Basic Optics of a Television Film Chain

A TUTORIAL PAPER

By D. F. LYMAN and A. E. NEUMER, JR.

The fundamental optical principles involved in the projection of film into a television camera are reviewed. First, direct projection into a vidicon tube is cited. Then the relay system with its intermediate image is described in terms of the function of each optical element, the importance of proper alignment, and the mistakes to be avoided when a film chain is set up. Next, the requirements of multiplexing systems are discussed. Finally, three basic optical formulas are given by which approximate values can be obtained to aid in the design and coordination of equipment.

THE FILM CHAIN in television broadcasting is usually comprised of several 16mm motion-picture projectors, a slide projector, an optical multiplexer, and the vidicon camera. With several projectors feeding the same vidicon camera, the optical path must be long so the mirrors or prisms can be inserted in the path to accommodate the various inputs. The long optical path and the critical nature of the vidicon camera require great care in choosing and aligning the various optical components.

The purpose of this article is to review the fundamental optical principles involved in the projection of film into a television camera. Shown, step by step, are the functions of the optical elements. The importance of proper alignment is shown, also the mistakes to be avoided when a film chain is set up.

A contribution submitted November 13, 1962, by D. F. Lyman and A. E. Neumer, Jr., Eastman Kodak Co., Apparatus & Optical Div., Hawk-Eye Works, Rochester 4, N.Y.

Uniplex Operation

The simplest way of transferring the film image to the photosensitive surface of the television tube is by direct projection, as illustrated in Figs. 1A and 1B. As can be seen, only a single projection lens is needed; there is no objective lens on the television camera. It functions in exactly the same way as a slide projector does in projecting an image onto a screen, the screen in this case being the face of the vidicon tube.

This method is commonly used when multiplexing is not necessary. Depending on the focal length of the projection lens, the system can be made long or short. The face of the vidicon tube is only slightly larger than the image on the 16mm film. This low magnification ratio between the film and the television tube means that the projection lens must be extended a relatively long distance from the film plane. For this reason, care should be taken to avoid vibration in the projection system.

The Relay System

Another method of constructing a film chain is by means of a "relay" system, as shown in Figs. 2A and 2B. The description "relay" arises from the fact that an intermediate image is formed in space by the projection lens; a second lens, on the vidicon camera, relays the final image to the plane of the photosensitive surface of the television camera tube.

For purposes of demonstration we have set up a simple optical bench, shown in Figs. 3A and 3B. The system is made up of a simple slide projector,

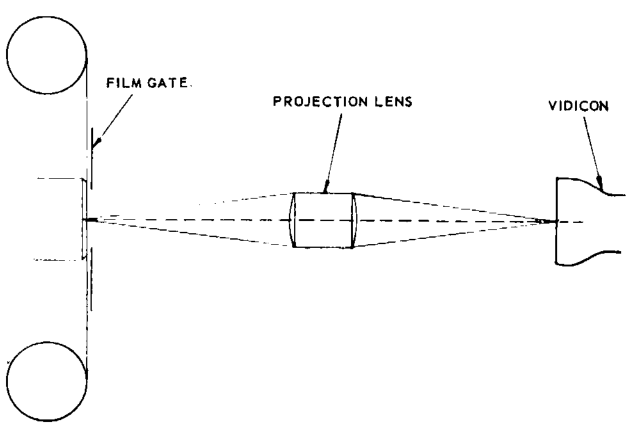


Figure 1A

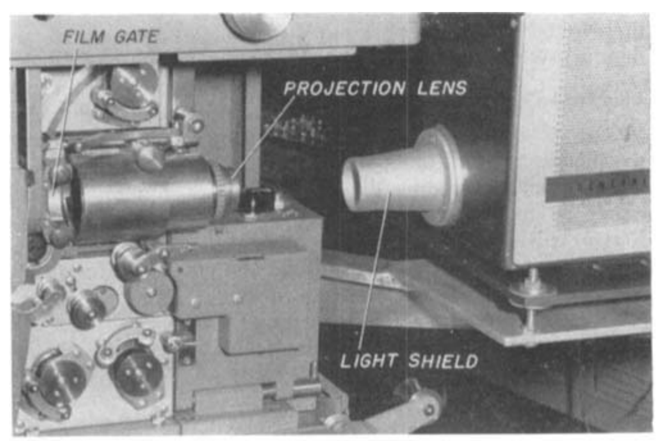


Figure 1B

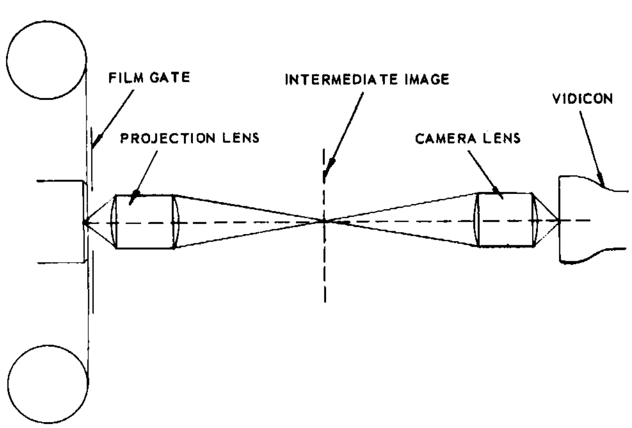


Figure 2A

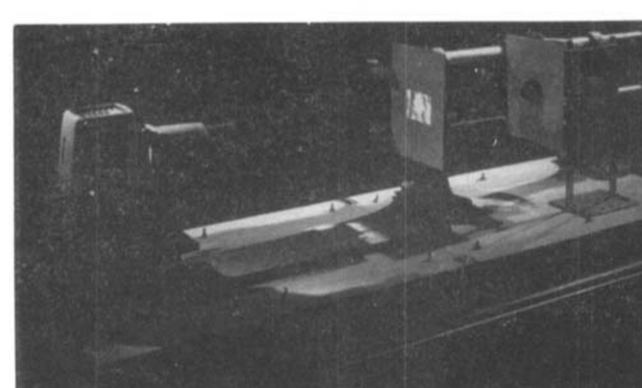


Figure 2B

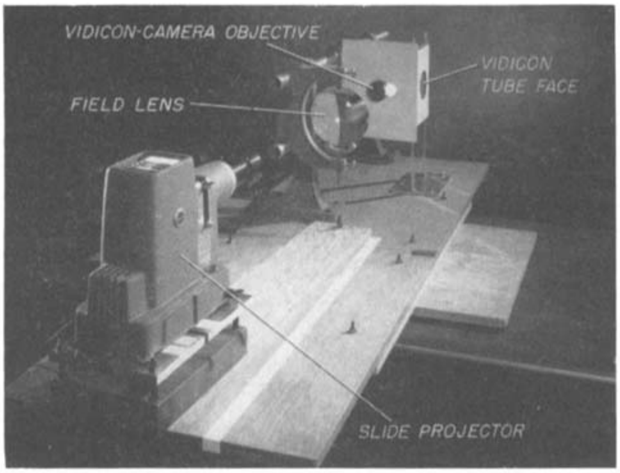


Figure 3A

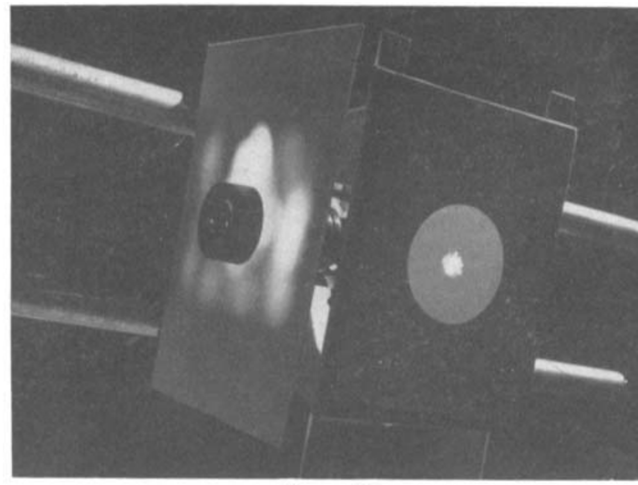


Figure 3B

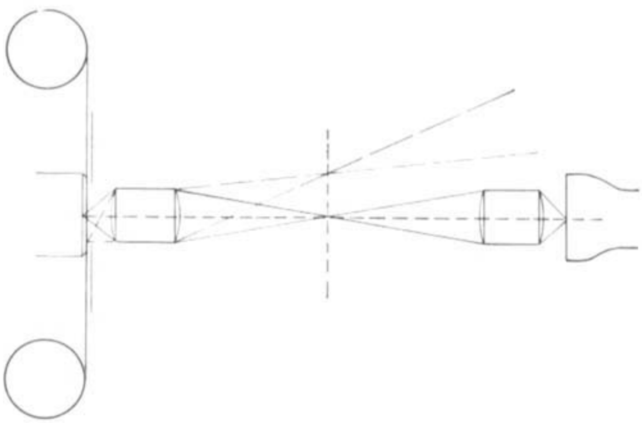


Figure 3C

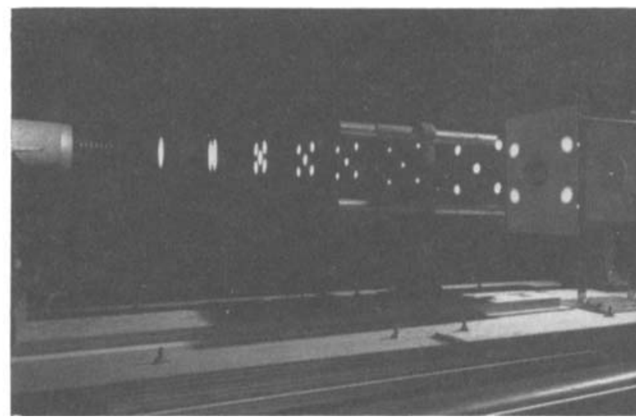


Figure 3D

an intermediate-image plane (indicated by the field lens), a vidicon-objective lens, and a rear-projection screen to simulate the photosensitive surface of the face of the vidicon tube. For convenience in viewing the image on the tube face, we have put a 45° mirror behind the vidicon-objective lens to deflect the image 90°, as shown in Fig. 4A. Thus, as we watch the image on this circular screen, it looks the way it would if we were inside the vidicon tube.

The Intermediate Image

As shown in Fig. 2B, with this relay system we can insert a screen in the intermediate-image plane and see the image formed there. This is very useful for alignment and focusing. The entire image is formed in the intermediate plane; but Fig. 3B shows that only the center portion of the picture reappears in the plane of the camera tube because the remainder misses the vidicon-camera lens. The reason for this is shown in Fig. 3C. Here, we have added to the diagram broken lines indicating a cone of light coming from the corner of the film frame. Note that the cone of light comes to a focus in the intermediate-image plane but then spreads out and completely misses the camera lens.

We can demonstrate this by inserting in the film plane of our slide projector an opaque slide having five small holes, one in the center of the frame and one in each corner. Figure 3D is a multiple exposure of the five light beams. They come to focus at the intermediate-image plane but continue to diverge as they approach the vidicon-objective lens. Only the center beam gets through to the circular vidicon surface.

We can correct this situation by inserting some diffusing material, like ground glass, in the intermediate-image plane. This is shown in Fig. 4B. Now the light striking the ground glass from the left is scattered in all directions. Hence, some of the light rays from the cones at each corner will be redirected into the camera lens; the entire image will be re-formed in the camera-tube plane, as seen in Fig. 4C. But we have paid a price for this; the center spot is dimmer than it was in Fig. 3D because the ground glass has scattered some of the light from this beam, light that previously got through the camera lens. Not only is the center spot reduced in brightness, but the corners are even less bright, resulting in a "hot spot." This is because the ground glass is not a perfect diffuser; after the light passes through the glass, the intensity of the light is always greatest along the axis of the incident beam. This is further illustrated in Fig. 4D. Here the shading across the face of the vidicon tube is evident when a blank slide is substituted for the five-hole slide.

The Field Lens

Instead of ground glass we can insert a lens called a field lens in the intermediate-image plane as shown in Fig. 5A. The action of the lens is such that the light rays passing through the center are essentially undisturbed, but the corner rays are refracted, or bent, toward the camera lens. We can now reconstruct the full picture. Also, since no light is lost due to scattering, the picture will be brighter and more uniform than it was with the ground glass.

The convergence of the light beams by the field lens is clearly shown in Fig. 5B for the five-hole slide, and in Fig. 5C for the picture slide. In both cases note that all the light passes through the vidicon-objective lens — resulting in a complete, uniformly bright picture on the tube face.

The power of the field lens must be chosen carefully. For example, if the field lens is too weak, as shown in Fig. 6, the corner beams of light will not be bent enough to converge on the lens of the vidicon camera. It is clear that

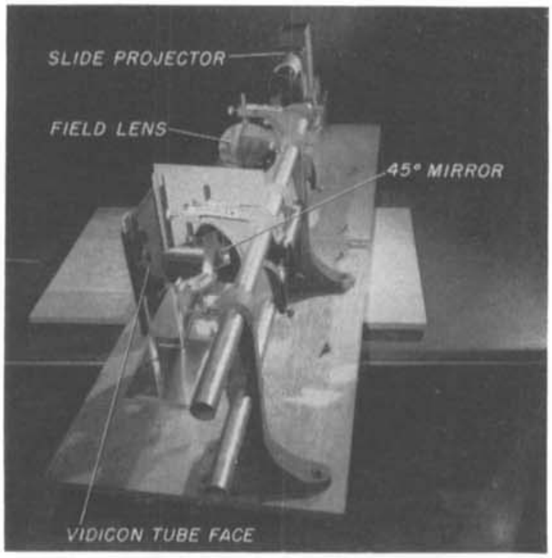


Figure 4A

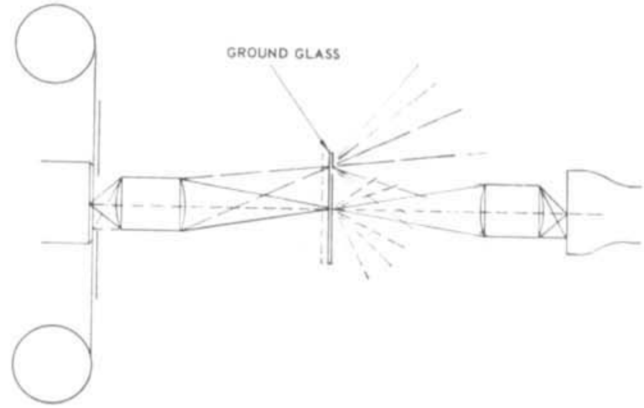


Figure 4B

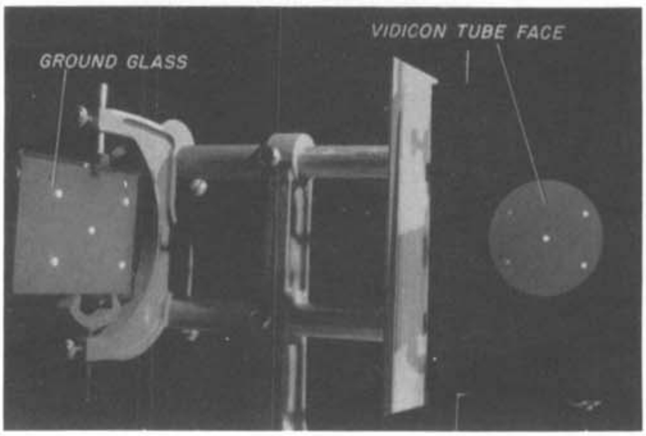


Figure 4C

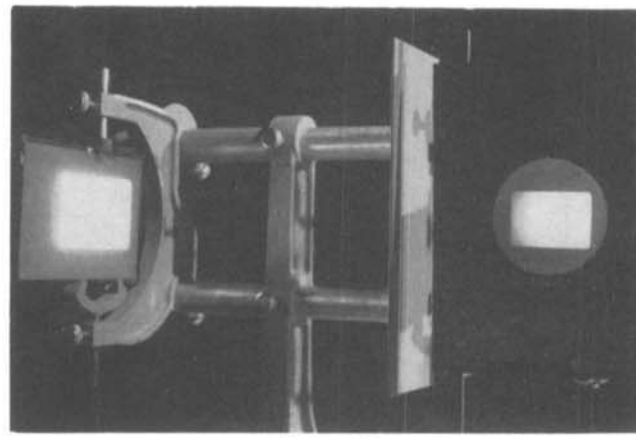


Figure 4D

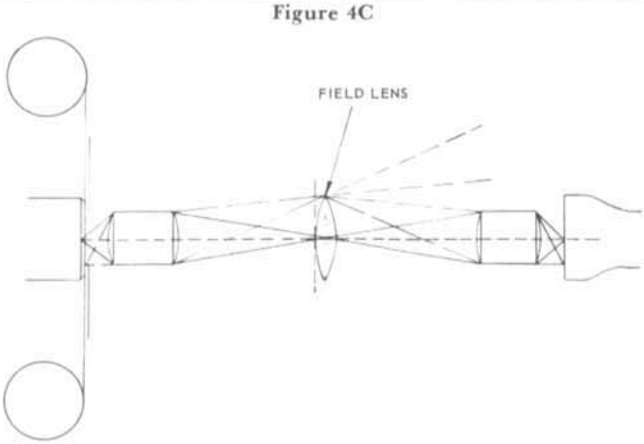


Figure 5A

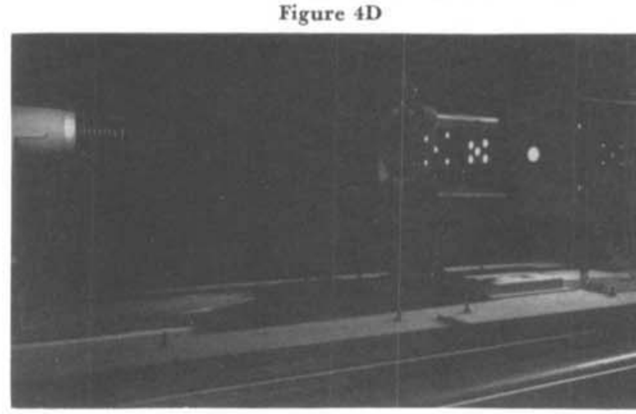


Figure 5B

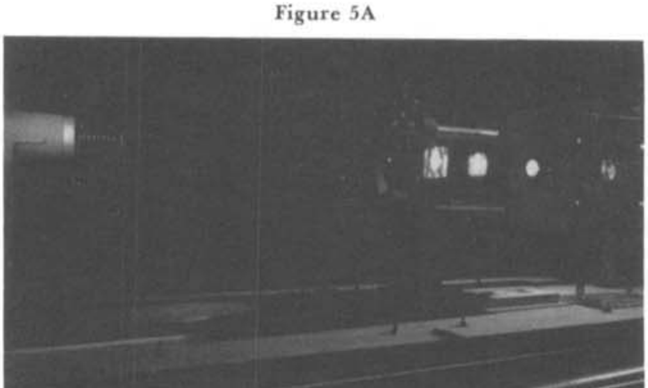


Figure 5C

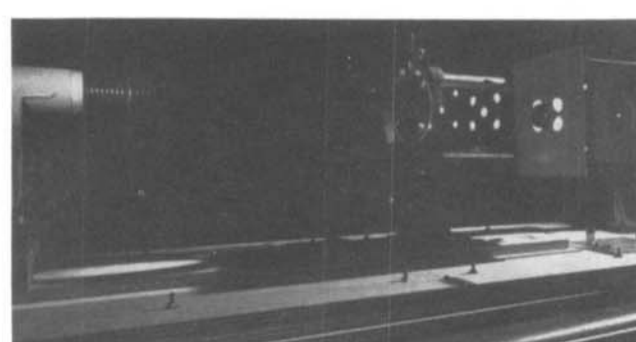


Figure 6

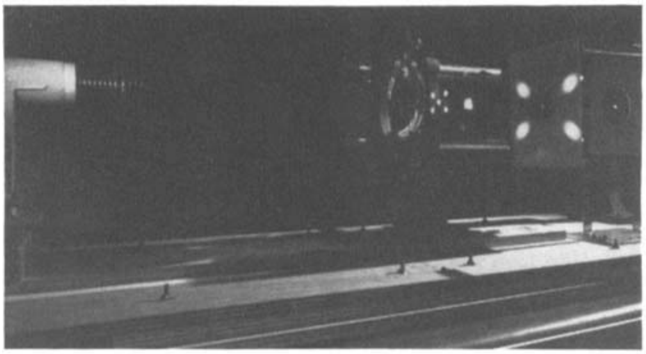


Figure 7

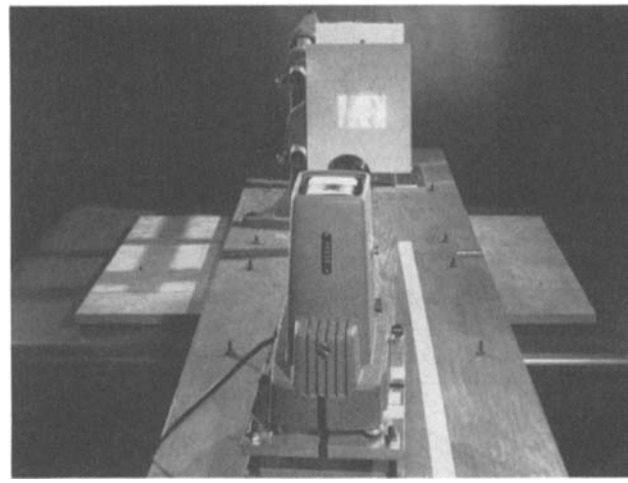


Figure 8

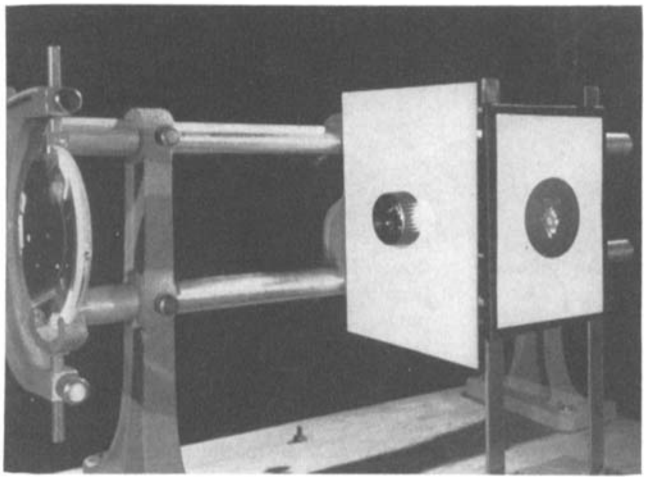
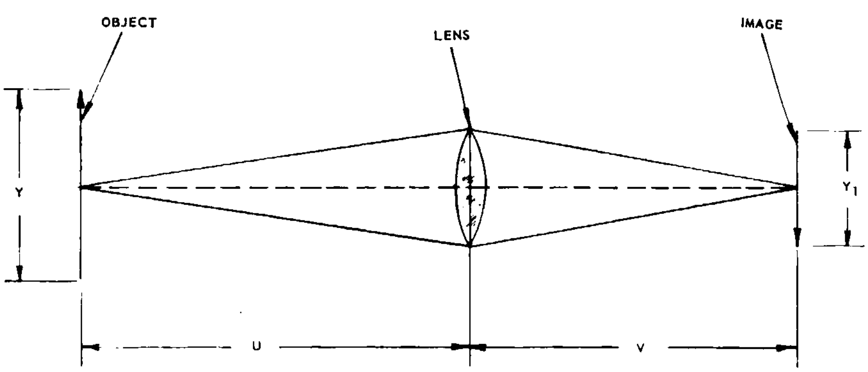


Figure 9



1 $\frac{1}{U} + \frac{1}{V} = \frac{1}{F}$

2 $M = \frac{U}{V} = \frac{Y}{Y_1}$

3 $U = F(1 + M)$

F = FOCAL LENGTH

M = MAGNIFICATION

Fig. 10. Basic lens formulas.

the entire picture will not get through. On the other hand, if the field lens is too strong, the convergence occurs in a plane ahead of the camera lens, as seen in Fig. 7. Beyond this plane the corner beams diverge, so they again miss the vidicon-objective lens.

To illustrate this principle we have deliberately used field lenses that are excessively weak or excessively strong. But even with less departure from optimum design the picture on the face of the vidicon tube would have been shaded.

In order to assure maximum optical efficiency, the convergence of the light beams must occur at the entrance pupil (in most cases at the front of the lens) of the vidicon camera objective; also, this entrance pupil must be large enough to collect the entire beam.

Proper Alignment

With the demonstration optical bench we can show also the importance of proper alignment. We have arranged our projector on a board that is pivoted directly below the center of the field lens. We have swung the projector off axis, as indicated by the white line on the board in Fig. 8. When we do this, we see that the image at the intermediate plane is still centered and generally quite acceptable. Had we been aligning a projector with a multiplexer and evaluating the picture at the field-lens position alone, we might have assumed that our alignment was correct. However, Fig. 9 shows the adverse result of this misalignment. The light beam is decentered with respect to the vidicon lens; and as a result, the image on the face of the vidicon tube is badly shaded at the sides. Of course, vertical misalignment would cause shading at the top or bottom of the final picture.

The relay system we have shown is the one most commonly used in television film chains. For simplicity we have shown a single projector input, but the system can readily be converted to a multiplex system by the insertion of one or more mirrors or prisms between the projection lens and the field lens. In this article we have demonstrated the function of each optical element. It should be remembered that each component depends on all the others and that the system must be an integrated design if it is to work efficiently.

Practical Applications

Now that the principles of the relay system have been considered, it will be easier to discuss multiplexing and multiplexers. While there are many ways to arrange projectors and cameras for multiplexing, in most cases a multiplexer consists of a bench or stand that supports mirrors or prisms (to direct the beams from the projectors to the camera), a focusing and alignment screen, a field lens and, sometimes, the camera itself.

There are several variables for the projector manufacturer to consider as he designs his projectors to work with existing multiplexers. For example, picture widths at the field lens vary between 2.5 and 4.44 in. Field-lens power varies from 2.79 to 8.0 diopters.

A review of certain optical formulas will help in the simple calculations required to properly match pieces of

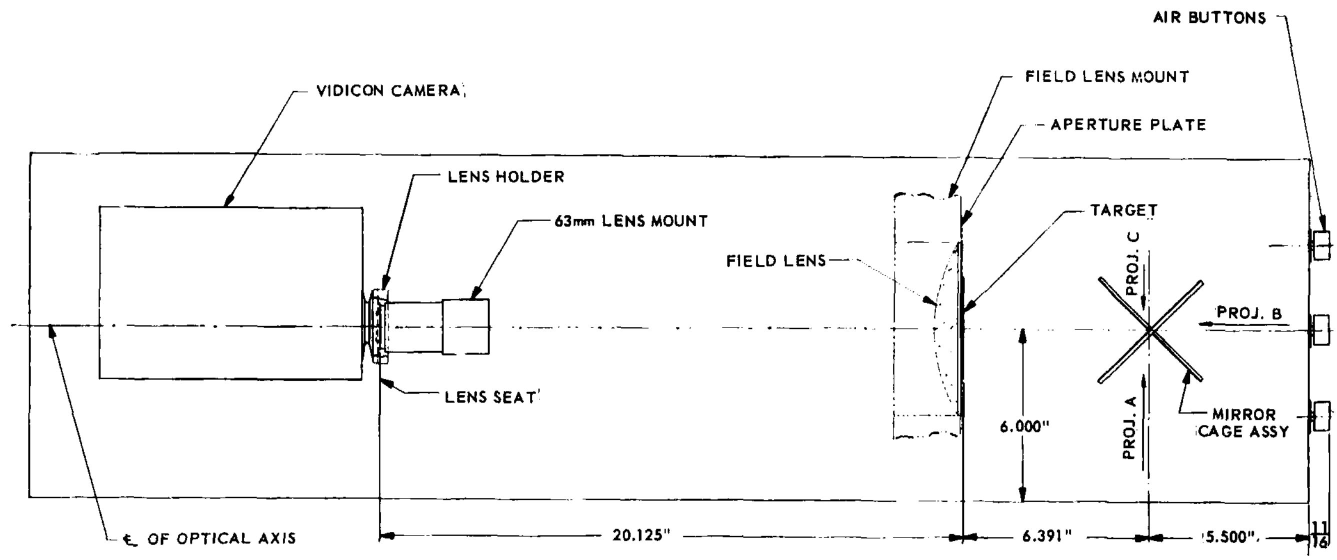


Figure 11. Optical layout for Eastman Pneumatic Multiplexer, Model 1, (GE PF-11-A).

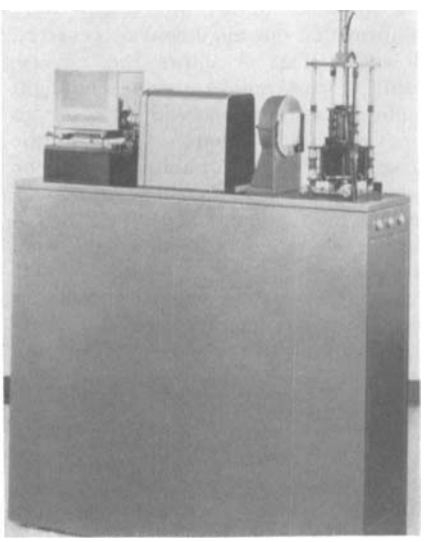


Fig. 12. Eastman Pneumatic Multiplexer.

equipment. From the basic formulas shown in Fig. 10 it is possible to obtain approximate values, as shown in the following examples. For more exact work it is necessary to know the locations of the gauss points in the lenses; but, since they are often near the center of the objective, the approximations may be of value.

Problem 1: Find the projection throw, that is, the distance from the projection lens to the image at the field lens.

Given: picture width at the field lens = Y = 3.8 in. (assumed)
picture width at the film gate = Y_1 = .380 in.
projection lens focal length = F = 3.5 in. (often used on projectors)

Solution: $M = \frac{Y}{Y_1} = \frac{3.8}{.380} = 10$
$M + 1 = 11$
$U = F(M + 1) = 3.5 \times 11 = 38.5$ in.

Problem 2: Find the distance from the field lens to the vidicon-camera lens.

Given: picture width at the field lens = Y = 3.8 in. (as in Problem 1)
picture width on the surface of the vidicon tube = Y_1 = .500 in.
camera lens focal length = F = 2 in.

Solution: $M = \frac{Y}{Y_1} = \frac{3.8}{.500} = 7.6$
$M + 1 = 8.6$
$U = F(M + 1) = 2 \times 8.6 = 17.2$ in.

Problem 3: Find the power of the field lens; that is, its focal length if the U and V values are as calculated in Problems 1 and 2.

Given: U = 38.5 in. (from Problem 1)
V = 17.2 in. (from Problem 2)

Solution: $M = \frac{U}{V} = \frac{38.5}{17.2} = 2.24$
$M + 1 = 3.24$
$F = \frac{U}{M + 1} = \frac{38.5}{3.24} = 11.9$ in.

Power in diopters $= \frac{39.37}{11.9} = 3.3$ diopters

(Diopters $= \frac{1}{F(\text{in meters})}$. In this case F in meters equals $\frac{11.9}{39.37}$ since there are 39.37 in./meter. Thus, diopters $= \frac{1}{11.9/39.37} = \frac{39.37}{11.9} = 3.3$ diopters, as shown above.)

Design of a Multiplexer

The choice of the focal length of the vidicon camera lens is too often based on space considerations. In general, it is advisable to make its focal length long in order to keep the angle subtended by the picture as small as possible. This improves flatness of field and keeps the power of the field lens low, which reduces spherical aberration. This aberration is troublesome because it focuses the rays from different parts of the field lens at different distances, whereas they should be focused in one plane at the entrance pupil of the vidicon lens. Other aberrations become serious if the picture is not formed exactly in the plane of the field lens; the stronger the field lens, the more serious these effects become. Distortion is always a problem.

In the relay type of system, there are really two systems that must work in close harmony if good results are to be obtained. There is an image-forming system that is vital to transmission of the information in the picture, and there is an illumination system that must be efficient enough to fulfill the requirements of the vidicon tube. Both systems work better if the angles of the lenses are kept small. Field-lens powers should not be allowed to exceed 3 to 4 diopters if it can be avoided.

When the fundamental requirements outlined above had been considered in relation to the multiplexers now in existence, it seemed important to make a new approach to multiplexing. This was to provide the best optical system that could be devised for the projection of film into a vidicon chain, a system that would make no compromises with respect to resolution, contrast, illumination, fidelity of color and centering of the image. This dictated the substitution of front-surfaced mirrors for beam splitters or prisms, and it resulted in the arrangement of crossed mirrors shown in Figs. 11 and 12. Shown in Fig. 12 is the Eastman Pneumatic Multiplexer, Model I (GE PF-11-A). It has a 3.2-diopter field lens, a picture width of 3.140 in. and a 63mm vidicon camera lens. There are three projector positions.