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Introduction

The ATA provides an electron beam pulse of 70-ns duration at a 1-Hz rate. Our present optical diagnostics technique involve the imaging of the visible light generated [1] by the beam incident onto the plane of a thin sheet of material. It has already been demonstrated [2,3] that the light generated has a sufficiently fast temporal response in performing beam diagnostics. Not withstanding possible beam emittance degradation due to scattering in the thin sheet, the observation of beam spatial profiles with relatively high efficiencies has provided data complementary to that obtained from beam wall current monitors and from various x-ray probes and other electrical probes. The optical image sensor consists of a gated, intensified television system [4]. The gate pulse of the image intensifier can be appropriately delayed to give frames that are time-positioned from the head to the tail of the beam with a minimum gate time of 5-ns. The spatial correlation of the time frames from pulse to pulse is very good for a stable electron beam; however, when instabilities do occur, it is difficult to properly assess the spatial composition of the head and the tail of the beam on a pulse-to-pulse basis. Multiple gating within a pulse duration becomes desirable but cannot be performed because the recycle time (20-ms) of the TV system is much longer than the beam pulse. For this reason we have developed an optical-loop framing technique that will allow the recording of two frames within one pulse duration with our present gated/intensified TV system.

Optical Loop Framing Concept

The optical-loop framing concept is shown in Fig. 1 in the object space of the telephoto lens. A beam splitter is used to form two beam paths from the object located at O. The primary image path is OBT; the secondary, optical-loop, image path is BRCDB, and it provides a time delayed ΔT image into the BT beam path. It is desirable to have the intensity and the magnification of the secondary image the same as the primary image. First, with respect to intensity, the primary image is reflected only once at the beam splitter whereas for the secondary image the beam traverses through the splitter twice; therefore to achieve equal image intensities $r=t^2$ where r and t are the reflection and transmission coefficients, respectively, of the beam splitter. Assuming no absorption losses, r=38.2% is the requirement for the beam splitter to achieve equal intensities for both images. Secondly, with respect to magnification, a relay focusing mirror R must be inserted in the optical-loop path. For unity magnification, the focal length f_R is selected as $4f_R=c(\Delta T)$ where c is the velocity of light, and OBR=RCD. The beam path BD is made equal to OB in order to maintain the same object distance, and thus avoid a depth of field problem with the telephoto lens, if unequal beam paths were used. Typically, for a 10-m object distance to a 1-m telephoto lens, the depth of field is less than 1-m.

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When the telephoto lens is coupled to a gated, intensified TV system, two frames can be captured within a single optical event, where the head and the tail of the pulse are framed in the secondary and primary images, respectively. To prevent superposition of the two images, mirror positioning adjustments can be made to set apart spatially the two images on the TV monitor.

Laboratory experiments have been performed to demonstrate the spatial characteristics of optical-loop framing with an ungated TV system. A 1.65-m focus mirror was selected to provide an optical loop delay of T=22-ns. A 1-m telephoto lens was used with a primary image path of 15-m that was reflected (r=33%) from a beamsplitter. A 1-cm quadrille pattern was used as the object; the primary and secondary images captured in a single frame are shown in Fig. 2. There is some indication of astigmatism in the secondary image which is due to the standing wave pattern in the 25-cm diameter pellicle beam splitter. The astigmatism observed in the quadrille pattern of the secondary image varied with the air current movement in the room.

Relay Lens

Optical loop-framing can be performed either in the object-space or the image-space of the telephoto lens. The first experiments to be performed at ATA will be in object space similar to the optical arrangement as discussed in the laboratory experiments as shown in Fig. 1. This arrangement allows the use of a small diameter relay focusing mirror, because the beam angle as defined by the telephoto lens in object space is relatively small. For example, the 9.65-cm diameter for the 1-m telephoto lens with a 15-m object distance has a 6.4 mrad beam angle. Therefore, for an optical-loop delay of T=40-ns, the 3-m (focal length) relay focusing mirror (for unity magnification) requires a 3.84-cm diameter in order to match the beam angle of the telephoto lens. Obviously, to ease the optical alignment procedure the mirror diameter should be made larger. Since the beam angle of the relay focusing mirror can be made larger than that of the telephoto lens, there is no requirement for a field lens at the image plane of the focusing mirror to concentrate the ray bundle into the aperture of the telephoto lens.

The requirements for optical-loop framing in the image space of the telephoto lens is different as shown in Fig. 3. The optical-loop delay ΔT occurs in the path ABRCA. Since the beam cross-section is smaller in image-space, a much smaller size beam splitter can be used as compared to the beam splitter used in the object-space. However, the beam angle in image space is much larger; therefore, the beam diverges rapidly past the image plane. For example, in the 1-m telephoto lens used in our experiments, the ray bundle expands to 15-cm at a distance of 76-cm from the image plane. For a proposed 2.25-m (focal length) relay focusing mirror, a very large mirror (89-cm) is required to capture the entire ray bundle. For this reason it is preferable to have a field lens located at the image plane in order to concentrate the ray bundle to a smaller relay focusing mirror and thus avoid the optical losses. Based upon the parameters of the telephoto lens and the requirements for a unity magnification time-delay relay focusing mirror for a specified optical-loop delay ΔT, one can calculate the focal length and the magnification of the field lens. The field lens focuses the aperture D_T of the telephoto lens onto the relay focusing mirror of diameter D_R. The magnification M_F of the field lens is determined primarily by the image distance (l_{iF}= .5cΔT) of the field lens (or the object distance of the relay focusing mirror) since the object distance of the field lens is fixed by the image distance of the telephoto lens. The M_F determined as a function of ΔT also specifies the relay focusing mirror diameter for a given telephoto lens diameter, since D_R=$D_T M_F$. For example, to provide a T=30-ns, a 40-cm diameter relay focusing mirror of 2.25-m focal length is required for the 1-m telephoto lens in our experiments; the field lens for this application has a 0.3-m focal length and a 5-cm diameter. Although the larger diameter relay focusing mirror in the image space case is a disadvantage, the tradeoff in having the optical-loop components in a radiation-free environment is a major inducement in performing the framing in the image space rather than in the object space.

Other Framing Techniques

Optical-loop imaging provides a simple and inexpensive means of framing 2 images within a single pulse. An optical-loop within an optical loop can provide additional frames; however, this scheme cannot easily provide equal intensities without incurring a big loss in the image signal content. To increase the number of recorded frames in an optical event, some experimenters have used N number of sequentially-triggered cameras to perform framing. The information is stored on film from each of the cameras and then later image processed at nominal rates when the digital processing equipment is available. Alternatively, the information can be recorded on tape with a television pick-up/recording system for N channels.

Commercially available framing cameras[5] can provide 2 frames, possibly, of limited use in ATA applications. These cameras provide six-frame formats for a minimum interframe period of 50-ns with an approximate 2-cm frame size at about 5-lp/mm; however, a reduction in the interframe period of a factor of 5 is required before these cameras become useful to ATA applications. Other fast framing cameras have been developed[6,7]; however, their uses are intended for subnanosecond applications.

An attractive goal for a framing camera development is to separate the two features of shuttering and framing into two components. In this modular approach the shutter will be similar to the MCP image intensified tube except that a fast-decaying phosphor is substituted for the conventional phosphor. The MCP has a transit-time dispersion of less than 0.3-ns. The fast decay phosphor would preferably be a GaAs deposited layer since GaAs has a carrier lifetime less than a few hundred picoseconds and also has a relatively high recombination radiation efficiency. Once having developed a GaAs screen intensifier that has an MCP-phosphor screen with a speed capability of less than 0.5-ns, the overall shutter speed would now be determined by the gating speed at the photocathode-MCP. Gating speed can be improved into the sub-nanosecond range by increasing the photo-cathode substrate conductivity[8]. Further improvements in speed can be made by using strip-line techniques.

The proposed shutter allows the sequential gating of images at GHz rates instead of the present KHz rates. These images are then arranged spatially in a prescribed format by the framer. The framer is merely a fast deflecting image converter tube. Streak tubes with an orthogonal set of deflector plates can be used for this purpose. For a 3 x 2 frame format on the phosphor screen of the framer, a single electrical read-out CCD device fiber-optically coupled (minified) to the screen could put into the memory board the information from six frames in one cycle of the TV acquisition system.

The modular system is attractive because it will allow upgrading the system without re-inventing a new system. Components can be easily replaced with new ones when the technological improvements are made in the commercial market.

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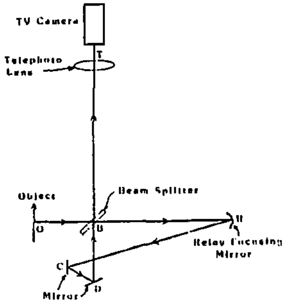

Fig. 1 - Optical-loop configuration in the object-space of the telescopic lens.

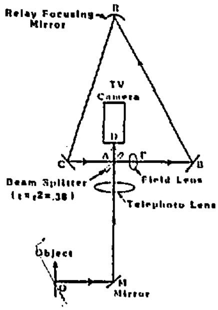

Fig. 3 - Optical-loop configuration in the image-space of the telescopic lens.

Secondary Image **Primary Image**

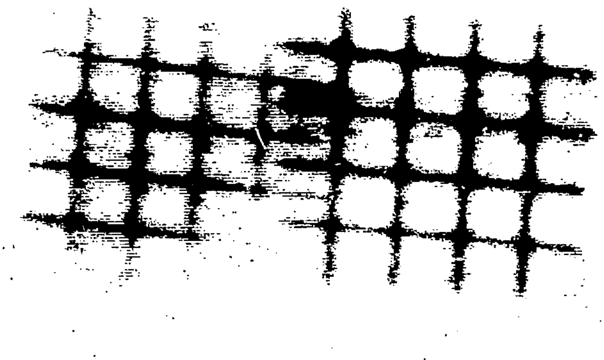

Fig. 2 - Optical-loop framing in a non-gated camera.