

**White Paper
#3**

HDTV Lens Design

*Management
of
MTF*

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Introduction

In the previous paper we related traditional discussions of lens-camera resolution to the more pertinent issue of the picture sharpness perceived when viewing a display from some distance (as is typical in both television and cinema viewing). We briefly reviewed the all-important concept of Modulation Transfer Function (MTF), its influences on picture sharpness, and the optical design challenge of obtaining as even a distribution of MTF as possible across an image plane. As a reminder, MTF is a curve that describes the behavior of the *contrast* of increasing spatial frequencies across the total frequency band of the HDTV system.

The intent of this paper is two-fold: one, to discuss the technological challenges entailed in achieving the requisite MTF characteristic required by an HDTV lens in comparison with its SDTV counterpart; two, to emphasize that lens design strategies can be quite different among manufacturers and that careful evaluation of lens-resolution characteristics may well be far more important than evaluating camera resolution.

HDTV Challenge to Lens-Camera Design

There are four significant challenges in extending lens-resolution performance from the realm of SDTV to HDTV:

- 1) Elevating the in-band MTF – and then extending this to the higher spatial frequencies required for HDTV
- 2) Maintaining that high MTF over the focal range of the HDTV lens
- 3) Controlling the MTF as the object distance from the lens is changed
- 4) Managing the lens MTF as the aperture is altered for different scene lighting levels

The HDTV digital video signal has the potential to sustain up to six times more spatial detail than the best 4:2:2 digital 4:3 SDTV video signal (as defined within contemporary HDTV Production Standards). To fully exploit that tremendous increase in picture information the lens must be capable of imaging and delivering to the HDTV camera sufficient spatial detail to satisfy its formidable digital information capacity.

In the SDTV domain: If a lens-camera system combines a lens having the ability to resolve 30 line-pairs per millimeter (LP/mm) and the 480-line camera (having a 4:3 aspect and operating at 30 interlaced frames /sec) has a bandwidth of 5.0 MHz, then that imaging system can resolve a maximum of 400 television lines per picture height (TVL/ph). A modern high-end SDTV studio lens would be expected to exhibit a 90% MTF at 30 LP/mm. This would typically fall to about 70% at 56 TVL/ph (an HDTV optical reference frequency) and continue to fall off more quickly at higher spatial frequencies.

In the HDTV domain: The 1080-line HDTV system is far more demanding. It is sampling 1080 lines at 30 frames per second and has 1920 horizontal samples per television line, and is as a consequence a far faster sampling system that devours bandwidth. If such a lens-camera system has a lens that can resolve 84 line-pairs per millimeter and the HD camera has a bandwidth of 30 MHz then the maximum horizontal resolving power of that imaging system is 875 television lines per picture height.

This level of performance calls for a significant increase in the resolving power of the HDTV lens over that of the SDTV lens. The MTF of the lens over that wide spatial frequency band should also be as high as possible to ensure high picture sharpness. Figure 1 compares a typical high-end HDTV studio lens MTF with that of a high-end SDTV studio lens.

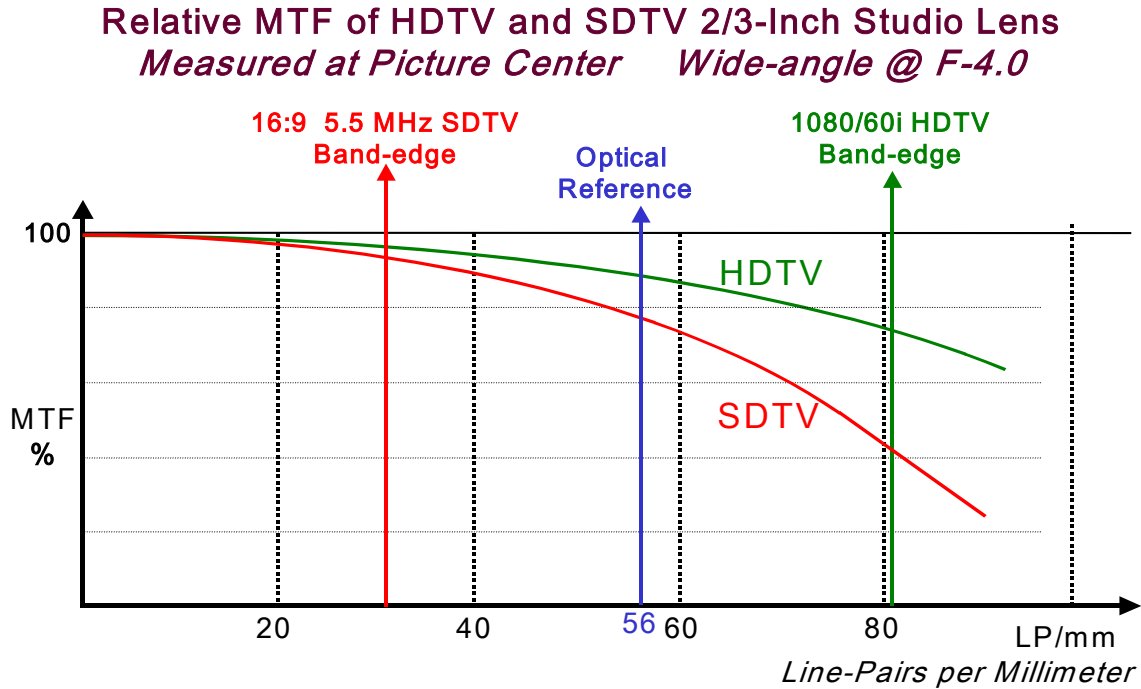


Figure 1 MTF curves for contemporary HDTV and SDTV studio lenses – this diagram highlights the challenge to lens designers to significantly raise the MTF of HDTV lenses

Managing MTF Across the Image Plane

As discussed in the previous paper, maintaining a high MTF from picture center to the image plane extremities is one of the primary challenges in HDTV lens design. New optical materials, new element design techniques, strategic element groupings, and advanced optical coatings all have combined to facilitate significant lens MTF improvements.

Figure 2 shows the relative performance of a high-performance SDTV studio lens and a typical HDTV studio lens (measured at 56 LP/mm). Note: The picture center, middle, and corner dimensional positions are referenced in Figure 5 in our previous paper.

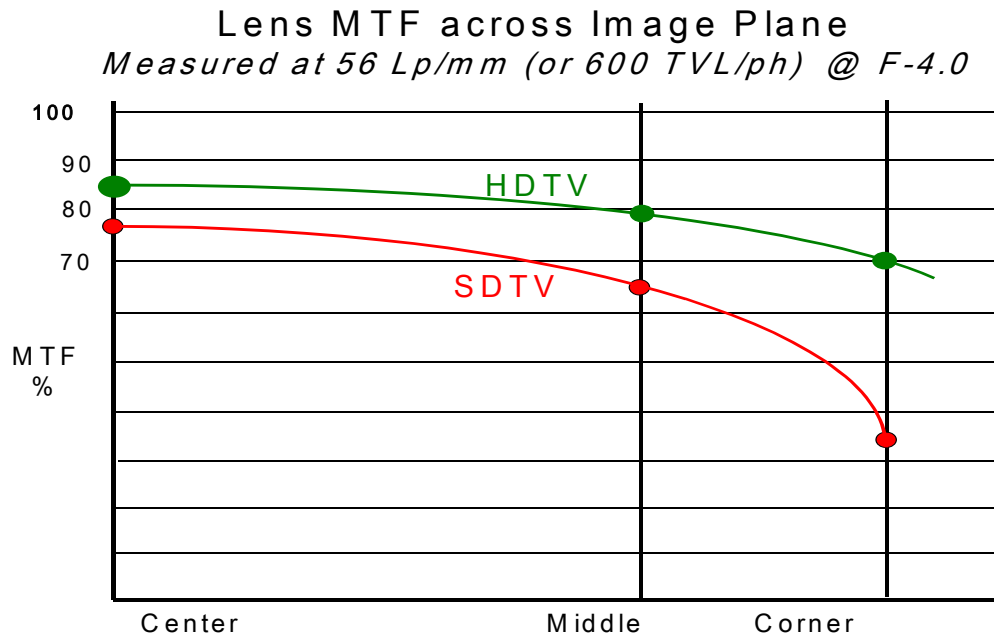


Figure 2 Comparative MTF behavior of an HDTV and SDTV lens across the image plane

The Dynamic Behavior of HDTV Lens MTF

Lens resolution is always changing – in response to any and all optical controls that are exercised in the course of a normal production. Lens MTF will alter when:

- The lens focal length is changed (when exercising the zoom control)
- The distance of an object from the lens is varied (and the lens is refocused on that object) for a specific angle of view (fixed setting of the zoom control)
- The lens aperture is altered (when exercising the lens iris control to restore video level with scene lighting changes or to alter depth of field in a given scene)

Each of these will be briefly examined in turn.

Maintaining High MTF over the Focal Range

Exercising the zoom control in a broadcast lens involves precision relative movement of two groups of lens elements. This in turn has an inevitable impact on a variety of lens imaging characteristics – and on lens aberrations. One impact is on the lens MTF. Because of the far greater clarity of the HDTV picture it is necessary to institute a much tighter control over this variation. Figure 3 outlines the relative MTF variation of a typical SDTV and HDTV studio lens – measured at a reasonably high spatial frequency of 56 LP/mm (a popular optical reference frequency) – being approximately 600 TVL/ph for the 1080/60i system and roughly 500 TVL/ph for the 720/60P HDTV system.

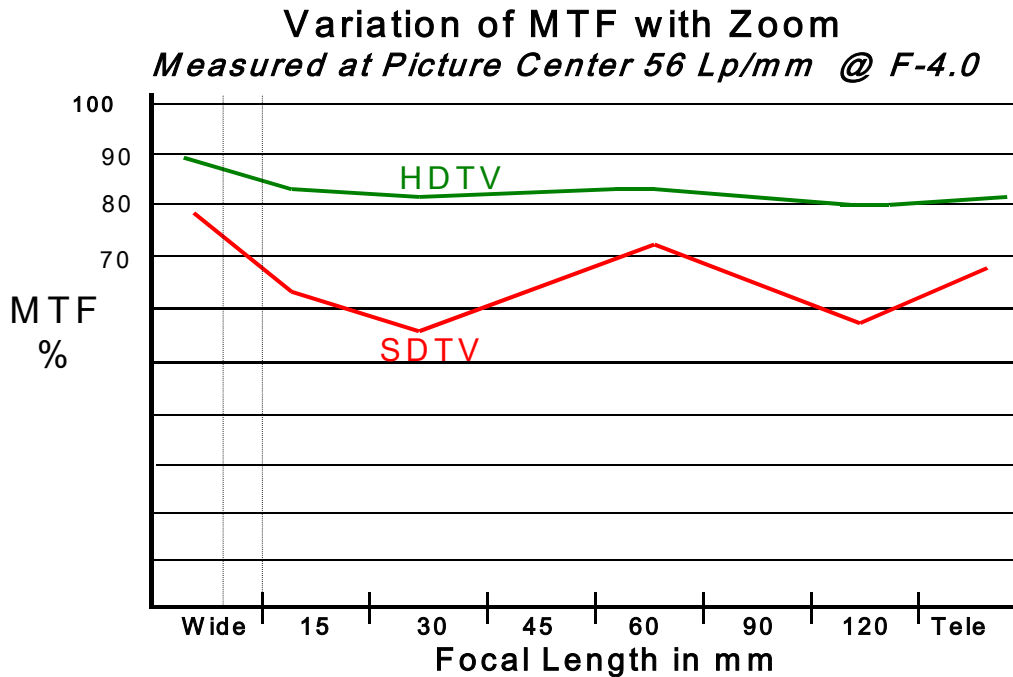


Figure 3 MTF variations over focal length range of SDTV and HDTV studio lenses

Maintaining MTF with Changes in Object Distance

Studio production regularly entails a particular framing for a given scene (appropriate adjustment of the zoom control to achieve a specific angle of view) and subsequent talent activity within that framing. For example, a principal actor may be say, six feet from the lens (and sharply focused) – but then may move away to perhaps 25 feet from the lens (and is refocused – with no alteration of zoom or iris). Or, the camera operator might “rack focus” between two actors separated by such a distance or greater. Lenses will change their MTF between those two focus settings – again, a consequence of lens elements physically moving during a focusing action.

Figure 4 illustrates, by way of a reference, the behavior of a high-performance SDTV studio lens at the higher spatial frequencies (where SDTV/NTSC design really does not need to concern itself). But, because of the high sharpness expectations of HDTV, the HDTV lens *does* need to pay close attention to MTF behavior in this critical spatial frequency region of 56 LP/mm (or roughly 600 TVL/ph for the 1080-line HDTV system).

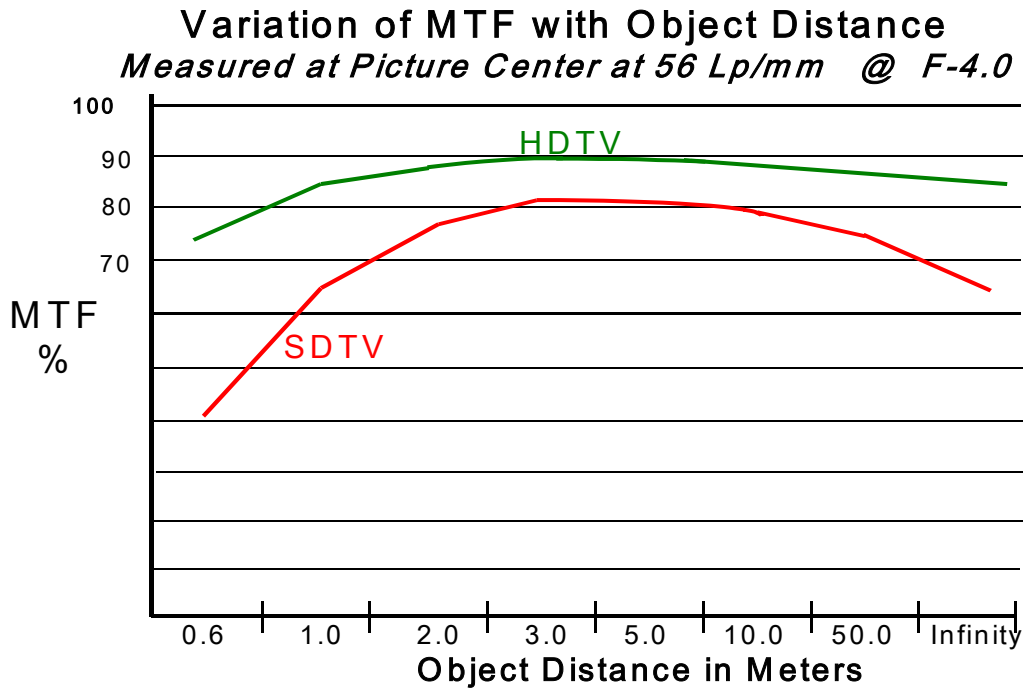


Figure 4 Showing the significant improvement that had to be made to the behavior of the HDTV MTF when refocusing as a subject moves from one position to another

The Effect of Aperture Settings on Lens MTF

Optical science is confronted by some fundamental physics – and one of those is diffraction. Diffraction is a consequence of the wave nature of light and it has the effect of modifying an infinitely small point source of light by “spreading” this as it passes through an optical element. In a perfect lens that is diffraction-limited, MTF would be at a maximum when wide open, and this would progressively lower as the lens aperture is stopped down. In the real world, however, lens designers use a variety of optical techniques to manage the linkage between MTF and aperture setting. Depending on the application (such as studio, field, ENG, or cine) they will optimize the overall MTF profiles (also paying close attention to MTF changes with focal length) to be at their very best at the anticipated lens aperture settings *for those applications*. Broadcast studio lenses for example, are generally operated in the general vicinity of f-4.0, and consequently the design may optimize MTF at that aperture and at the medium focal length that is more common – allowing it to lower (to a modest degree) when wide open. Long telephoto field lenses will have different optimization criteria.

Figures 5 and 6 show a typical HDTV studio lens and how its MTF profiles vary between two aperture settings. The MTF is measured at 56 LP/mm (again in the vicinity of 600 TVL/ph for the 1080-line system) and its variations across the image plane at three different focal lengths are shown. Figure 5 shows the characteristics when the aperture is modestly stopped down to f-4.0. Figure 6 shows the alterations to those same profiles when the lens iris is opened wide. Note the favoring of the wider angle at this setting (because this is where the scene detail is at its highest).

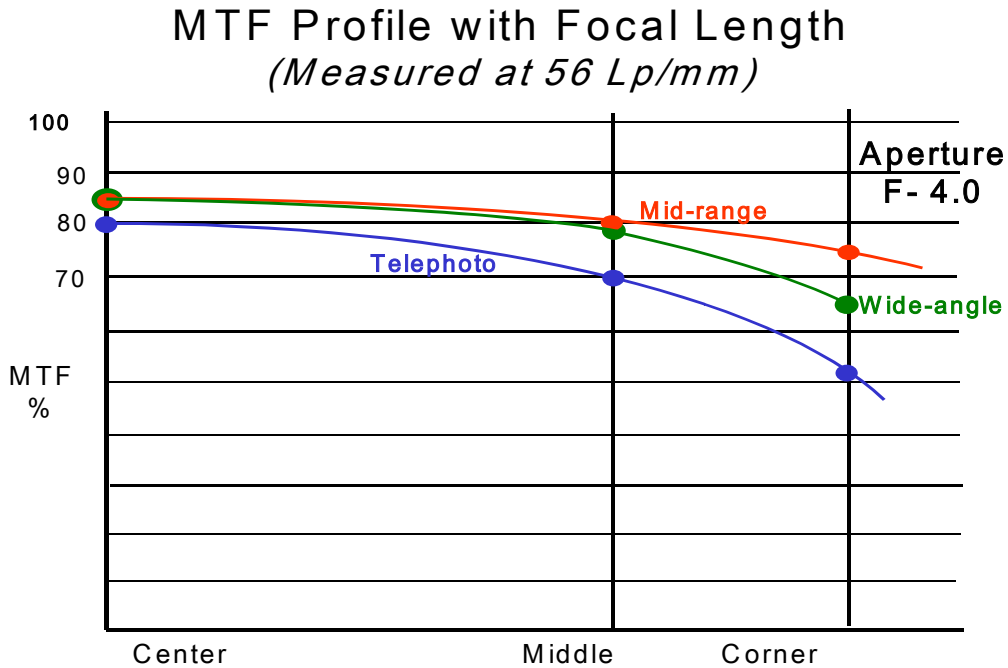


Figure 5 The variation in MTF across the image plane at a singular setting of the iris (for different focal lengths) – shown here at the aperture of f-4.0 common to broadcast television studio operation

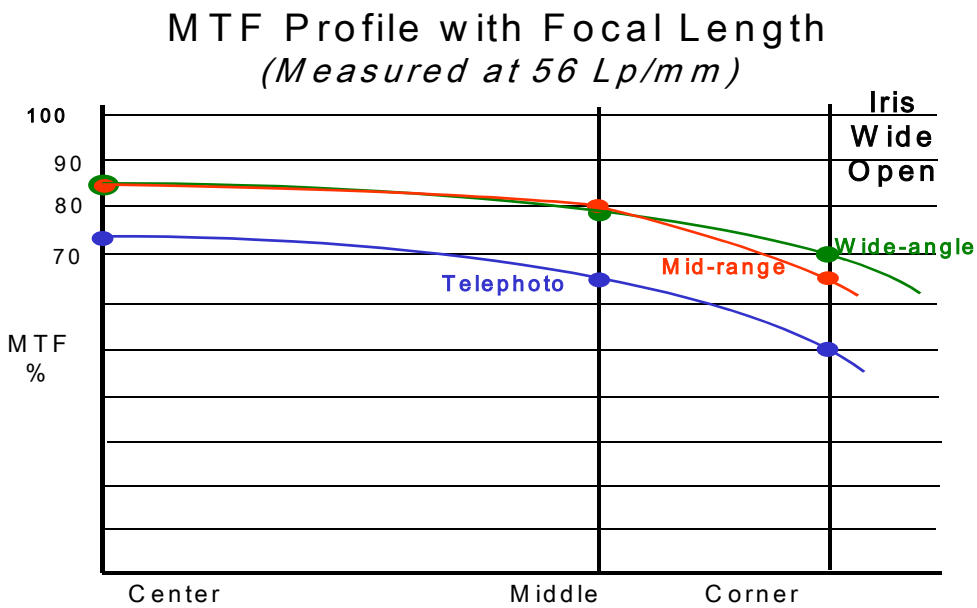


Figure 6 The variation in MTF across the image plane as the lens aperture is fully opened

Summary

It should be apparent that management of MTF in an HDTV zoom lens is a Herculean technical task. Yet, marvelous technical progress has taken place over the past decade. The HDTV lens today exhibits extraordinarily high quality despite the multifaceted challenges within this enormously complex system.

It should also be clear from the imaging characteristics shown in Figures 1 through 4 that coupling an HDTV lens to an SDTV camera will significantly enhance the performance of that imaging system. The extended HDTV lens-performance introduces significant performance enhancements within the much more limited 5.5 MHz bandwidth of the SDTV camera (approximately 0 – 33 LP/mm for the lens). Overall SDTV picture sharpness will be visibly enhanced. This means that an investment in HDTV lenses today is worthwhile – even if the transition to an HDTV camera is some years hence.

