The Fox Movietone News Preservation Project: Optical Systems Design

By David A. Grafton

This paper describes the optical systems design for the Fox Movietone News Preservation Project. Among the items discussed are the design considerations, telecentric anamorphic relay lens system, illumination optical system design, and laser sound reading optics.

The film frame and charge-coupled device (CCD) dimensions defined the optical requirements for this project. Two sizes of film formats, one representing a silent full-frame format measuring 0.950 in. x 0.690 in., and the other a regular Academy format measuring 0.825 in. x 0.600 in., are handled by the printer system. These formats are optically relayed so that each format will fit into a square CCD format measuring exactly 0.362 in. on each side.

Design Considerations

The spectral bandwidth of the system was a matter of compromise. Making it wide would allow the flash lamp to be used with a minimum charge per flash, increasing the flash lamp life, but would complicate the optical design with respect to chromatic aberration correction of the replay lens. Figure 1 shows the spectral distribution of the system as a result of these considerations. The spectral bandwidth is centered at 660 nm, with 50% points at 530 and 720 nm, respectively. This choice allows a relatively wide spectral bandwidth throughput while keeping the region in the deep red where it is easier to achieve good chromatic correction, excluding the more difficult blue region.

Objective Lens

To keep film curl at a minimum the film is passed over the gate, which has a 24-in. radius. This cylindrical-shaped curvature imparted to the film object plane was incorporated into the optical design of the anamorphic relay lens.

Finally, depth-of-focus considerations influenced the design of the anamorphic relay objective and made it desirable to make the *f*-number cones subtended at the film plane essentially telecentric; that is, all the chief rays are parallel to the optical axis and to each other for all field locations. This feature is often employed in the design of special effects printer relay lens systems where the depth of focus is required, so that more than one or two film emulsions, when sandwiched together, all yield the same exact size images.

Illumination System

Because these films were decaying and flammable, the system design required that they not be subjected to a normal frame-by-frame exposure. They are transferred to the recording format while being kept in motion at a linear film speed of 18 in./sec. Due to the linear film movement it became necessary to accomplish each frame exposure in the shortest possible time in order to minimize loss of resolution by smear in the direction of the film movement. A flash xenon lamp with the smallest arc dimension commercially available was chosen. Consistent with the exposure requirements of the CCD, the flash duration was in the order of 10 μsec or less. While the small size of this light source permitted fast exposure times, it placed a severe demand upon the optical design of the illumination system.

Sound Reading Optics

There was concern that the stiffness and possible rippling in the film would impair the audio quality of the sound track. This is because conventional sound-track-reading optical systems

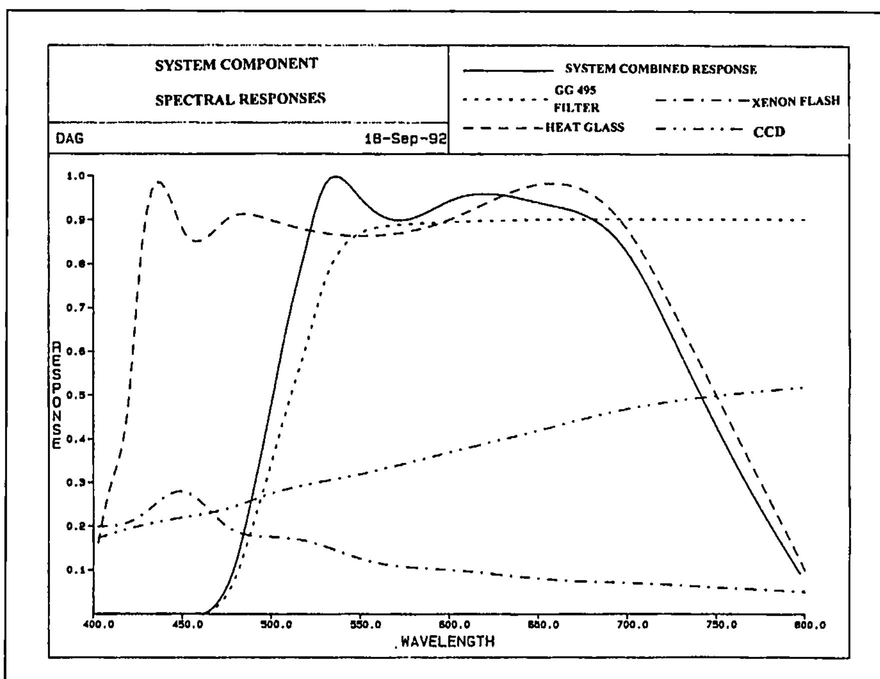


Figure 1. Spectral responses of the system components.

A contribution received from David A. Grafton, Springville, CA 93265.

employ a white light system working into a fast, low *f*-number optical pickup system. Such systems have a relatively short depth of focus. It was decided to use the high brightness associated with a helium-neon (He-Ne) laser combined with the slowest *f*-number optical pickup system consistent with providing the .001 in. wide line reading source required for this purpose. This was the first time that a laser had been used for reading sound tracks. The system provided the required narrow-line light source over a depth of focus many times larger than any conventional sound reproducer optical system.

Telecentric Anamorphic Relay Lens System

Although two different anamorphic reduction ratios are required (silent full aperture and sound Academy), the design is essentially similar for each ratio. The reduction ratio change is accomplished by removing the first two elements of the design and replacing them with another pair of lens elements, which yield the desired magnification changes. In addition to changing the front-end attachment, some refocusing becomes necessary.

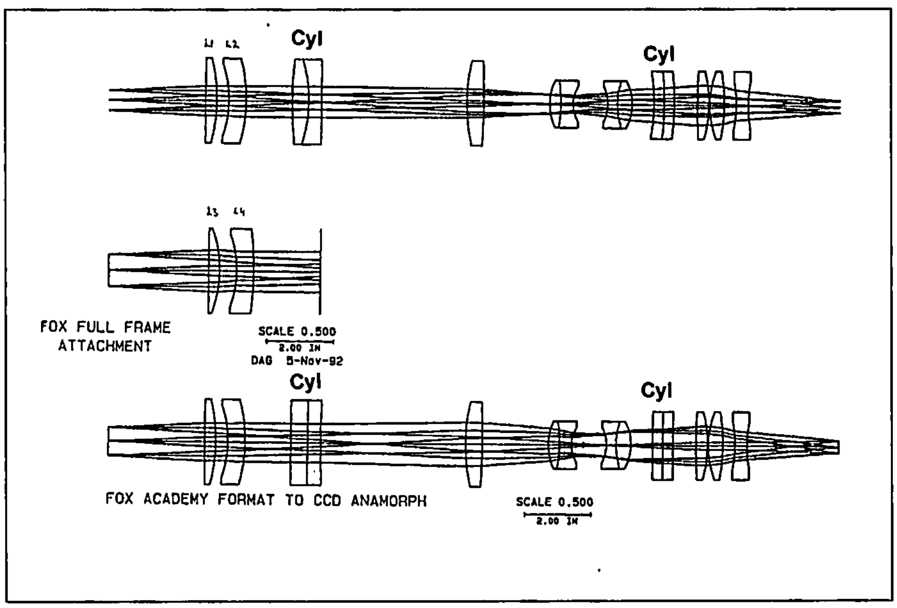


Figure 2. Schematic of anamorphic relay optical lens.

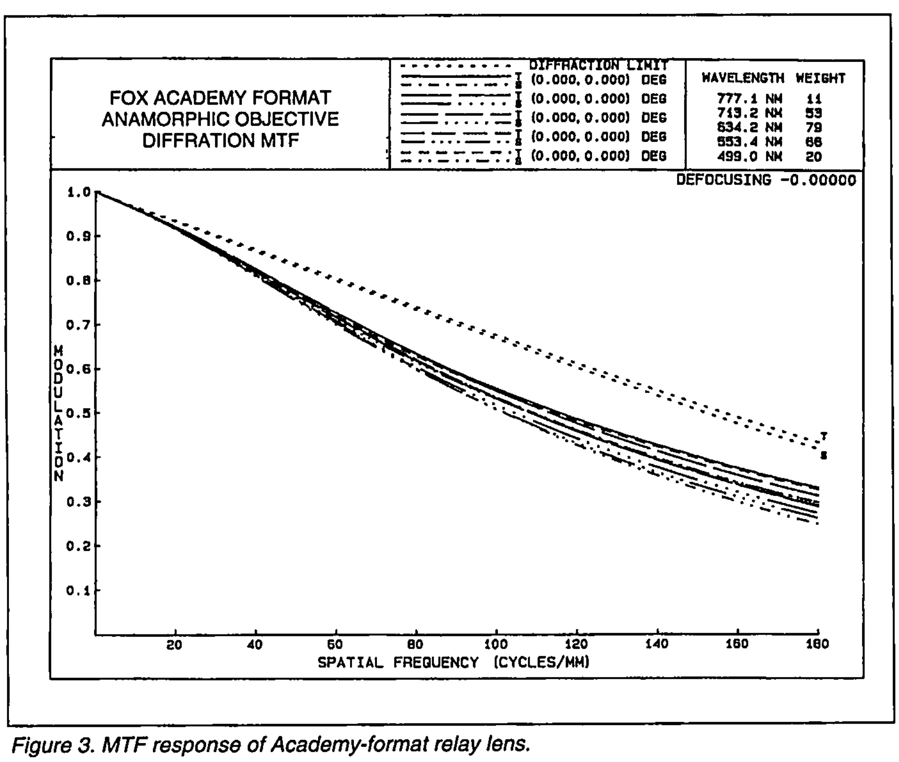


Figure 3. MTF response of Academy-format relay lens.

Figure 2 shows an optical schematic of the 14-element anamorphic relay system, of which four of the elements are cylindrical. The upper drawing shows an Academy format relay viewed from the side of the vertical dimension of the film format. The center schematic shows the full-frame two-element attachment that converts the upper schematic from Academy to full-frame format. The lower schematic shows the Academy relay when viewed looking down upon the horizontal film format. It is clear from the upper and lower schematics just which elements are cylindrical, yielding the required anamorphic squeeze ratios.

The *f*-number subtended at the CCD image plane in the horizontal film direction is *f*4.8. In the vertical film direction it is *f*6.6. The *f*-number of the telecentric rays subtended at the film plane is *f*11. The design objective was to ensure that the modulation transfer function (MTF) performance at any location within the CCD format exceeded 100 line pairs/mm, 50% resolved. Figure 3 shows the MTF for five field locations for the Academy format at the plane of best focus; Fig. 4 shows the same data for the full-frame-format objective.

Illumination Optical System Design

The optical design of the illumination system was somewhat challenging. The xenon flash "nominal" arc size was given as 0.125 in. x 0.09 in. For design purposes it was assumed to be 0.1 in. round. Figure 5 shows an optical schematic of the illumination system, which is composed of six optical elements and two filter elements. It provides the required *f*11 telecentric cones at the film plane. Filters W1 and W2 consist of a heat-absorbing filter and a Schott GG495 red cutoff filter. L2 through L6 geometrically image the arc at the intermediate image plane at a reduction of about 2.5 times at the lamp electrode plane. As can be seen, a good image of the film plane is formed about 1.2 in. ahead of L4, while the final rays subtended at the arc plane reach a half angle of 38° maximum.

The important feature of this illumination design is that each bundle of rays reaching the arc lamp from any portion of the film plane field locations arrive at the arc source almost perfectly collimated. This essentially keeps the image of the arc source as far as possible from becoming imaged at the film plane. Under such circumstances the intensity variations within the arc itself do not effect the uniformity of illumination achieved at the film plane. Figure 6 gives a magnified look at the ray bundles as they approach the arc source. (Note that each of the ray bundles is well collimated.)

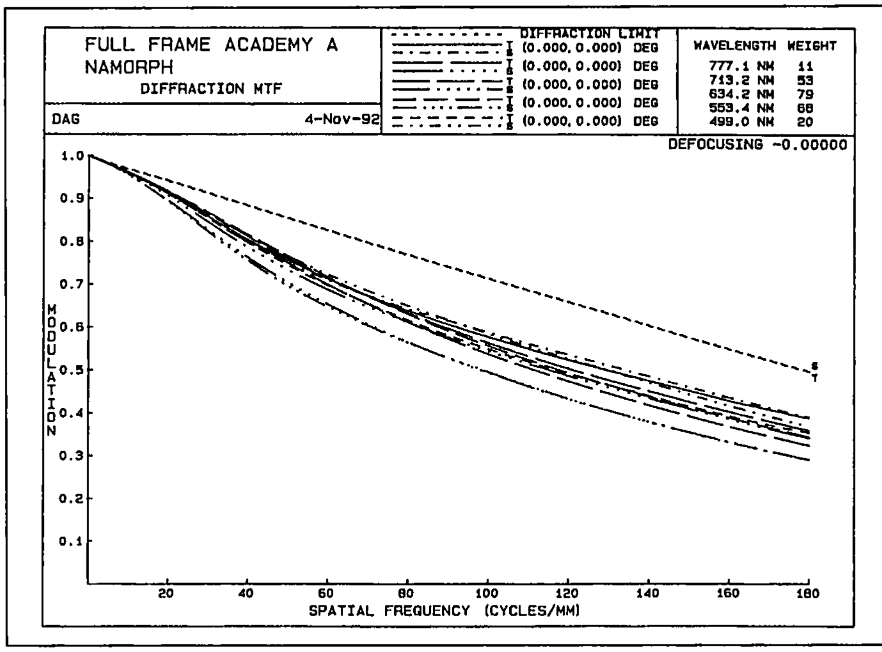


Figure 4. MTF response of full-frame-format relay lens.

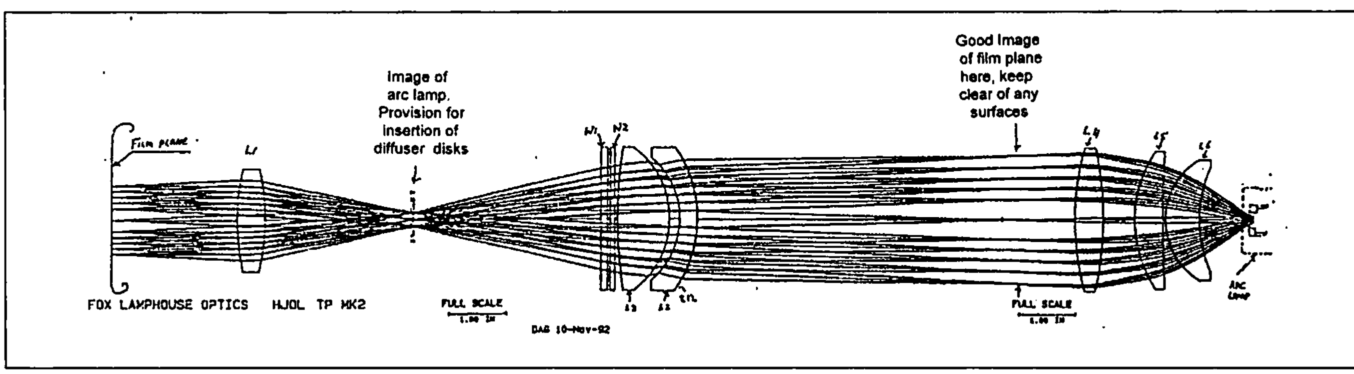


Figure 5. Optical schematic of illumination system.

The practical disadvantage of such a system is that, due to the small size of the arc source, any minute blemishes or bubbles that may exist within optical elements can show up as fixed contours of variable illumination at the film plane. To minimize this problem lenses L4 through L5 were made of special high-quality fused quartz, since all the ray bundles traveling through these three lenses have smallest physical dimensions. If such blemish marks were to occur, then it would have been necessary to insert some diffusion at the intermediate arc source image plane, resulting in not only a loss of illumination but also some loss in uniformity. In practice this rather highly specular illumination system worked very well, and no diffusion was necessary.

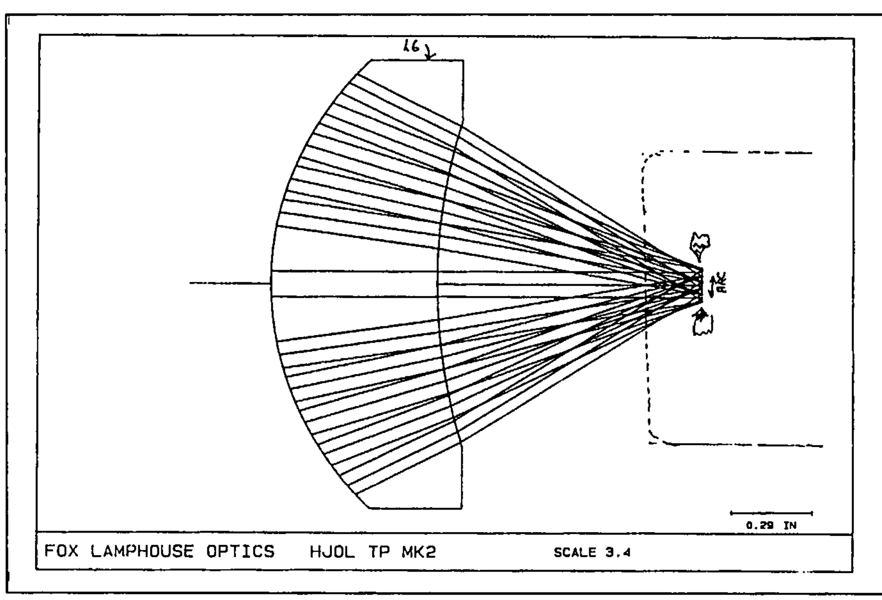


Figure 6. Optical schematic of ray convergence at arc lamp.

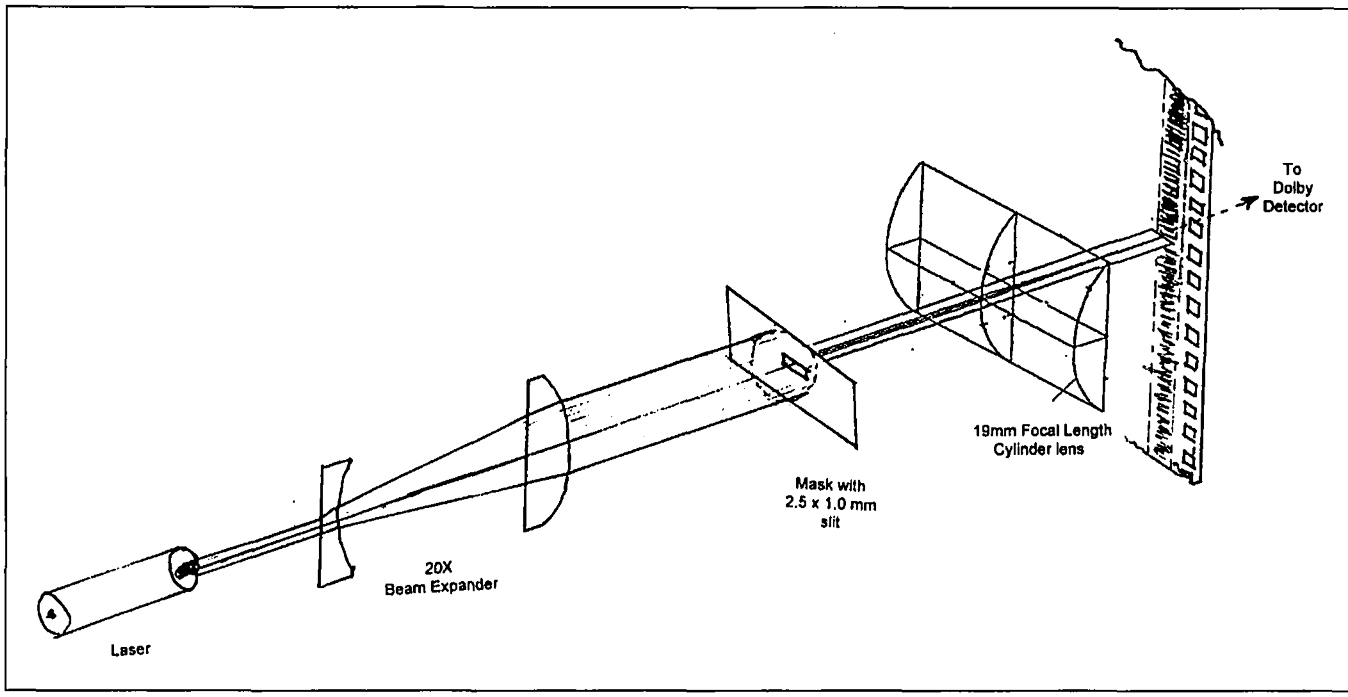


Figure 7. Optical schematic of laser sound reader system.

Laser Sound Reading Optics

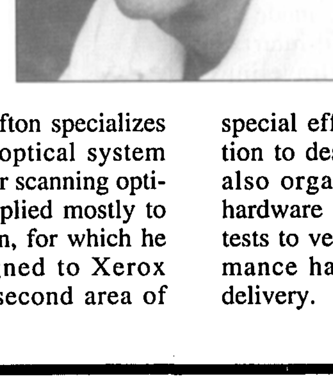
The object of using a He-Ne laser and the associated optical system for reading the sound tracks was to achieve the largest possible depth of focus and a large working distance at the sound detector plane. The required light source dimensions for illuminating the sound track are a horizontal dimension of 0.1 in. and a line width of 0.001 in.

The optical configuration is very simple. The He-Ne laser has a nominal beam diameter of 0.5 mm at the 13.5% intensity points. This beam was fed into an off-the-shelf 20X beam expander, producing a round collimated beam about 10 mm in diameter.

This was made incident upon a slit mask 2.5 mm long x 1 mm high. The emerging beam was then made incident upon a plano convex cylinder 19 mm in focal length. Placing the 2.5-mm dimension of the beam along the no-power direction of the cylinder and the 1-mm dimension of the slit along the power direction of the cylinder results in a diffraction-limited *f*/19 focused beam, 2.5 mm long. The focused direction produces a beam about 20 μ wide at the 13.5% points, or 26 μ at the minimum of an airy diffraction distribution. These results were observed in practice.

This system not only provides a good depth of focus, but also provides a large working distance of about 17 mm from the plano surface of the cylindrical focusing objective. Figure 7 shows a sketch of the system described.

THE AUTHOR



David A. Grafton retired from Xerox Corp. after a ten-year period and is now an independent optical systems scientist and consultant in Springville, Calif. Prior to joining Xerox he held the position of senior scientist executing optical system design tasks at EG&G Inc., National Cash Register Co., and IBM. Grafton specializes in two categories of optical system design. The first is laser scanning optical systems design, applied mostly to laser printer application, for which he holds several (assigned to Xerox Corp.) patents. The second area of specialty is the design of relay and anamorphic relay lens systems for special effects optical printer systems, which are used by the major film studios.

Grafton has received two scientific and engineering awards from the Academy of Motion Picture Arts and Sciences, one in 1980 and one in 1986, for special effects lens designs. In addition to designing optical systems, he also organizes their translation to hardware and executes optical bench tests to verify that appropriate performance has been achieved prior to delivery.