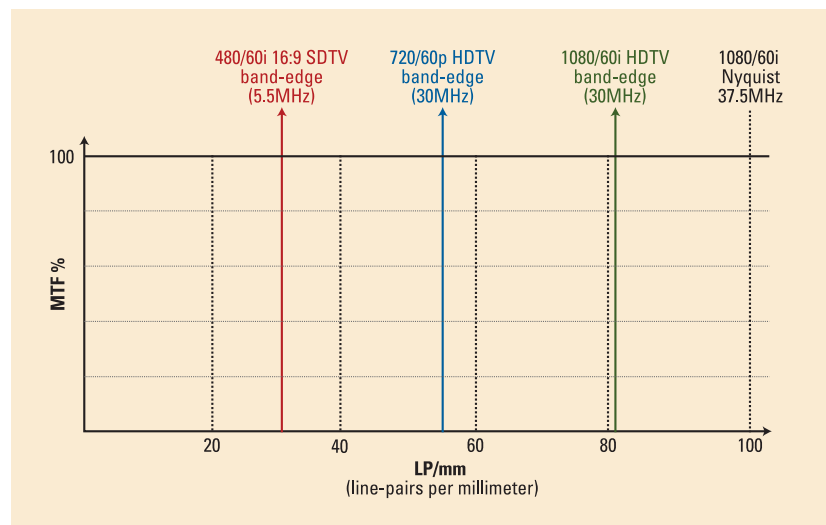


Figure 1. The concept of optical bandwidth, relating optical line-pairs per millimeter with electronic bandwidths for different digital television systems

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contemporary zoom lens:

- The *optical system* is made up of the many optical elements that work in tandem to provide the requisite lens operational requirements and high imaging performance.
- The *optomechanical system* is the mechanical system that supports the precision mounting of all the lens elements and implements the physical movement of those elements when zooming and focusing — in addition to the iris aperture control.
- The *electronic system* is the precision digital servos systems for operational control of zoom, iris and focus.

Each of these subsystems adds cost in a professional lens. This is because each of them involves high technologies, materials and progressive refinements (dictated by global end users). But their addition results in enhanced stability and reliability and makes lenses increasingly impervious to environ-

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mental conditions. With optical and optomechanical systems also comes the cost of the manufacturing processes.

The optical system

The overall optical performance of a lens is dependent upon:

- *The optical design criteria.* This is associated with every element comprising the lens system and made increasingly sophisticated with computer-aided design tools.
- *The optical materials used.* Different materials are used for different lens elements; some of these are particularly costly.
- *The multilayer coatings used.* This is a highly refined process involving the deposition of various exotic materials.
- *The manufacturing tolerances of each element.* This involves the cutting and shaping processes, followed by the long grinding and polishing processes to achieve the specific surface tolerances prescribed by the par-

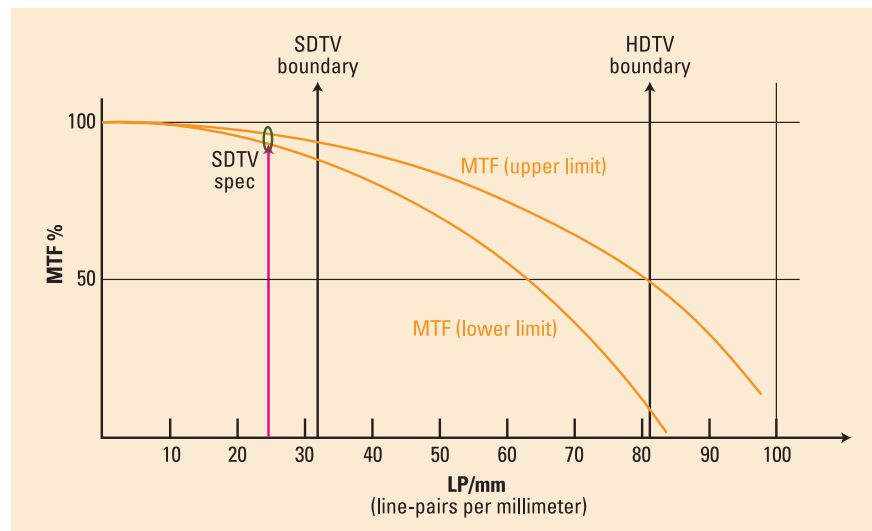


Figure 2. The tightly specified SDTV lens MTF across the passband of interest (5.75MHz or 32LP/mm) and the relaxation of the MTF spec beyond. (Note: This curve is generic and does not refer to a specific SDTV lens.)

ticular lens design criteria.

Differentiating between an HDTV and SDTV lens

The most discernible performance difference between the HD and SD lens is that of resolution. That, in turn, is determined by the quite distinct

ure 1 on page 72.) The recommended 30MHz SMPTE filter guideline for that system would define an 82LP/mm optical boundary. The equivalent for 5.75MHz SDTV is 32LP/mm. That is almost a 3:1 difference.

Designing a lens system involves a careful choice of glass materials, element thicknesses, precision of design curvatures and precision of element alignment that ensures system performance specifications that meet the intended application. There is a fine balance between the implementation of the design and the overall associated costs.

SDTV lens resolution requirements

In the case of an SDTV lens, the

modulation transfer function (MTF) characteristics of the two lenses.

The optical passband of an HDTV lens for 1080-line HDTV (in terms of its Nyquist frequency) is 100LP/mm (line pairs per millimeter). (See Fig-

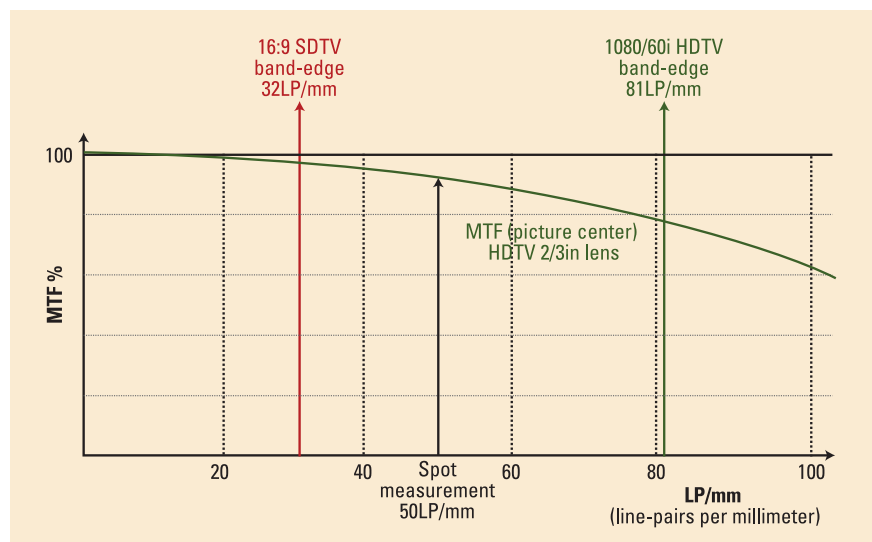


Figure 3. A typical MTF curve for a contemporary HD lens

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goal is to achieve an MTF specification that is high and tightly controlled across the required spatial frequency passband of 0LP/mm to 32LP/mm. The science of modern lens system design is to meet all specifications over the optical passband of interest — and to stop there. Any refinements that further enhance the performance beyond those specifications can be accompanied by a rapid rise in manufacturing costs. Close familiarity with manufacturing processes is essential for lens designers to optimize the performance-cost tradeoffs.

An SDTV lens is typically specified and measured at 25LP/mm, a convenient “spot” measurement in the upper portion of the SDTV optical passband. The complex manufacturing processes are all meticulously tailored to ensure that the MTF level at 25LP/

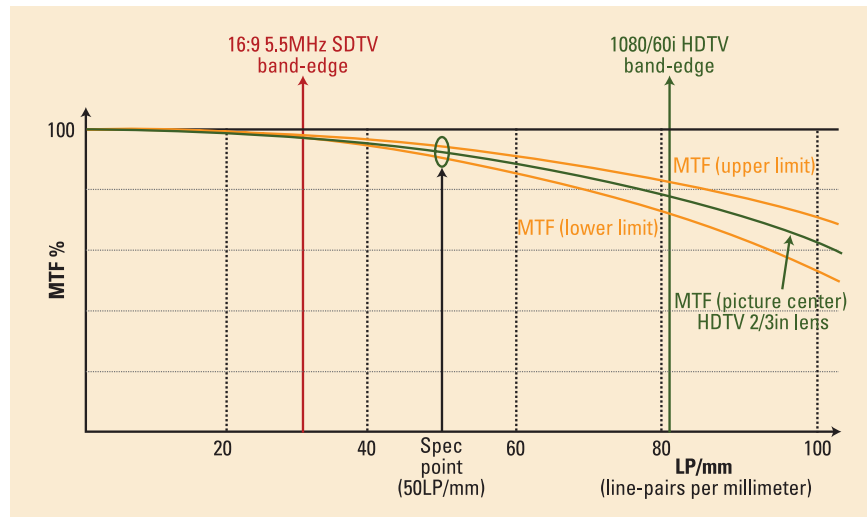


Figure 4. The tolerance in HDTV lens MTF characteristics when tightly specified at 50LP/mm. (Note: These curves are generic and do not refer to a specific HD lens.)

tical limitations in optical element grinding and polishing. The behavior of the lens element at the much higher spatial frequencies entailed by HD needs a much greater degree of control, involving much tighter tolerances in manufacturing.

band-edge of 82LP/mm. Glass materials, lens element multilayer coatings and tighter manufacturing tolerances contribute to this high performance. Optics is physical, and there are no shortcuts.

The most discernible performance difference between the HD and SD lens is that of resolution.

mm will fall within a tightly specified window. (See Figure 2 on page 74.) Beyond that point, the lens tolerance is considerably relaxed.

HDTV lens resolution requirements

The HDTV lens seeks the same tight specification control as its SDTV counterpart — but at a considerably higher spatial frequency. To ensure that it meets the more stringent resolution demands of HDTV, the lens seeks a high MTF across the much wider 0LP/mm to 82LP/mm passband and also a tighter control of that MTF across the entire 16:9 image plane. (This is particularly important as HDTV viewing entails considerably larger screens than NTSC television.) The design also implements a tighter control of MTF as lens elements are moved during zooming and focusing. (See Figure 3 on page 74.)

Optical surfaces deviate from the mathematically precise models of the computer-aided design due to prac-

The cosmetic quality of each lens element also demands close quality control — and optical designers specify scratches and pits down to tens of microns. Centration is another specification that seeks to precisely align the optical axis of the multi-element system with the centers of curvature of all of the optical surfaces involved.

Realities of high-end HDTV lens design

Canon identifies its high-end HD lenses with the HDxs logo (and HD-EC for the cine lens variants.) For these lenses, the manufacturing process is governed by a well-defined MTF specification at 50LP/mm — a frequency that lies inside the HD passband but significantly beyond the SD passband. This seeks a high MTF at that spatial frequency with a tight tolerance on that number. (See Figure 4.)

Achieving a narrow specification window at the inband spatial frequency of 50LP/mm helps ensure preservation of a high MTF at the HD

The quest for lower-cost HDTV lenses

The recent arrival of much lower-cost HD cameras and camcorders in the marketplace has created a need for HD lenses that are lower in cost than the “best that can be made.” These new cameras have been specifically developed to facilitate cost-effective HD origination for broadcast newsgathering and other program genres governed by tight budget strictures.

Canon recently introduced a new HD lens platform, HDgc. It provides HD performance carefully aligned to the performance of these lower-cost HD cameras and camcorders now emerging from numerous professional manufacturers.

Unlike the high-end HD lenses, which exclusively conform to the internationally standardized 2/3in image format, some lens strata support the 2/3in, 1/2in and 1/3in image formats reflective of the broad range of these new camcorder designs.

End users have clearly stated that they expect such lower-cost lenses to retain the same robustness, reliability and operational precision of the high-end HD lenses. Accordingly, of the three subsystems that constitute the overall lens system, the

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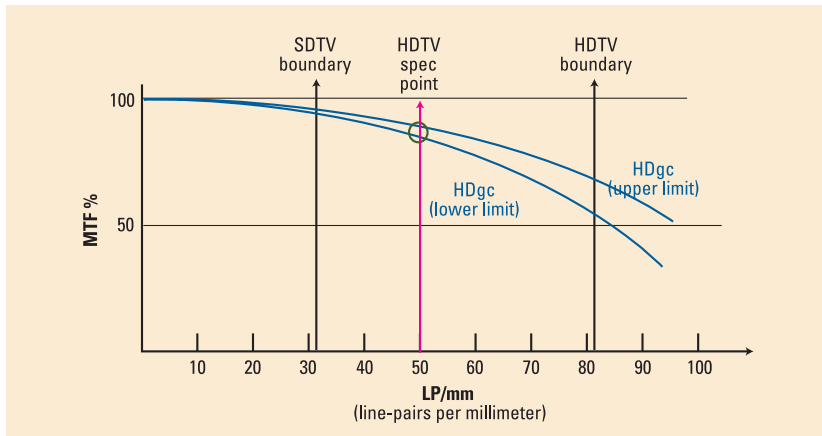


Figure 5. A lower cost HD lens and the compromise that might be necessary in the MTF characteristic. (Note: These curves are generic and do not refer to a specific lens.)

optomechanical and the electronic subsystems cannot be altered. Thus, the burden of cost reduction falls squarely on the optical subsystem.

To meet this challenge, optical designers must return to the same set of variables — glass materials, design curvatures, coatings and manufacturing tolerances. There is no silver bullet here — only solid optical engineering principles and pragmatic compromises. Each manufacturer will harness some proprietary combination of the variables (in materials and manufacturing) that will realize the sought-for optimum HD performance and cost goals. Figure 5 shows the approximate form of the MTF characteristics that typify the lower-cost HD lens families.

Clearly the HDgc lens has a lower MTF than high-performance counterparts. Bear in mind, however, that these lenses are intended to operate with lower-cost HD cameras and camcorders, with their own pragmatic design compromises. The driving design imperative for both these camcorders and associated lenses are costs that meet the highly competitive needs of HD newsgathering and other low-budget programs.

The camcorders have mobilized a wide array of design strategies to meet these costs, including smaller image formats, subsampled imager lattices and aggressive bit-rate reduction strategies in their associated recording systems. This is all in the interest

of dramatically lowering costs while producing HD performance that is “good enough” for a wide range of applications that do not seek top-of-the-line image quality.

Summary

Figure 6 summarizes the concept behind the design criteria of three types of professional broadcast lenses — an SDTV lens and two levels of HDTV lenses. Specific MTF characteristics are different between categories of lenses (studio, field, cine and EFP/ENG), so these curves are illus-

trative only. But they do represent the essential differences underlying these three lens types.

Lens design does not benefit from the dramatic cost-reducing dynamics of digital electronics. Lens design is intractably physical. Specifying lens performance entails management of multiple variables followed by lens element manufacturing and precision assembly and alignment.

Within that complex mix lie the variables that can be creatively engineered to realize specific performance levels and their associated costs. Fortunately, optics is a highly sophisticated science that not only leverages advanced new materials but also the latest supercomputer simulation technologies to extend the boundaries of lens performance to unprecedented degrees.

These advances impact high-end HD lens technology and make possible new, more affordable lenses for cost-effective HD cameras. For image acquisition in the new age of HDTV, this is good news for everyone. **BE**

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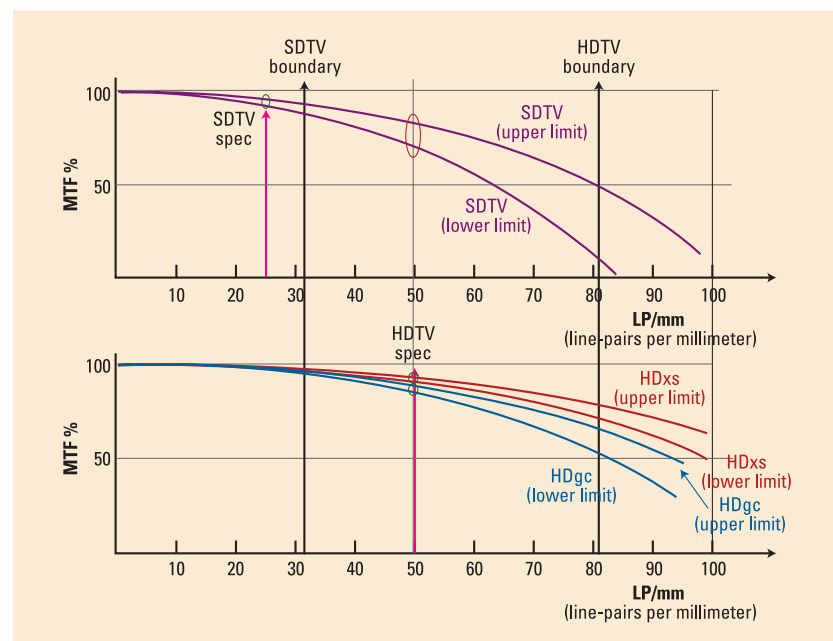


Figure 6. The essential differences between an SDTV lens and two different performance levels in HD lenses