**White Paper**
**#1**

# HDTV Lens Design

# *The Creative Role*

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## The Lens and the Camera Operator

The art of lens design predates any camera by some hundreds of years. The optical lens evolved literally over the ages. That long evolution began as a fundamental optical tool to create images for real-time scrutiny – in microscopes and telescopes – as exemplified by the sixteenth century work of Galileo on astronomical telescopes. It would be quite some time later – in the middle of the 19th century – before the lens became a primary tool in image capture on new photographic media. The growth of the consumer still photography business stimulated global development of lens technologies that continues unabated to this day. With the arrival of motion picture film at the turn of the 1900s, a gigantic engine of entertainment program production was born. The arrival of live television half a century introduced real-time motion imaging that dramatically expanded the scope of motion picture production. The pace of optical lens development was now to be vigorously propelled by unceasing advances in film camera and television camera.

Along the way, the ingenuity of countless practitioners has shaped this optical tool into a mechanism capable of significant creative intervention. Not only does the lens create the optical image for presentation to a film or a video camera – but, it has emerged as a powerful means of *manipulating* that image to augment the art and vigor of storytelling. This very significant creative role of the lens is sometimes taken for granted. The camera lens has become a unique interpreter of the scene being imaged – facilitating highly refined optical control over some separate attributes of the framed image. Indeed, the very art of cinematography speaks to the vast accumulated skill sets that have emerged in image management – all made possible by numerous innovative operational capabilities that have been incorporated into the lens.

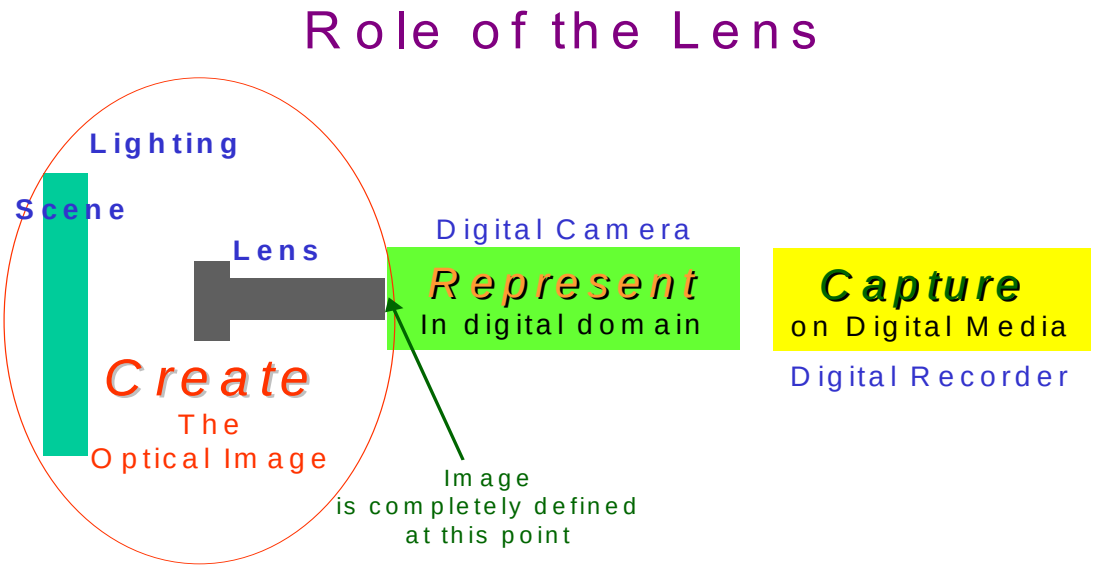


Figure 1 The cinematographer controls the lens in concert with the practitioners of set design and lighting to create the optical image for presentation to the camera sensors

## Multidimensional Aspects of Imagery

All pictures are multidimensional in the sense that they constitute a collection of separately quantifiable attributes. It is the subjective aggregate of these "dimensions" of the picture that produce the final aesthetic quality of the picture. This is true of a drawing or painting, a printed photographic still image, an optically or digitally projected image. In the context of digital motion pictures, the final picture that is viewed will have seen most of those image dimensions pre-determined by the lens itself (in close association with the lighting). Some of them are further modified by the camera (film or digital), the recording system, and finally, by the display system (optical or digital). It should never be forgotten that the primary role played by the lens is, in fact, the essential shaping of most of the dimensions of the image being reproduced from an object scene.

The present intense industry focus on digital imaging has spawned the perception of the lens as merely "prepping" an optical image prior to its being "created" within the contemporary digital camera – and its subsequent recording on some digital media. But, it is actually far more accurate to see the lens as *creating* the desired image in the first place – with the technically challenging role of the camera being to produce a faithful *representation* of this creation within its opto-electronic transformation, and the subsequent digital recording attempting to faithfully *capture* that camera's digital reproduction – see Figure 1. This does not in any way diminish the possible role of the contemporary digital camera in further enhancing that image (when this is creatively sought) – as depicted in Figure 2. Certainly, the many digital RGB video processing controls within the modern video camera do facilitate an unprecedented ability to do so. But the lens remains the undisputed primary arbiter of the final image quality – both aesthetically and creatively.

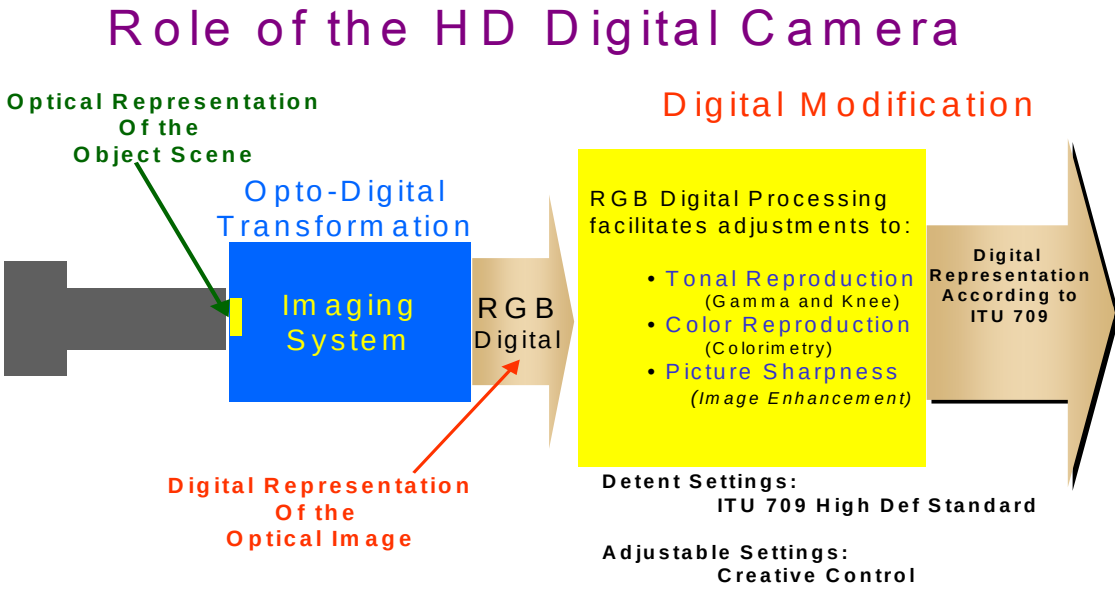


Figure 2 The HD camera conducts an opto-electronic transformation on the image created by the lens to produce a digital representation of that image – which is then digitally processed to produce the specified digital representation according to the HDTV production standard

Prior to an examination of the many different classes of high-end lenses used in the broadcast and production domains it is illuminating to first review the many "dimensions" of an optical image – and to briefly examine each from the standpoint of the creative and the technical capability of the lens.

## Multiple Dimensions of an Optical Image

***Angle of View*** – determines the essential "framing" of the image. Technically, it is the limit within which the subject scene can be imaged in accordance with the focal length and the image format size and shape of the lens. This action is similar to human vision itself.

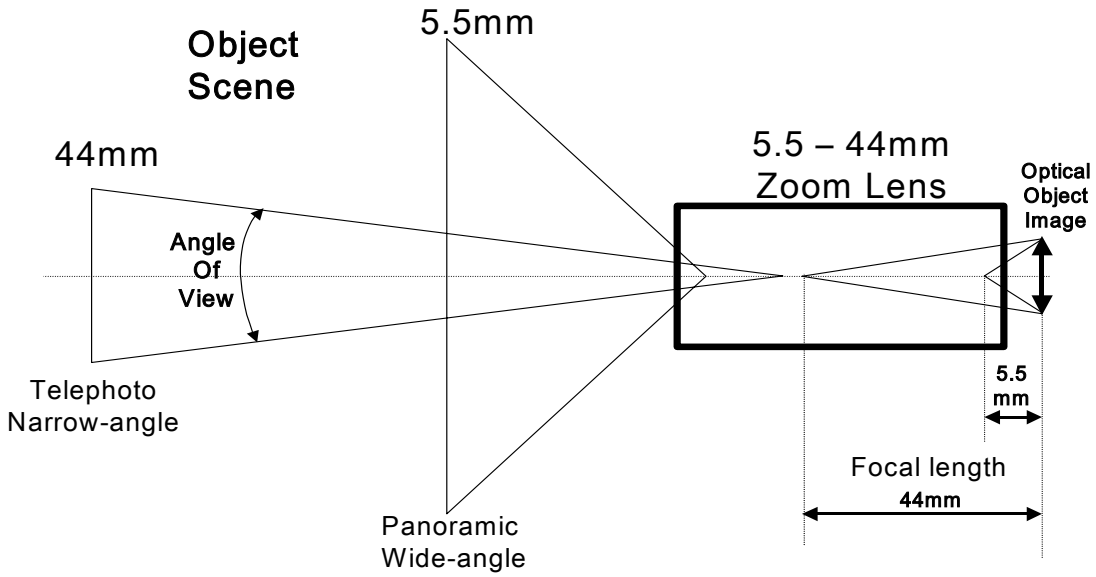


**Figure 3** A Lens "sees" a specific area of the object scene depending upon its focal length and that view is expressed as an angle. The illustration shows a lens having a zoom ratio of 8 times with the wide angle capture at the short focal length of 5.5mm compared to the narrower "telephoto" capture at the 44mm extremity

***Zooming*** – is a strictly optical phenomenon that was born relatively recently within the historical development of the lens. It introduced an entirely new dimension to the *framing* of the image – allowing dynamic adjustment in real time to the angle of view without moving the lens relative to the subject scene. It represents an artificial yet powerful augmentation of the imaging process in facilitating an image presentation that the human eye-brain visual complex cannot duplicate.

***Depth of Field***--refers to a fundamental optical constraint on a lens complex whereby the optical image appears in focus within a limited range in front and in back of the specific scene subject on which the lens is focused. Depth of field varies with the lens image diameter, and with lens focal length and aperture settings. Cinematographers creatively exploit depth of field by skillful adjustment of lighting and lens settings to

present selected scene objects in sharp focus while simultaneously defocusing others portions of the scene. This helps portray a sense of depth to the 2-dimensional optical image. The human eye-brain visual system cannot do this.

***Perspective*** – an essential dimension within any image representation (by drawing or painting, film, electronic). It seeks to portray a 3-dimensional representation in the same manner that the human visual system sees a live scene – with objects linearly diminishing in size as they recede from the position of the viewer. Accurate portrayal of perspective in drawings and paintings only became a science in the fifteenth century. Artificial manipulation of perspective became a central new artistic freedom in the realm of modern art at the entry into the twentieth century. The design of a lens can also support some degree of manipulation of perspective – and this, too, has become a refined creative tool for the cinematographer. One hears of "strong" perspectives and "subdued" perspectives with respect to different lens angle of views and focal lengths. The ultra wide-angle lens can, for example, portray a strong sense of separation between the foreground and the background. The fisheye lens takes manipulation of perspective to an extreme. Overall, the evolution of prime Cine lenses has been greatly influenced by the director of photography's desire to harness this particular creative capability in their quest for augmented storytelling.

***Aperture control*** – where the operation of the lens optical iris allows management of a vast range of scene light levels. In that sense, the lens emulates a very powerful capability of the human visual system in controlling the amount of light to a level appropriate to the capabilities of the sensor (human retina or the camera sensor).

***Contrast or Tonal Reproduction*** – is a measure of the lens ability to reasonably reproduce the full dynamic range of the light levels contained within the object scene. It is a measure of the faithfulness with which the lens optics can maintain the degree of distinction between the many brightness levels in the scene. A high contrast lens is one that can simultaneously differentiate between levels of brightness within the high brightness portions of the scene, while simultaneously clearly distinguishing between the lower levels of brightness in the shadowed areas of the scene.

***Color Reproduction*** – is an important "dimension" of the optical image that speaks to the light transmission characteristics of the lens. This characteristic varies with the wavelength of the light passing through the lens. The balance of colors of the light through a lens is expressed as a color temperature. In the case of the film camera the lens design must be cognizant of the colorimetric characteristics of the emulsions in the particular film being used. In the case of the digital camera the lens design must be coupled to that of the light-splitting system in the camera and the colorimetric characteristics of the sensors employed.

***Picture Sharpness*** – a measure of the response of the lens optical system to the overall reproduction of contrast over a range of spatial frequencies. This is the most complex dimension of any image – and, in the case of the lens, it involves assessments of resolving power and Modulation Transfer Function (MTF) at a variety of points over the two-dimensional image. What is ultimately seen by the eye-brain is a convolution of the picture sharpness of the lens, the capture media (film or video), and that of the reproducing medium (print, display, or projection system). But, the lens is the primary determinant of the final perceived picture sharpness.

## Differentiation between Lens Designs

If we take the above list of imaging attributes – relating to any lens – and arrange them into two groupings it will permit an interesting examination of what primarily distinguishes one lens type from another. The first grouping combines those parameters of the lens behavior that literally "shape" the *content* of the optical image extracted from the object scene. The second grouping relates to the indelible imprint that the lens will leave on the picture produced at the camera output – speaking to those lens performance parameters that directly qualify the subjective *picture quality* of the optical image that has been formed by the lens for presentation to the camera image sensors.

### *Shaping the Optical Image*

- Angle of View
- Zoom Ratio
- Depth of Field
- Perspective
- Aperture

### *Qualifying the Image*

- Contrast
- Color Reproduction
- Picture Sharpness

Clearly, the digital video camera operator exercises a very direct control over the five listed dimensions of the lens imaging system that create or shape the optical image sent to the camera. A combination of these lens attributes, and the artistic manipulation of related lens controls by the cinematographer, bear directly upon the aesthetic result. Separately, the three image "qualifiers" listed can be controlled, to a degree, by optical filtration in front of the lens. They can also be further digitally manipulated within the camera.

## Lens Requirements as a Function of Picture Creation

Lens designs have broadened into extraordinary varieties – each addressing a wide range of capabilities. Ultimately, each design has been tailored and refined to specific production applications. These applications, in turn, are separated by unique operational needs in terms of manipulation of certain "dimensions" of the image. Quite significant differences in the physical size and weight of a lens can be related to the particular priority placed upon operational aspects of the lens control over certain prioritized dimensions of the sought-for optical image.

### *Unique World of Television Live Sports Coverage*

At one extreme – in live television sports coverage – a special weighting is given to a wide zoom range that can be covered at high speed. That is, the ability to rapidly alter the angle of view is inextricably tied to the dynamics of effective capture of fast sports activities. The lens is the supreme interpreter of the action on the field and how this is to be dramatically presented to the viewer. Long shots that can encompass an entire ball field are alternated with medium shots (focusing on a particular flurry of activity involving some players) – and also with extreme close-ups portraying the emotion of an individual

player on the field. That same lens type – which today can achieve zoom ratios up to 100:1 – must also provide a very high sensitivity (or large lens aperture) because sports coverage regularly involves nighttime shooting, or simultaneous imaging of a bright sunlit section of a ball field with another section of that same ball field in a deep stadium-created shadow.

***Imperatives of the Motion Picture Prime Lens***

At another extreme – the shooting of many scenes within a motion picture might call for the most subtle and careful real-time adjustment of both angle of view and the depth of field in concert with scene lighting adjustments. Here, speed of operation is generally not a consideration, but precision is of primary consequence. Precision in the mechanical adjustments, precision in the related focus and iris displays are of paramount importance to the director of photography. Rehearsal and multiple "takes" are a norm here, and speak to a craftsmanship in imaging that is hugely different from, say, television sports coverage.

The director of photography who is sculpting and shaping an image by careful adjustment of scene lighting, optical filtration, picture angle of view, and depth of field, feels an intimacy with what is being created in the viewfinder that invariably demands a close physical tactile relationship with the lens. The director of photography is, after all, engaged in the highly complex process of translating a vision conjured from a three-dimensional live scene into a two-dimensional optical rendition. It is for this reason that the optical viewfinder of the film camera is so beloved – for, it accurately portrays the cinematographer's creation. It is for this reason too, that the Cine lens has evolved to become a distinctly different tool from that of its counterpart in the video world.

The mechanical craftsmanship that typifies the contemporary Cine lens is an expression of the precision sought by the cinematographer who is so central to the creation of the "look" and atmosphere sought by the movie director.

***Unrelenting Demands of the ENG Lens***

Between the two extremes of dexterous long zoom field lenses and Cine prime lenses there is today a very wide range of lens types – with each of them crafted to the many forms of program production that typifies modern television and theatrical presentation. Broadcast News – or Electronic Newsgathering (ENG) – has its own set of shooting imperatives so aptly described by some as "run and gun". Mobility surfaces as a major imperative here, and this is coupled with a need for rapid response in both zoom and focus – for there is rarely opportunity for any rehearsal or second "takes" on the ENG shoot. It is in this highly competitive realm of News that cost pressures are highest and manufacturers have been pressed to relentlessly refine ENG lens design to the most pragmatic combination of low size, weight and power consumption combined with the highest performance allowed the necessary highly cost-effective design and manufacturing.

***Discipline of the Production Studio***

The television News studio, on the other hand, will embody studio cameras mounted on precision pedestals and the discipline of long-established studio practices – so here the lens priorities revert to high performance and precision control of zoom and focus. Both manual lens control (with a video camera operator) and robotic control are deployed. In the case of the latter special lens control systems have been developed.

For the drama studio, the lens will represent the very highest quality possible – with customer expectations for the very best in lens sensitivity, contrast, picture sharpness, and color reproduction.

## Summary

It has been the intent of this paper to draw the larger "landscape" of the modern high definition lens. This includes the multidimensional nature of the lens in terms of its creation of the optical image – and the different priorities placed upon each of these for different program origination applications (that help define quite different lens categories).

The lens for a high-performance digital camera, and especially that for a high definition camera, warrants a careful selection priority commensurate with the imaging results that are expected. The understanding of the degree of control that lens has over all facets of the final digital picture should never be forgotten. The better the optical image presented to the camera sensors the better will be the digital representation transformed by the technological miracle of the modern digital camera system.

Our next paper will examine the high definition broadcast studio zoom lens – from the technical viewpoint of the optical designer's struggle to optimize the multidimensional image HD image.