AIIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202

Centimeter

Inches

MANUFACTURED TO AIIM STANDARDS
BY APPLIED IMAGE, INC.

Conf-940723--21

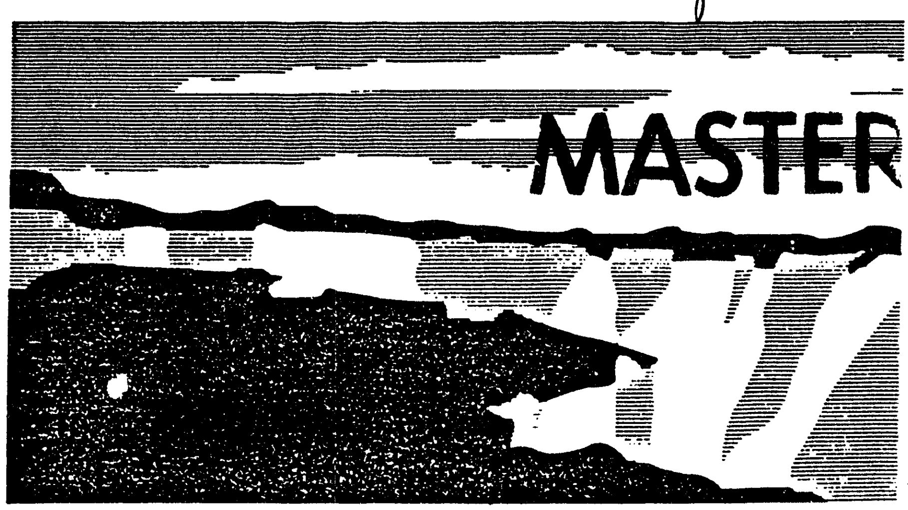
LA-UR- 94-2898

Title: HIGH FRAME RATE CCD CAMERAS WITH FAST OPTICAL SHUTTERS FOR MILITARY AND MEDICAL IMAGING APPLICATIONS

Author(s): NICHOLAS S. P. KING; KEVIN L. ALBRIGHT; STEVEN A. JARAMILLO; THOMAS E. McDONALD; AND GEORGE J. YATES

Submitted to: SPIE's 1994 INTERNATIONAL SYMPOSIUM ON OPTICS, IMAGING, AND INSTRUMENTATION, 24-29 JULY 1994 SAN DIEGO, CA

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED



Los Alamos
NATIONAL LABORATORY

High Frame Rate CCD Cameras With Fast Optical Shutters for Military and Medical Imaging Applications

Nicholas S.P. King, Kevin Albright, Steven A. Jaramillo, Thomas E. McDonald, and George J. Yates
Los Alamos National Laboratory

Bojan T. Turko
Lawrence Berkeley Laboratory

ABSTRACT

Los Alamos National Laboratory (LANL) has designed and prototyped high-frame rate intensified/shuttered Charge-Coupled-Device (CCD) cameras capable of operating at Kilohertz frame rates (non-interlaced mode) with optical shutters capable of acquiring nanosecond-to-microsecond exposures each frame. These cameras utilize an Interline Transfer (ITL) CCD, Loral Fairchild CCD-222 with 244 (vertical)x380(horizontal) pixels operated at pixel rates approaching 100 Mhz. Initial prototype designs demonstrated single-port serial readout rates exceeding 3.97 Kilohertz with greater than 5lp/mm spatial resolution at shutter speeds as short as 5ns. Readout was achieved by using a truncated format of 128 x 128 pixels by partial masking of the CCD and then subclocking the array at approximataely 65Mhz pixel rate. Shuttering was accomplished with a proximity focused microchannel plate (MCP) image intensifier (MCPII) that incorporated a high strip current MCP (28uA/sq.cm) and a LANL design modification for high-speed stripline gating geometry to provide both fast shuttering and high repetition rate capabilities. Later camera designs use a close-packed quadruple head geometry fabricated using an array of four separate CCDs (pseudo 4-port device). This design provides four video outputs with optional parallel or time-phased sequential readout modes. Parallel readout exploits the full potential of both the CCD and MCPII with reduced performance whereas sequential readout permits 4x slower operation with improved performance by multiplexing, but requires individual shuttering of each CCD. The quad head format was designed with flexibility for coupling to various image intensifier configurations, including individual intensifiers for each CCD imager, a single intensifier with fiber optic or lens/prism coupled fanout of the input image to be shared by the four CCD imagers or a large diameter phosphor screen of a gateable framing type intensifier for time sequential relaying of a complete new input image to each CCD imager. Camera designs and their potential use in ongoing military and medical time-resolved imaging applications are discussed.

INTRODUCTION

High frame rate focal plane array (FPA) video cameras capable of optical shuttering in the nanosecond regime with good shutter ratios require the use of image intensifiers. Although various electronic shuttering techniques are possible with FPA devices, most provide exposures in the microsecond or longer regimes. The intensifier also provides higher system optical sensitivity than that attainable from the high frame rate, uncooled FPA alone.

This paper summarizes work in progress utilizing MCPII coupled camera systems based on the Fairchild CD222 interline transfer(ITL) FPA. Some discussion on upgraded camera systems is also presented. The present solid state imaging systems were developed over the past six years for use in an explosive environment with fast shock arrival (few ms) and a 500ns precursor pulse of gamma-ray and neutron radiation during image formation. Subnanosecond to microsecond image integration times were needed. The basic camera system requirements and performance are: 1) Few millisecond readout with a minimum of 256 X 256 FPA pixels. 2) Fast electronic shutters (< 2us) and fast array clearing of radiation induced artifacts. 3) Event synchronous 4) Optically shutterable (subnanosecond to microseconds) with shutter ratios in excess of 10^5 and 100X100 resolution elements 5) Dynamic range of 8 bits.

Fiber optic coupling has been necessary to maximize the sensitivity since cooling and long integration times are not possible. Most MCPIIs have degraded resolution (eg 5lp/mm vs 10lp/mm) when fast gated due to losses in proximity-focussing from internal electric field degradation and spatial nonuniformity associataed with gate pulse propagation characteristics (Ref. 1,2).

The application of these camera systems to fast framing vs single event recording have resulted in necessary modifications to optimize performance. High frame rates push the MCPII into poor gain by exceeding the recharge time requirements for the microchannel plate and phosphor excitation/decay time requirements to prevent reciprocity and smear problems. A charge-transfer-efficiency (CTE) degradation of the ITL CCD may also contribute to image smear at very high frame rates.

Self-clocking sample and hold circuitry was designed using "constant fraction" techniques to follow the individual pixel charge amplitudes as functions of pixel clock rate and charge. This technique was essential to assure proper sampling of slew rate limited pixel charge where peak amplitudes vary with both input optical intensity and pixel frequency readout.

HIGH-SPEED IMAGING APPLIED TO MINE DETECTION

One of the more technologically demanding applications for high-speed imaging is in the area of military reconnaissance for mine field detection. The basic concept is to identify, with a high degree of certainty, a mine field via a low flying jet aircraft utilizing high speed, shuttered electronic camera systems. The area of interest is illuminated with a pulsed laser, the reflected image captured, and the data transmitted to an analysis center where it is examined to determine the presence or absence of mines.

An alternative mission would be detecting submerged mines in a broad ocean area with a helicopter and the high-speed gating capability of the system used to determine depth. The imaging system must be relatively small and light-weight to be able to fit into the aircraft, have sufficiently high speed to image the area covered by the aircraft, and have adequate resolution to identify mines or other items of interest. The most extensive requirements for such a camera system is a frame rate of approximately 3500 frames per second, a scene resolution of 256X256 image elements, inter scene dynamic range of 10bits, and shuttering capability of 5ns. We have developed a variety of prototype cameras for this application based on the previously described CCD camera system coupled to different MCPII configurations.

The camera can be operated in progressive at a readout rate of up the to 70 Mpixels/s, which results in a frame readout time of approximately 1.6 ms for the entire array of 244 X 380 pixels (Ref 3). The camera electronics is designed to operate at a 100 Mpixels/s rate; however, the CCD222 can only be usefully operated at a peak readout rate of 70 Mpixels/s due to bandwidth limitations of the on chip output amplifier. Image intensifiers are employed to achieve the high-speed shuttering needed for the experiments. With conventional image intensifiers, as shorter electrical shutter gates are used to achieve the required 1- to 10-ns shutter speed, turn-on and turn-off delays and nonuniformities are often encountered that are due to the low bandwidth of the electrical path of the gate pulse. This problem has been ameliorated by design modifications of the image intensifier that include increasing the effective conductivity over the the photocathode and providing parallel plate transmission lines into the intensifier. With these techniques, gate widths in the subnanosecond region can be achieved. (Ref 4)

The design philosophy for the present camera systems features surface mount technology for high-speed operation in both analog and digital circuitry.

Specialized clock driver/level shifting circuits were designed utilizing "charge dump" techniques to quickly charge/discharge the CCD's vertical and horizontal clock line input capacitances and then remain idle for most of the actual clock period (duration). This approach reduces power dissipation significantly over that achieved by conventional full duty cycle switching driver technology employed in many camera designs.

The manufacturer believes that a redesign of the CCD222 could be carried out relatively easily to incorporate a wider bandwidth output amplifier and achieve a pixel readout rate well over a 100 Mpixels/s. This would allow a frame readout rate of approximately 1000 frames/s of a 244 X 380 pixel array or approximately 1500 frames/s of a redesigned 256 X 256 pixel array.

The current cameras can be operated at standard RS170 television rates and accept external clock and reset signals. This makes the camera easily adaptable to a wide range of operating requirements and permits syncrhonizing it with randomly occurring events for single field recording of transient optical phenomena. In the RS170 mode, the camera has been used to record data from a "tank test" where targets were submerged in water at varying depths Water depths were discriminated with a delayed gate pulse. Widths of 5 and 10 ns were employed and the data compared at the two widths. The next step in the project is to carry out similar tests in an ocean environment from a pier.

HIGH FRAME RATE CAMERA DESIGN OPTIONS

A Prototype Camera (four time-phased 875-Hz frame rate cameras)

The first prototype camera system (our most conservative approach) was designed to use four individual cameras operated in a pipeline mode. Each camera uses one CCD 244(V) by 256(H) pixels (Fairchild CCD-222) at a clock rate that achieves 875 f/s. Each head reads out in serial fashion to individual video ports. To provide an effective 3500f/s, all CCDs are in sync but each is consecutively phase shifted by approximately 286 us, the "Gatling Gun" scheme. Each CCD requires its own image intensifier, which is sequentially shuttered at the 875 f/s rate. This design can use a standard (1 to 2 uA/cm2) strip current MCPII with available relatively short persistence phosphors to prevent smearing between successive frames. This accumulation of latent images causes smear.

The image transfer system to the four MCPII can be either an active framing tube or a passive "pyramidal" splitter. The former, while more complex, results in no loss in sensivity while the latter, at a minimum gives a loss of 4 in sensitivity.

B. Prototype Camera (four segment four port 3500-Hz frame rate camera)

Our second prototype employs an image splitter in which the MCPII phosphor image is split into four quarters and each quarter is read by a 128 x 128 camera operating at 3500 f/s. Light to the unused area of each CCD is blocked by using an opaque coating. An alternative image splitter uses a coherent fiber optic bundle butt-coupled to the MCPII phosphor and split into four segments, which are then coupled to the four CCDs. Either of these designs require the use of a single high-strip current (10-50 uA/cm2) MCPII with short persistence (Approximately 100 ns to 200 ns e-fold decay constants) P-46 or P-47 phosphor (Ref. 5).

A common control unit drives four identical camera aheads with CCD-222 sensors. The control unit provides camera frame rate synchronism with the laser period and MCPII gate timing to coincide with laser pulse arrival.

MEDICAL X-RAY IMAGING

High speed X-ray imaging is needed for medical research; as this capability becomes available to researchers, we expect to see development of high-speed imaging within health care as well. The project being described is a feasiblity study to investigate and validate concepts being considered for a specific study involving application of high speed X-ray imaging to dynamic bone and joint research.

The application of the current high frame rate ICCD camera to a desired 1000fps X-ray imaging application places different requirements than presented above on the camera system due to alternative types of X-ray sources (pulsed or continous) as well as the complication of X-ray to light conversion. The time response and large format, high spatial resolution of the X-ray to light converter are significant factors in achieving an optimum system. The emphasis presented here will be a discussion of limitations in the initial experiments due to finite resolution in the camera system, CCD architecture, and time response of the X-ray to light converter. A more detail review of the initial experiments is given in reference 6. The prototype X-ray camera system is comprised of a Precise Optics X-ray Image Intensifier lens coupled to the ICCD camera system described above (see figure). Frame rates of 1.5ms/frame and 100us MCPII optical shutter times were used. Standard CsI/photocathode X-ray to photoelectron conversion is used with electrostatic focussing onto a P20 phosphor. The accelerating voltage in the converter tube is 25KV. Typical spatial resolution of such X-ray tubes is 4lp/mm over a 300mm imaging area resulting in approximately 40lp/mm on the P20 phosphor screen after a 10:1 demagnification. As a result, the ICCD camera will degrade the spatial resolution of the system unless a restricted FOV on the P20 phosphor screen is coupled onto the full 18mm MCPII format. No attempt was made in initial tests to optimize the spatial resolution in this manner.

The primary objective was to demonstrate that optical shuttering of the light from the X-Ray Image Intensifier, P20 phosphor could eliminate motion blur as well as obtaining images under shuttered conditions with available X-ray intensities. The test system involved a rotating wheel between the X-ray source and camera system with imbedded Pb attenuating spheres. Velocities of the Pb spheres (6.35mm, 4.5mm, 2mm diameter) were typically 8.5m/s such that 100us shutter times resulted in 2 resolution elements(re) of "motion blur" compared to a typical 16re image of a 6.35mm sphere. The X-ray source was operated in the DC mode. Frame rates of 650 per second from the ICCD camera were recorded with a TeK RTD710 with extended memory (Data Cache System).

Current tests of the X-ray image intensifier are being performed with a nanosecond pulsed X-ray source to measure time response, resolution, and sensitivity vs X-ray intensity. Modified coupling of the ICCD is also being carried out to better assess electronic readout requirements for resolution. This will permit obtaining a modified system optimized for 1000fps applications.

REFERENCES

1. N.S.P. King, G.J. Yates, S.A. Jaramillo, J.W. Ogle, and J.L. Detch, Jr., "Nanosecond Gating Properties of Proximity-Focused Microchannel-Plate Image Intensifiers," Los Alamos Conference on Optics '81, August 1981, SPIE, Vol. 288.

2. J.L. Detch, Jr. and J.W. Ogle, "A Distributed R-C Radial Transmission Line Theory Applied to the Gain Characteristics of Gated Microchannel-Plate Image Intensifiers," EG&G Energy Measurements Group report EGG Il183-2404 S-699-R, June I980.

3. B.T. Turko, G.J. Yates, K.A. Albright, and N.S.P. King, "High Speed CCD Image Processing at 75MPS and l0-Bit Resolution, submitted to IEEE for presentation at IEEE I993 Nuclear Science Symposium and Medical Imaging Conference, November I993.

4. M.C. Thomas; G. J. Yates, and P. A. Zagarino, "Fast Optical Gating Using Planar-Lead MCPIIs and Linear Microstrip Impedance Transformers," SPIE, Vol. 2273-26, Ultrahigh- and High-Speed Photography, Videography, and Photonics Conference, San Diego, July 24-29, 1994

5. G. J. Yates, K. L. Albright, P. A. Zagarino, and M. Thomas, "Rate Effects of Standard and High Strip Current Microchannel Plate Image Intensifiers (MCPIIs)," SPIE, Vol. 1539, Ultrahigh- and High-Speed Photography, Videography, and Photonics '91, pp. 33-39, San Diego, July 24-26, 1991

6. N.S.P. King, F. H. Cvema, K. L. Albright, M. J. Flynn, S. Tashman, V. H. Holmes, S. A. Jaramillo, G. J. Yates, "High Frame-Rate Digital Radiographic Videography," SPIE. 2273-09, Ultra-and High-Speed Photography, Videography and Photonics Conference, San Diego, July 24-29, 1994

DATE

FILMED

10/26/94

END