

A New Innovation in HDTV Studio Lens Design

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Abstract:

The number of HDTV camera systems available today includes traditional field and studio “hard” cameras, portable “soft” cameras and a variety of miniature “POV” cameras. The portable cameras in particular are numerous, and embody most of the sophistication of the larger studio cameras in terms of picture performance, creative features, and system facilities. This reflects the growth of mobile location shooting in HDTV, and an increasing trend to utilize such cameras in the studio as a more cost-effective alternative to the historically popular and larger “hard” cameras.

To date, it has been typical to mount such portable cameras within a “sled” or “build-up kit” in order to configure a studio package capable of supporting the desired larger “box” type studio lens. This, in turn, is a recognition that high-end HDTV studio performance demands the very best that can be optically presented to the portable camera. But, the overall lens-camera assembly is usually large (requiring a commensurate large pedestal) and certainly incurs significant costs.

Recognizing that the use of portable HDTV cameras in the studio continues to grow briskly and that their sophistication would only expand, Canon launched a development project to design a miniature fully-featured studio “box” lens that would mount directly to the portable HD camera. The physical challenges to achieve a lens size, weight, and ergonomic design, aesthetically compatible with the different form factors of the various HD portable cameras were many. The optical challenges were no less significant. Sensitivity, relative light distribution, picture sharpness and contrast, chromatic and geometric aberrations – all had to meet performance expectations of the production studio (rather than those of portable HD EFP). Nor was any compromise possible in the operational performance of the servo-controlled zoom, focus, and iris systems, nor in the interface to robotic and virtual studio systems.

This paper will outline the technologies and techniques underlying a novel design that produced a bona fide HD studio less than a third of the weight of the full-size studio lenses and almost a quarter of the volume – while preserving high quality HDTV studio imaging performance.

XJ25x6.8B IE



Full-body 2/3-Inch
HDTV Studio Lens

New Compact 2/3-Inch
HDTV Studio Lens



XJ22x7.3B IE

1.0 Introduction

High Definition Television (HDTV) is advancing at an increasing pace in the U.S. It is being propelled by vigorous competitive dynamics between terrestrial broadcast, cable and satellite delivery services. A long and protracted preparatory process paved the way for what has at last become a serious marketplace reality. On a global basis, HDTV has also seen significant uptake. Most recently, HDTV has again become a renewed debate in Europe and present indications are that it is likely to be soon embraced by many of their countries and broadcast organizations.

The discussions about the high costs associated with HDTV – for content creators, broadcasters, and consumers alike – continues to preoccupy all. Encouraging indications abound, however, as professional equipment manufacturers aggressively expand R&D in all facets of the program origination and distribution chain. They are embracing new technologies and novel techniques to relentlessly drive down costs.

The HDTV lens is no exception in this quest. The modern studio lens represents the most challenging component of the program production chain in achieving lower costs. Unlike solid-state image sensors, digital processing micro technologies, and digital recording technologies – all of which ride the contemporary curve of fast-paced technological advances and equally fast-paced lowering of costs – optical technologies are historically far more slow moving.

Indeed, the arrival of HDTV was to abruptly thrust optical technologies close to the limit of available scientific capabilities [1] – and initially the associated costs moved entirely in the wrong direction. But the world's major optical manufacturers quickly recognized that HDTV was an inevitable progression in electronic imaging and that the sooner it was grappled with the faster would move the requisite developments. The new studio lens reported on in this paper represents one element of an expanding development agenda to offer new options to the world's producers and broadcasters.

2.0 Categories of Lenses

The broadcast and high-end production arenas are serviced by five distinct lens categories: Field, Studio, Portable Field Production (EFP), Electronic Newsgathering (ENG), and Cine. Each category encompasses design criteria unique to the application – and these criteria affect three distinct attributes of any given lens:

- *Optical* – performance level and operational capabilities
- *Mechanical* – size, weight, and form factor
- *Control* – digital servo systems and related accessories

2.1 The Studio Lens

Among the lens categories described, the traditional studio lens-camera system has long been considered the “flagship” in the context of aspiring to the very highest performance possible. Lens performance is multidimensional – in terms of the many attributes that contribute to the final overall quality of the object image that exits the optical system.

In this studio category, more than the others, the world's broadcasters and producers have relentlessly pressed for higher and higher performance in sensitivity, contrast, color reproduction, and resolution. High aperture optics is the very basis of achieving high optical sensitivity and this has led to larger glass elements. Weight increases dramatically with the diameter of the optics. The achievement of high resolution must grapple with the limits imposed by optical diffraction. Achieving excellence in contrast performance requires meticulous care in the design and manufacturing of each and every element within the lens, the all-important use of multilayer coatings (using ever-evolving and exotic new materials), and ingenuity in mechanical techniques to minimize flare and to manage internal reflections.

The studio lens has evolved to a quite sizeable package over the past sixty years primarily because of an unceasing quest for longer zoom ratios and achievement of the very highest performance. A typical modern studio lens (with a zoom ratio in the vicinity of x 25) will weigh in at 45 – 50 lbs. When mounted on a typical modern studio camera weighing approximately 60-65 lbs (with a 7-inch or 9-inch viewfinder) the total lens-camera system weight is in excess of 100 lbs. A substantial pedestal is required to support such a television imaging system.

3.0 Choices in Studio Lens-Camera Configurations

A broad range of production and operational requirements developed by many end-users around the world have produced a number of variants on the lens-camera configurations deployed in diverse studio environments. A similar situation has evolved within mobile television facilities used for sports, entertainment, and events coverage.

Creative aspirations and budgets enter into the decision on which configuration a given end-user might put into service. Typically these studio configurations separate into three broad forms:

- 1) Traditional larger studio camera head (the “hard” camera) with the larger “box” lens
- 2) Portable camera mounted in a special mechanical support system that can in turn mount the traditional large studio “box” lens
- 3) Portable camera with a portable production lens

The choice among these configurations devolves into overall picture performance expectations, operational requirements (lens and camera controls and their associated displays), system interfaces (robotics, virtual studio, teleprompters, intercom, program audio needs), and often, physical issues (overall size and weight of the total system).

Large Lens Options

Camera	15 lbs
7" VF	10 lbs
Sled	25 lbs
Lens	40 – 50 lbs
Total	< 100 lbs

Portable HD Camera Mounted in Large Lens Adapter System



Traditional "Hard" HD Camera with "Box" Studio Lens

Camera	60 – 65 lbs (with VF)
Lens	40 – 50 lbs
Total	> 100 lbs

Figure 1 Showing the two choices in studio camera configurations that mount the traditional large "Box" studio lens

4.0 Developments in Portable Camera Designs

The concept of a portable production camera (sometimes dubbed the "soft" camera) operating as a companion to the traditional "hard" studio camera was born in the 1970s with the advent of smaller pickup tubes and the growing aspirations of producers and directors for the new creative flexibilities afforded by handheld and shoulder-mounted mobile camera. In the early days there were inescapable compromises in such portable cameras – necessitated by the constricts of the technologies of the time, and the desire for a lower cost than the companion larger studio camera.

The arrival of solid-state imagers and increasingly sophisticated digital processing would ultimately change all that. Slowly and inexorably, the companion studio portable cameras have converged on their larger studio companion in the level of picture performance, operational flexibilities, and systemization that they could offer. Today, many of these portable cameras – both SDTV and HDTV – are virtually indistinguishable from the larger companion studio cameras in performance and creative flexibilities. Only the desire for the very highest performance lenses (necessitating a lens that is large in size), enhanced operational considerations, and better system facilities sustains the popularity of the large "hard" studio camera. To many, these are still very important.

4.1 The Large Lens Adaptor for the Portable Camera

Portable production cameras presently weigh upward of 15lbs (with a typical small 2-inch viewfinder). When mounted within the Large Lens Adapter (sometimes called a System Expander, Build-up Kit, or even a “Sled”) to facilitate support of a full-size studio lens and a large viewfinder (7 or 9-inch being typical) that camera-sled package can reach 65lbs – and, with a 7-inch viewfinder they can often top 80lbs. This is not too far removed from the full studio camera with box lens system.

The biggest advantage, however, of the build-up kit remains the flexibility of system configurability. During certain types of entertainment shows, especially – that might often involve dozens of camera systems – the nature of the coverage can require reconfiguring some of the camera system between a portable handheld system and a full studio system with a large long lens. This requirement is likely to grow as HDTV continues its penetration into all forms of program production – sports, large events, and entertainment extravaganzas.

4.2 Seeking Cost-effective HDTV Acquisition in the Studio

A sizeable number of end-users feel that the performance of current portable cameras does indeed meet many studio needs. Their production budgets simply may not sustain the requisite investment in the full studio camera system with its box lens companion. For some, the use of the build-up kit is not attractive. The lens-camera system cost remains the driving imperative. This can be especially true today with the transition to HDTV and its additional cost premium over SDTV production. Accordingly, some choose to use a portable camera and portable EFP lens on the basis that it is good enough for the application. And, for some studio applications this is true. For those, however, who aspire to the very highest quality studio performance (in prime time drama production and network news studios, for example) there has been the frustration that a bona fide studio lens that is physically compatible with the contemporary portable cameras simply does not exist.

Canon believed that this latter constituency is a growing and important sector of the television production industry and that it warranted an investment in developing a miniaturized full-performance studio lens intended to directly couple to all of the major HDTV and SDTV 2/3-inch portable cameras – without the use of a complex support cradle.

In undertaking to develop such a lens, Canon applied all of the design criteria for a studio lens. Specifically, this entailed careful selection and prioritization of those imaging parameters to which the greater weighting would be applied in seeking a high overall picture performance.

5.0 Priorities in Design of the Studio Lens

5.1 Traditional Studio Performance Expectations

The contemporary studio lens has a long history. It is the category of lens most closely scrutinized in terms of formal technical evaluations by many organizations all over the world. In terms of specific image performance parameters the following are generally agreed to be the key design priorities for the studio lens:

- (a) A high *MTF (Modulation Transfer Function)* characteristic – at picture center as well as the extremities of the picture plane (with as even an MTF characteristic as possible across the image plane)
- (b) Minimization of *lateral chromatic aberration* – that blur and color detail transitions (especially at the extremities of the image plane) – that directly impairs lens MTF
- (c) Achievement of a *maximum relative aperture* – competitive with that of the larger studio “box” lens
- (d) Maximization of *contrast* performance – by minimization of flare and veiling glare at the black extremity, and ghosting and highlight-related optical interferences due to strong light sources
- (e) Optimization of *relative light distribution*
- (f) Minimization of *curvature of field* – one of the classic optical aberrations that contribute to corner defocusing
- (g) Careful control of *spherical* and *comatic* aberrations – to remove an image distortion that can be visually objective
- (h) Elimination to the degree possible of *geometric distortion* – especially at the wider angles of view

In consideration of this listing it should be remembered that the essential dilemma of optical design lies in the unceasing quest to strike an optimum balance between a multiplicity of variables. Performance gains in one area are invariably accompanied by compromises in others. Highly sophisticated (and incredibly complex) management of the enormous number of variable parameters (many conflicting with one another) is the very essence of the optimization strategies developed and refined over decades by the optical manufacturers. These strategies were to prove even more challenging in the ambitious task of miniaturizing an HDTV studio lens.

5.2 Design Goals for a Compact Studio Lens

The challenge facing the designers was to closely match high-end studio box lens performance – per the priority listing above – while simultaneously curtailing the size and weight of the system. The necessary compromises guiding the design of portable EFP and ENG lenses were *not* applicable here. High mobility, small size, and low weight requirements of such lenses dictate priorities quite different to those listed for the studio lens.

A succinct summary of the general design goals for the compact lens were as follows:

- Significantly smaller in *total volume* – than a traditional studio box lens (goal was to achieve one third the total volume of that larger lens)
- *Weight* – approximately equal to that of contemporary portable cameras

- Target full *HDTV studio performance* – to the degree possible
- No compromise whatever in *operational capabilities* – as measured by the precision, repeatability, and speed of operation of the zoom, focus and iris controls
- All contemporary *interfaces* (robotic, virtual studio) to be built-in
- *Creative digital controls* – that match those of high-end studio lens systems

6.0 Final Design Achievements

6.1 The Physical Features

The first decision lay in choosing the diameter of the input port of the lens – as this had a direct bearing on the optical speed of the lens – and would constitute the first critical design choice with respect to overall physical size. This would then be augmented by proprietary innovations in the lens element designs – their specific physical design, the number employed, the different materials used for each, and the multilayer coatings separately deployed on each.

A decision on a 150 mm diameter was settled upon following initial computer simulation. The preservation of full studio configuration of optical elements quickly dictated the overall length of the optical path. Table 1 below compares the physical aspects of the new compact studio lens with that of a current EFP portable HD lens. There is a quite striking increase in glass compared to the portable EFP lens.

	XJ 22 x 7.3 Compact Studio	HJ 22 x 7.6B EFP Portable
Optical Port Diameter (mm)	150	105
Overall Glass Length (mm)	316	222
Weight (lbs)	13.4	6.03

Table 1 Showing the distinctly larger optical system of the Compact Studio lens compared to an EFP portable HD lens of approximately equivalent zoom and wide angle

However, this difference must now be put in perspective with the physical attributes of a full-bodied studio box lens. Table 2 summarizes this (here the new compact lens is compared to the current high-end Canon HD studio lens).

Physical Attributes	Large Studio Lens 25xs	Compact Studio Lens 22xs
Size (mm)	558 (L) x 250 (W) x 255 (H)	336 (L) x 165 (W) x 175 (H)
Weight	47 lbs	13.4 lbs

Table 2 Compares the size and weight of the new Compact Studio lens with that of its full size contemporary “Box” lens

The aesthetics of the lens design is exemplified by how it looks when mounted on all of the contemporary portable HDTV cameras. Figure 2 shows how it appears on three of the current HDTV portable cameras.



With Sony Portable Camera



With Ikegami Portable HD Camera



With Thomson Portable HD Camera

Figure 2 Showing the new compact studio HD lens on three contemporary HDTV portable cameras

6.2 Performance of the Compact Lens

The performance achieved for some of the more salient imaging parameters will be reviewed. The desired wide angle of view and the zoom ratio go hand in hand (in terms of a basic manageable optical design) and the decisions for this compact lens settled on a 7.3mm wide angle extremity (see Table 3 below for the specific angles achieved) and a x22 zoom ratio – both being operational parameters comfortably consistent with most studio needs. This wide an angle of view posed technical challenges to achieving a low geometric distortion – but as reported below the lens design successfully achieved a very contemporary performance level.

6.3 Optical Sensitivity

All optical elements of a lens attenuate the light bundle passing through them. The larger the diameter of the entrance glass port the more light that can be transmitted through the lens system. The unavoidable light attenuation within each and every optical element can be effectively lowered using modern optical materials and the exotic coatings presently available. Multilayer coatings were used on all elements of the lens. The fact that the compact lens comprises a multiplicity of such elements ultimately defines an overall attenuation that is difficult to reduce. This bears directly on the optical sensitivity – or the *geometric aperture* – specification of the lens.

Optical Performance	Large Studio Lens 25xs	Compact Studio Lens 22xs
Max Relative Aperture	1 : 1.5 @ 6.8 to 122mm 1 : 2.1 @ 170mm	1 : 1.8 @ 7.3 to 111.5mm 1 : 2.6 @ 161mm
MOD	0.6m	0.8m
Field of View (Degrees)	70.4 (H) x 43.3 (V) 3.23 (H) x 1.82 (V)	66.7 (H) x 40.6 (V) 3.4 (H) x 1.9 (V)

Table 3 Compares the prominent optical capabilities of the new compact studio lens with that of a large studio HD lens

The current high-end HDTV studio box lens has a maximum relative aperture of 1 : 1.5. The new compact lens was able to achieve a maximum relative aperture of 1 : 1.8 – which holds up over a zoom ratio of almost 16:1. This will address a great deal of normal studio needs. The maximum relative aperture falls to 1 : 2.6 at the telephoto

extremity of 161mm (this being a measure of the “ramping” characteristic inherent to long zoom lenses).

6.4 Lens Resolution and Picture Sharpness

Resolution has historically stood as one of the prominent performance yardsticks for any television camera system – with that system comprising a chosen lens and camera (from two different manufacturers). The specific contribution of the lens to overall picture sharpness is much less understood than the simplistic formal resolution measurements (using appropriate television test charts) typically conducted on competing cameras. With respect to resolution, the lens is technically far more unruly in its behavior than today’s cameras with their well defined solid-state imagers. The fixed sampling lattice of the camera sensors quite precisely predetermines the resolution characteristics of the camera in the horizontal and vertical domain. The complex zoom lens enjoys no such technical order.

The resolution of a lens is its capability to reproduce a subject point. Formal measurements entail examination of the number of lines per millimeter (of the finest black and white line pattern) – and produces numerical values that express the resolving power of the lens. This merely informs on the possible degree of resolution without informing the on the degree of clarity or contrast of the reproduction. Perceived picture sharpness requires this information.

Diffraction limits the radius of the object image delivered by an optical element that is imaging an infinitely small object light source. The diffraction effect is directly proportional to the particular wavelength of that light – thus dictating a resolution behavior that is different for different colors over the visible spectrum. The concatenation of twenty to thirty optical elements within a lens greatly compounds the overall optical system behavior. In addition, lens resolution varies with setting of the lens aperture – typically being at a maximum when the lens is close to wide open. Stopping down the lens lowers the its resolution. Finally, actuation of the zoom function of the lens involves physical movement of multiple lens elements – further perturbing the resolution profile. The very nature of optics disallows constant picture sharpness over the entire image plane.

Today’s optical designers have powerful computing tools that allow exploration of optimization strategies to manage the enormous number of variables that bear on lens resolution. These tools can precisely simulate the characteristics of different optical materials (and considerable advances have emerged in these) and different physical profiles of the lens elements, and their concatenated interactions. This optimization also takes into consideration the special attributes of picture sharpness perceived by the human visual system viewing a television screen that is some distance from the viewer. In managing that optimization the optical designer utilizes the concept of the Modulation Transfer Function (MTF).

6.5 Modulation Transfer Function

For a lens-camera system Modulation Transfer Function (MTF) is a term used to depict the behavior of the *contrast level* of black and white bars of increasing frequencies that are being imaged by the system. The MTF of the system is the modulation of the

contrast level of successively higher black and white sets of bursts. Thus, *contrast performance is inextricably tied to perceived picture sharpness.*

MTF is a curve plotting contrast reproducibility (vertical axis) against spatial detail (horizontal axis) – see Figure 2. The camera designer seeks an optimum MTF characteristic in the horizontal and vertical dimensions of the image – primarily by the choice of the sampling lattice (horizontal and vertical) of the imager employed. The lens designer separately seeks an optimum MTF characteristic across the entire image plane (optics does not provide the luxury of a tidy separation of the two dimensions).

The most defining attribute of an image that is viewed from some distance is the *contrast* that is perceived between different portions of that image. This, in turn, has a direct bearing on perceived picture sharpness. Thus, for the human visual system there is a close relationship between contrast and the ability to resolve fine detail.

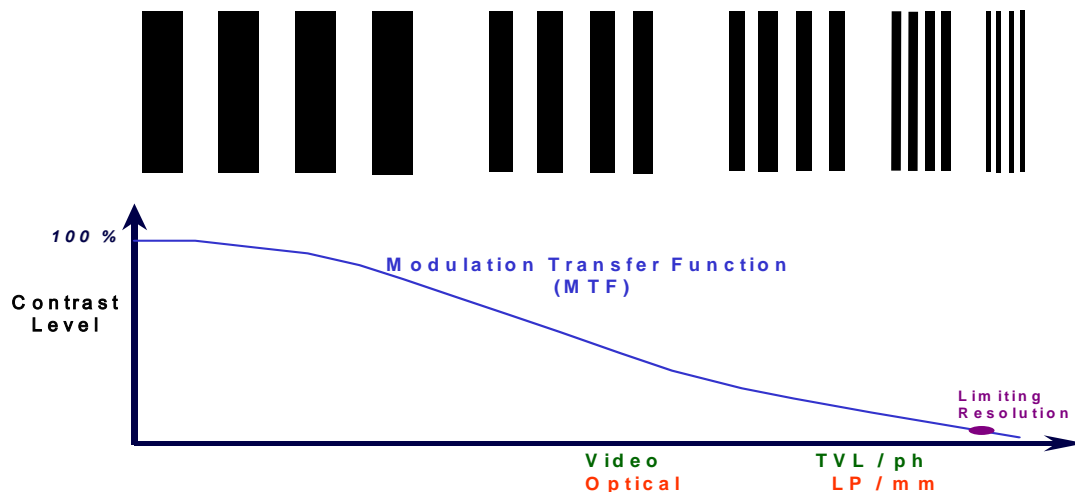


Figure 3 The Modulation Transfer Function (MTF) for an imaging system is defined as the relationship between contrast reproducibility over the spatial frequency range of interest

It is very important to pay close attention to the MTF characteristics of the overall image. Design optimization seeks the best MTF profile from picture center to the four corners – but compromise is inherent to these design strategies. Those compromises can differ significantly between a large studio lens and a much smaller portable EFP/ENG lens.

The traditional studio lens is not hampered by the severe size and weight constraints of the portable lens – and can use larger glass elements (which opens degrees of freedom in optimizing the MTF profile across the image plane) and a greater number of glass elements (offering further degrees of freedom in forming small groups that can compensate for various parameters, including MTF). Yet, the design imperative of this new compact lens still retained some constraints (in size and weight) compared to its larger traditional counterpart – and this posed some special challenges. Figure 4 shows the MTF profile at one particular setting of the focal length and the lens aperture. At the optical reference frequency of 56 LP/mm (or approx 600 TVL/Ph for the 1080-line system) the center to corner results are impressive.

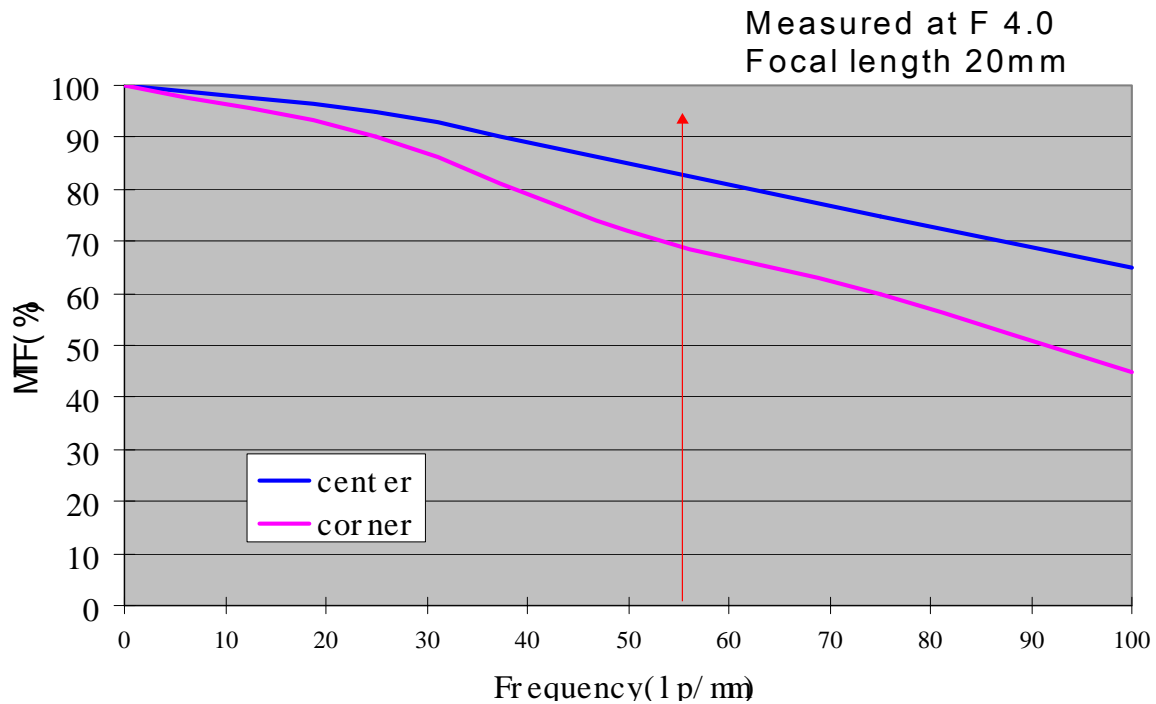


Figure 4 Showing the picture center MTF characteristic and that at the extremities of the image plane

6.6 Contrast

High contrast performance was a special priority for this lens because of the expectations for superb tonal reproduction in high-end studio production. Contrast was extended by meticulous control of black reproduction – with optical and mechanical design innovations that substantially reduced flare, veiling glare, and any internal reflections (special anti-reflection paints are employed on inner mechanical surfaces). Similar attention to minimization of ghost images and other highlight-related chromatic distortions caused by strong light sources (both on-axis and off-axis) further extend the operational contrast range of the lens.

6.7 Color Reproduction

While wrestling with all of the complexities in seeking an optimized MTF performance the lens designer is simultaneously preoccupied with shaping the overall spectral response of the multi-element lens system. This spectral transmittance characteristic of the lens has the first cut at predetermining the overall colorimetry of the camera system. The shape of that spectral transmittance curve (especially at the critical blue and red end of the visual spectrum) must concatenate with both the RGB spectral separation of the digital camera beam-splitting system and the spectral characteristics of its image sensors to implement the final digital camera system colorimetry. This light transmission system must anticipate meeting the colorimetry specified in the SMPTE 274M/296M (and in the international ITU R BT 709) HDTV production standards [2] – when the camera operational controls are set to their detent position. The Studio lens, in particular, must anticipate a close scrutiny in this respect.

The subsequent creative control of the digital camera over color reproduction – to meet production aspirations – must also be taken into account. Here, the ability to digitally alter the prescribed nonlinear transfer characteristic and the color matricing (both linear and nonlinear) from the camera video operational panel to successfully manipulate chosen colors (in brightness, hue, and saturation) does anticipate as wide a color gamut as possible from the lens, beam-splitter, sensor combination. The role of the lens within this combination is sometimes underestimated. Only careful testing will expose the superiority of one lens optimization strategy over another. The spectral transmittance characteristic of the new lens is reproduced in Figure 5 and was carefully structured to fully meet the highest HDTV performance when matched with all of the major HDTV portable production cameras.

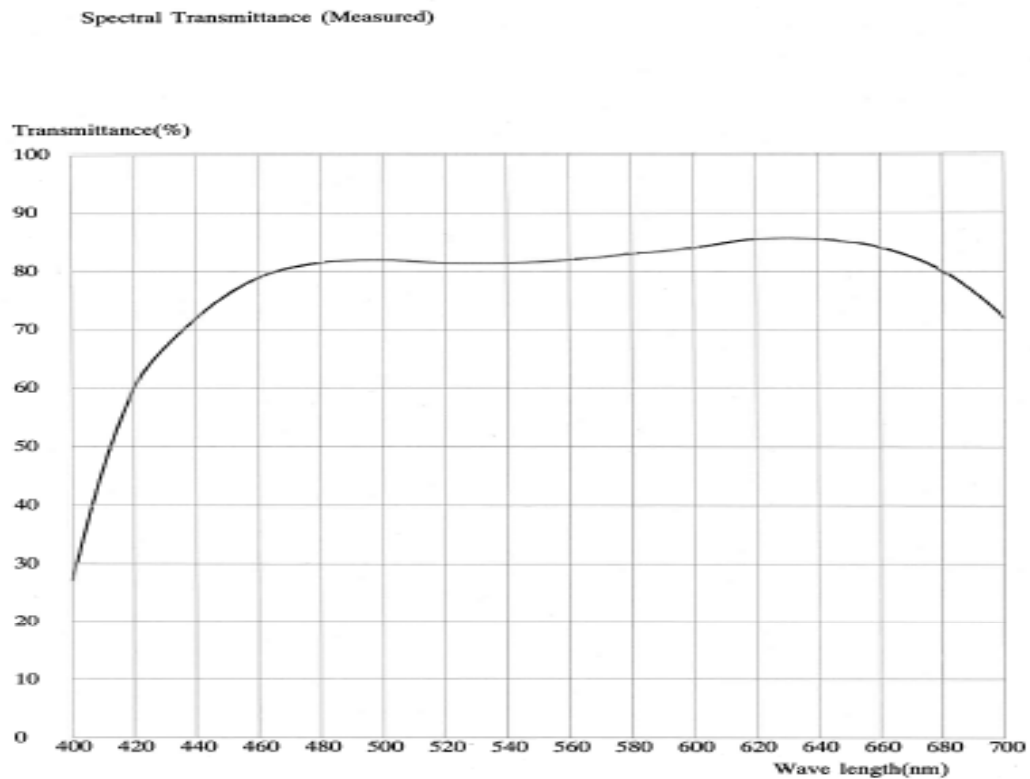


Figure 5 Showing the final spectral transmittance of the new Compact studio lens – achieving an 83% average transmittance and careful shaping of the two extremes of the spectrum for optimum color reproduction

6.8 Relative Light Distribution

The quoted F-number for a given studio lens is a direct measure of the light transmittance of the lens – *at the center of the image plane*. It is another of the frustrations of optical science that this light flux cannot be made perfectly uniform across that plane. Three forms of optical vignetting conspire to lower the light level as one moves from picture center toward the corners of the image plane:

- *Natural vignetting* – where light reaching the image margins decreases as the 4th power of the Cosine of angle of view (this is known as the 4th power cosine law)
- *Optical vignetting* – oblique light rays are presented with a lesser lens opening than on-axis rays (this opening is a full circle for on-axis rays but becomes a progressively narrower ellipse for rays furthest from on-axis)
- *Mechanical vignetting* – caused by extensions added to the lens – lens hoods, matte box holders etc

All contribute to a fall-off in light intensity with field angle of view. This is typically specified as a curve showing that light level shortfall from picture center along a radial termed picture height – as shown in Figure 6. This shortfall worsens as the geometric aperture is progressively opened. A variety of optical and mechanical design techniques have been developed and refined over the decades to ameliorate the degree of this optical limitation.

Light Distribution

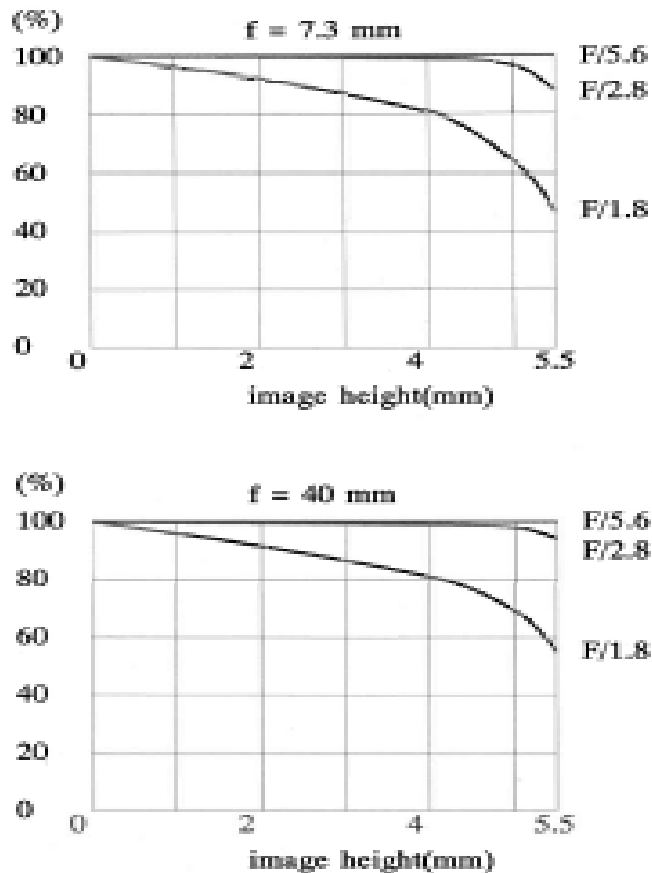


Figure 6 Showing the relative light distribution characteristic of the Compact Studio lens at short focal lengths and with different aperture settings

For the new compact studio lens the relative light distribution achieves a reasonable compromise when the aperture is wide open (competitive with that of the larger HDTV studio lens) where optical physics dictates the effect being greatest. Stopping down a little (to F.28) quickly improves this behavior over the most critical wide-angle focal lengths of interest in the studio – as is evident in Figure 6.

6.9 Optical Aberrations

The television studio lens design has traditionally placed a high priority on eliminating to the degree possible any geometric distortion of the image. Directors seek visually accurate image geometry especially at the short focal lengths (a considerable amount of wide angle shooting is common in contemporary drama production) where geometrical distortions tend to appear most visible on the orthogonal structures within the set.

In seeking a much smaller size studio lens this parameter posed a significant challenge. In addition, the wider 16:9 aspect ratio of HDTV imposes a more severe challenge to managing geometric distortion over the entire zoom range. It is very typical in optimizing the concatenation of geometric distortions across more than thirty elements in the studio lens to seek a compromise that shares this image distortion between its two manifestations – the concave (or “pincushion” form) and the convex (or “barrel” form). Typically, it has been easiest to spread the pincushion distortion over the longer focal lengths and to let this transition to barrel distortion at the short focal lengths.

A variety of optical technologies were mobilized to lower geometrical distortion – especially new lens element designs, and the use of new materials for some of the more critical optical elements within the lens.

The performance level that was ultimately achieved is shown in Figure 7. While the rate of change of the distortion increases at the shorter focal lengths, this is very tightly controlled by highly accurate design and by stringent manufacturing tolerances.

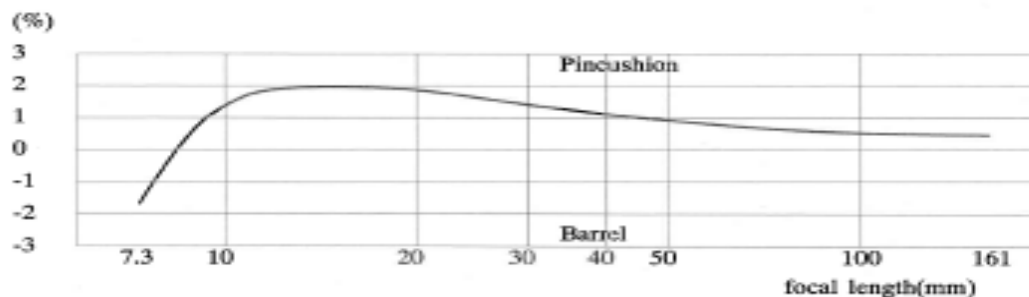


Figure 7 Showing the geometric distortion characteristic of the new compact studio lens

7.0 Digital Augmentations

7.1 Digital Interfaces

Today's studio lenses are expected to have the capability of interfacing with robotic systems and virtual studio systems. The new lens has a 20-pin connector labeled "Virtual" – where the 16-bit digital outputs of the three optical rotary encoders are made available for direct and bidirectional digital communication with digital robotic and virtual studio systems.

Two other 20-pin connectors provide direct communication interface with Canon's digital Zoom and Focus controllers.

An optional PC interface is available for the lens. This facilitates a digital communication link between the lens and a personal computer (using special software developed by Canon) for implementing lens diagnostics.

7.2 Digital Precision of Control

The use of the new miniature optical rotary encoders offers a whole new level of control precision. The combination of the controllers and the high-resolution lens system provides 13-bit repeatability for both zoom and focus. The digital interface with a camera's digital iris control has a 10-bit compatibility.

The Zoom servo provides an exceptionally wide dynamic range of control: From a fast zoom of 0.5 seconds to a super slow zoom of 3 minutes.

7.3 Digital Display

The lens has a built-in informational display (mounted on the side close to the rear of the lens) that provides a great deal of information relating to the many digital operational features that are incorporated into the lens control system.

Different Zoom servo characteristics can be selected that offer wide diversity in creative shaping of the zoom movement. It also supports preprogramming a variety of functions such as automatic shuttling between two chosen focal lengths, preset framing, and presetting of zoom speed.

7.4 Lens Focus Breathing

Focus breathing is a term used to describe an interaction between normal lens focusing action and an undesirable zooming action that accompanies that adjustment. To the program director this is perceived as a very irritating change in image size (basically an alteration in angle of view due to the unwanted zoom action) as the focus control is actuated. In television drama shooting (and historically on motion picture film) the use of rack focusing between a foreground and a background is commonly used to exploit depth of field in a manner that (a) visually translates a 3D effect onto the 2D palette of imaging, or (b) directs viewer attention to specific characters or objects along the depth (z-axis) of the set. Accordingly, focus breathing can be a significant distraction to directors and camera operators when they are attempting to implement such delicate creative focus moves.

Canon initially addressed this problem with an optical innovation [3] in the 1970's. This has since become known as the "*Three Group Internal Focusing Method*" – and it was formally introduced in broadcast EFP lens in 1985 and since that time has been progressively included in a range of Studio and EFP/ENG lenses. This solution was described in a later paper [4]. Ongoing refinements to the technique have continued with every new generation of lens design.

More recently the incorporation of microcomputers within the studio lens control systems has offered a novel new methodology to manage this undesired optical interaction to a degree where the effect is virtually eliminated. In this new compact studio lens a 32-bit microcomputer system works in coordination with 16-bit optical rotary encoders that report on the zoom and focus positions with high precision. As the focus control is operated precise digital calculations are made that in turn operate the physical movement of chosen elements to provide a precise counteraction to the undesired alteration in image angle of view. Focus breathing is virtually eliminated.

8.0 Conclusions

The design of this innovative new compact studio lens reflects an increasing desire to deploy smaller and more cost-effective portable production cameras within studio shooting environments. The relatively higher costs of HDTV program origination products has placed an onus on the professional equipment manufactures to stretch further in their quest for means to aggressively lower these costs. The pace of HDTV market penetration is critically dependent upon their success. The optical manufacturers have joined the camera and recording manufacturers in this quest to mobilize new technologies and new innovations to drive down the costs of HDTV acquisition systems.

HDTV production is still in its infancy. Yet, in the U.S. it already has manifested itself in a quite extraordinary hierarchy of performance and costs. Two separate HDTV production standards allow choices between spatial sampling structures and progressive versus interlace scanning. The 1080-line standard offers multiple picture capture rates – both progressive and interlace. Within the both HDTV standards cameras a variety of CCD and CMOS sampling lattices have emerged within the 2/3-inch standardized image format – offering a variety of MTF performance levels with an associated range of costs.

More recently, 1/2-inch and 1/3-inch image formats have appeared in both the 1080-line and 720-line HDTV production systems – further lowering costs. The associated digital recorders have also separated into an increasing variety of digital sampling structures and compression schemes – again supporting a wide diversity in performance and associated costs. Taken collectively, this quite extraordinary hierarchy in HDTV performance must be seen as driven by real world production applications and budgets.

The HDTV lens still remains a very significant component of the fiscal investment in HDTV camera and recording systems (indeed, some lenses are more expensive than the companion HDTV cameras – such being the pace of digital developments). Canon is presently exploring all of the implications of a lens hierarchy for HDTV. The new

compact studio lens reported upon in this paper is an example of a broadening strategy for HDTV lenses that seeks to march in step with the developments in cameras and recorders. The results of this project are highly encouraging. While the performance of various imaging parameters does not fully match those of the larger studio lenses, the shortfalls are modest. What is important is that the same broad optimization strategies applied to the large studio lens were carefully maintained in this new design in terms of the emphasis on MTF over the image plane, contrast and relative light distribution, optical sensitivity and color reproduction. High performance studio imperatives guided all.

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