LA-UR 92-516

LA-UR--92-516

DE92 008495

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SUBMITTED TO: Electronic Imaging West '92 Conference,
1050 Commonwealth Avenue
Boston, MA 02215-1135
March 23-26, 1992

HIGH-SPEED ELECTRONIC IMAGING APPLICATIONS AT LOS ALAMOS NATIONAL LABORATORY

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ELECTRONIC IMAGING WEST '92

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ABSTRACT

An overview is presented of high-speed imaging technology developed at the Los Alamos National Laboratory. High-speed imaging is used by Los Alamos primarily in the underground testing of nuclear devices at the Nevada Test Site (NTS). The first camera system developed, which is still the "work horse" of this application, uses focus projection scan (FPS) vidicon imaging technology operating at an effective pixel readout rate of approximately 40 Mpixels/s. In an effort to take advantage of charge-coupled devices (CCD) technology, a CCD camera is under development that currently operates at approximately 25 Mpixels/s, but, with an improved CCD sensor, has the prospect of operating at 70-100 Mpixels/s. A possible application of the technology to the detection of military ordnance is discussed. Also, a flexible test station is described that has been assembled for testing CCDs at high pixel readout rates. The station can operate at clock rates of up to 100 MHz and can accommodate a wide variety of single and multiport sensors.

INTRODUCTION

The Los Alamos National Laboratory, University of California, has been using high-speed electronic imaging technology since the late 1960s for telemetry of video pictures detecting the temporal and spatial evolution of nuclear devices tested underground at the Nevada Test Site (NTS). Electrostatic deflected focus projection and scan (FPS) vidicons have been developed into a highly capable tool for this application and is the current "workhorse" imaging diagnostic in NTS tests. The FPS technology permits image readout with an effective image size of approximately 256 × 256 pixels in under 2 ms per frame. As the technology of silicon-based imaging sensors has evolved, [charge coupled devices (CCD), charge injected devices (CID), and photodiode arrays (PDA)], we have investigated the use of these sensors in cameras that can be used as an alternative to FPS vidicons. The increased sensitivity to gamma ray and neutron radiation by solid-state imagers over the FPS cameras makes them more difficult to use. We have successfully used specially designed high-speed CCD cameras that can transfer close to 30 Mpixels/s for a single frame in underground experiments. Using the NTS technology, we are developing a CCD camera system that can image approximately 4000 frames per second continuously using CCD sensor arrays of approxi-mately 256 × 256 and a gated intensifier with optical shutter times of under 5 ns, and achieving a resolution of approximately 10 lp/mm (line pairs per millimeter). This application requires a pixel transfer rate of approximately 270 Mpixels/s, which can be achieved with increased clocking rates and sensor multiporting. Because most commercial CCD and CID sensors are designed to meet the requirements of the standard television RS-170 format, which has a much lower pixel transfer rate, we must assess sensor performance at the higher rates required for these applications. A test bed that can conveniently operate a wide range of solid-state sensors at high speeds is not readily available. Thus, in order to carry out sensor assessment, we have built a solid-state imager test bed that can be used to determine sensor performance up to a pixel readout rate of 100 Mpixels/s and can accommodate a wide variety of single and multiport sensors.

NTS APPLICATION - FPS CAMERAS

In imaging experiments of nuclear devices in underground tests at NTS, neutrons and gamma rays from a reacting device impinge upon a fluor through a pinhole. The image on the fluor is recorded by a high-speed camera and the data from the camera is transmitted to a recording device located on the surface before the shock wave from the device destroys the imaging equipment. The camera must have a read-out time in the range of 1-5 ms and survive in a radiation environment of tens of rads. A simplified diagram of the imaging system layout is shown in Figure 1.

Early in the effort, commercial TV cameras were found to be inadequate, so a special purpose camera was developed by Los Alamos to meet the requirements of the experiment (Ref. 1). The General Electric 7803 type FPS vidicon with an antimony trisulfide target was selected as the imager. This type of vidicon, electro-static deflection and magnetic focus, was chosen because of the many degrees of freedom available in controlling raster size, location, format, and readout speed. A photograph of this high-speed camera is shown in Figure 2. The technology has been transferred from Los Alamos National Laboratory to Xedar Corp where two models are produced, the XS503 and the XS504. The camera has an effective 256 × 256 pixel array with a readout time as short as 1.6 ms. Also shown in Figure 2 are the two vidicons used in the XS503 and XS504 cameras. The smaller tube is the 7803 used in the XS503 camera and the larger is a Philips 88XQ PbO target tube used in the XS504 camera.

A number of photoconductors that are used in FPS vidicons have been characterized for photoconductive response time, dynamic range, and resolution as functions of read-beam aperture diameter and raster size (Ref. 2) Radiometric sensor materials that have been evaluated include the standard target material, antimony trisulfide, Saticon (Se,As,Te), Newvicon (ZnSe), Pasecon (CdSe), and Plumbicon (PbO). These targets have been tested in various prototype 7803 configuration FPS vidicons that have been fabricated by several domestic and foreign manufacturers. We found that silicon and Saticon are the fastest targets, silicon requiring less than 12.5 microseconds and the Saticons requiring approximately 100 microseconds to reach final value. Newvicon, Pasecon, and Plumbicon are all similar, requiring approximately 250 microseconds to reach 80% of final value. Antimony trisulfide is the slowest, requiring approximately 500 microseconds to reach 60% of final value.

A major concern in these imagers is the effect of ionizing radiation that exists in the NTS environment. Such radiation creates unwanted photocharge that competes with the signal produced by the visible photons. Radiation sensitivity of several photoconductive, photoemissive, and solid-state silicon-based video imagers has been measured by analyzing stored photocharge induced by irradiation with continuous and pulsed sources of high energy photons and neutrons (Ref. 3).

All sensors show sensitivity to gamma rays and x-rays with a uniform buildup of background signal that increased linearly with absorbed dose. Most sensitive are the image intensifiers, which show gain behavior for gamma ray radiation similar to that for visible light. This indicates that the dominant effect of gamma-ray radiation on intensifiers is to cause photoemission from the photocathode. For nonintensified imagers, CCDs are the most sensitive and antimony trisulfide vidicons are the least sensitive to gamma radiation.

For neutron radiation, only the nonintensified silicon-based units showed significant sensitivity. Neutrons produce spatially random excitation of individual pixels (referred to as stars) with little or no background buildup. Intensified units showed no individual pixel interactions, but exhibited background buildup similar to that produced by gamma radiation, which again showed that the primary effect of neutron radiation on intensifiers is photoemission. Reverse-biasing of photocathodes or elimination of accelerating voltages in intensifier units virtually eliminates this induced signal due to gamma or neutron radiation.

NTS APPLICATION - CCD CAMERAS

The development activities on the FPS cameras have resulted in a reliable high-speed FPS vidicon camera that meets requirements of testing at the NTS. However, vidicons require extensive real-time calibration (while data are being acquired) to correct for shortcomings such as geometric distortion, gain shading, and photoconductive lag. In an effort to circumvent these shortcoming of the FPS vidicon and produce an improved imager, a high-speed readout CCD camera has been designed and fabricated that takes advantage of the inherent characteristics of CCDs, such as geometric uniformity, higher readout efficiency, and increased sensitivity (Ref. 4).

The high-speed CCD camera was first designed around the interline Loral Fairchild CCD222 sensor, which is the most commonly used sensor in the camera at present. The most recent model of the camera is referred to as the GY-2, which is shown in the photograph of Figure 3. The camera can be operated in either the interlaced or noninterlaced mode and at a readout rate of up to 70 Mpixels/s, which results in a frame readout (noninterlaced) of approximately 1.6 ms. However, at this rate the dynamic range of the sensor is significantly reduced. Satisfactory dynamic range is achieved at a pixel readout rate of approximately 32 Mpixels/s, which gives a read-time of 3.6 ms per frame. Two sources of distortion are observed that are unique to solid-state imagers. One is the potential for aliasing frequencies higher than the Nyquist limit and the second is the generation of "ghost" images when exposed to transient light impulses if the light is not synchronously time phased to occur entirely within the CCD's vertical sync interval (Ref. 5). Aliasing can be avoided by reducing spatial frequencies below the Nyquist limit and "ghost" images can be avoided by using a "fast dump" approach mentioned below.

The GY-2 is designed to accept external clock and reset signals, which makes the camera easily adaptable to many scan rates and permits synchronizing it with randomly occurring light flashes for single-field recording of transient optical events. A mode that was was designed into the camera especially for the NTS application is the "fast dump" mode. In this mode the continuous readout of frames is interrupted upon the receipt of a command, and two fast dump cycles are generated. These fast dump cycles clear all charge due to neutron radiation (stars) and "ghosting" and leaves the photosites and vertical registers free of any residual charge for the subsequent regular readout cycle of the desired image data.

The GY-2 camera has been successfully employed in NTS events and is developing into a reliable high-speed camera. Another consideration is that the small size of solid-state imagers requires fiber optic reducers or electrostatic minifiers to couple to proximity focused image intensifiers. This introduces some distortion and reduces the effective resolution of an intensified video system.

HIGH FRAME-RATE IMAGER FOR MILITARY APPLICATION

The concept of this application is to fly a high-speed imager over an area and transmit the image data to an analysis facility where the data will be analyzed to determine the presence or absence of military ordnance. The imaging system must be relatively small and light-weight to be able to fit into a jet aircraft, have high enough speed to image the area covered by the aircraft, and adequate resolution to identify the items of interest. These requirements appear to be well-suited for a high-speed CCD camera. We have undertaken an assessment of the applicability of the GY-2 high-speed camera technology to this detection system for the Department of Defense.

The basic requirements of the camera are a framing rate of approximately 4000 frames per second, a CCD pixel array size of at least 256 × 256, and a shutter speed in the 10s of nanoseconds or faster. The array size and frame rate translates into a pixel rate of approximately 262 Mpixels/s. We have used a modified GY-2 camera to demonstrate the continuous operation of a CCD222 at a pixel rate of 50 Mpixels/s and a frame rate of 2200 frames/s of an array size 138 × 120. It appears that with proper modifications of the output amplifier on the CCD222 sensor we can expect to achieve 70 to 100 Mpixels/s output rate. This will allow a camera having a 256 ×256 CCD sensor to achieve approximately a 1000 frame per second readout rate. A 4000 frame per second rate can be achieved by operating four such cameras in sequence or by modifying the CCD222 to have four ports and transferring data from the four ports in parallel.

A prototype camera for this application has been designed and fabricated. Referred to as the GY-5 camera, this prototype is designed to operate at a readout rate of 100 Mpixels/s. All indications are that a 4000 frame/s camera system with relatively high resolution and gating speed is close to achievable using current technology employed in cameras used for NTS testing.

SOLID-STATE IMAGER TEST STATION

The solid-state imager test station is a versatile high-speed testing system designed to evaluate a wide variety of single and multiport solid-state imagers. It will be used to determine the optimum clock rates, time phasing, and signal levels needed for maximum performance from a given imager. Experimental data obtained from the test station will be used by camera designers to implement dedicated logic with a high degree of success on first design, thus, eliminating the need for several iterations. The system essentially functions as a versatile "bread board" for prototype development.

The test station consists of a commercially available data acquisition system (Tektronix DAS 9200) with a programmable digital pattern generator and acquisition module. Special high-speed TTL or ECL clock drivers function as the "drive" component of the system and can operate up to 100 MHz clock rate. Specially designed level shifters condition the clock waveforms for the imager. Ancillary equipment includes a collimated optical projection system and a high-speed data capture and display system, which software scan-converts the high data rates to RS-170 standards for display. Also included in the system is a precision table with microscope and camera for positioning of the sensor and observation of microscopic features or defects on the sensor.

The solid-state imager analog video output will be digitized at rates up to 100 MHz and stored in digital memory for display (after appropriate conversion) or data analysis. Commercially available software (supplied by Big Sky Software Corp.) will be used to analyze the data. A photograph of the system console is shown in Figure 4.

CONCLUSION

High-speed vidicon and CCD cameras have been developed that can achieve pixel readout rates of close to 50 Mpixel/s. We are developing a solid-state imager camera that we expect to achieve pixel readout rates of between 70 and 100 Mpixels/s, and are also developing camera systems, which use either four or more imagers, or multiport sensors to achieve effective speeds of 270 to 300 Mpixels/s. Development and assessment of solid-state sensors for these cameras will be aided by the use of a test station we have constructed, which is a general purpose platform that will ease the evaluation and comparison of imagers over a wide range of frame rates, clocking schemes, and target issues.

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FIGURE CAPTIONS

Fig. 1. Simplified diagram of imaging system layout used in NTS experiments.

Fig. 2. Photograph of the Los Alamos developed high-speed camera using FPS vidicons. The camera has an effective pixel array of 256 × 256 with a 1.6 ms frame readout time and a pixel readout rate of approximately 40 Mpixels/s.

Fig. 3. Photograph of the Los Alamos developed high-speed CCD camera. The camera uses a 244 × 380 pixel array CCD with a 3.6 ms frame readout time and a pixel readout rate of approximatey 32 Mpixels/s. Modifications in the CCD sensor are expected to allow the camera to operate at between 70 and 100 Mpixels/s with a frame rate of approximately 1000 frames/s.

Fig 4. Photograph of console of solid-state imager test station showing the Tektronix DAS 9200 display monitor, a LeCroy 9109 arbitrary function generator (which will be used in displaying the video image), and a LeCroy 9424 oscilloscope (which will be used to digitize and store the high-speed video output from the sensor).

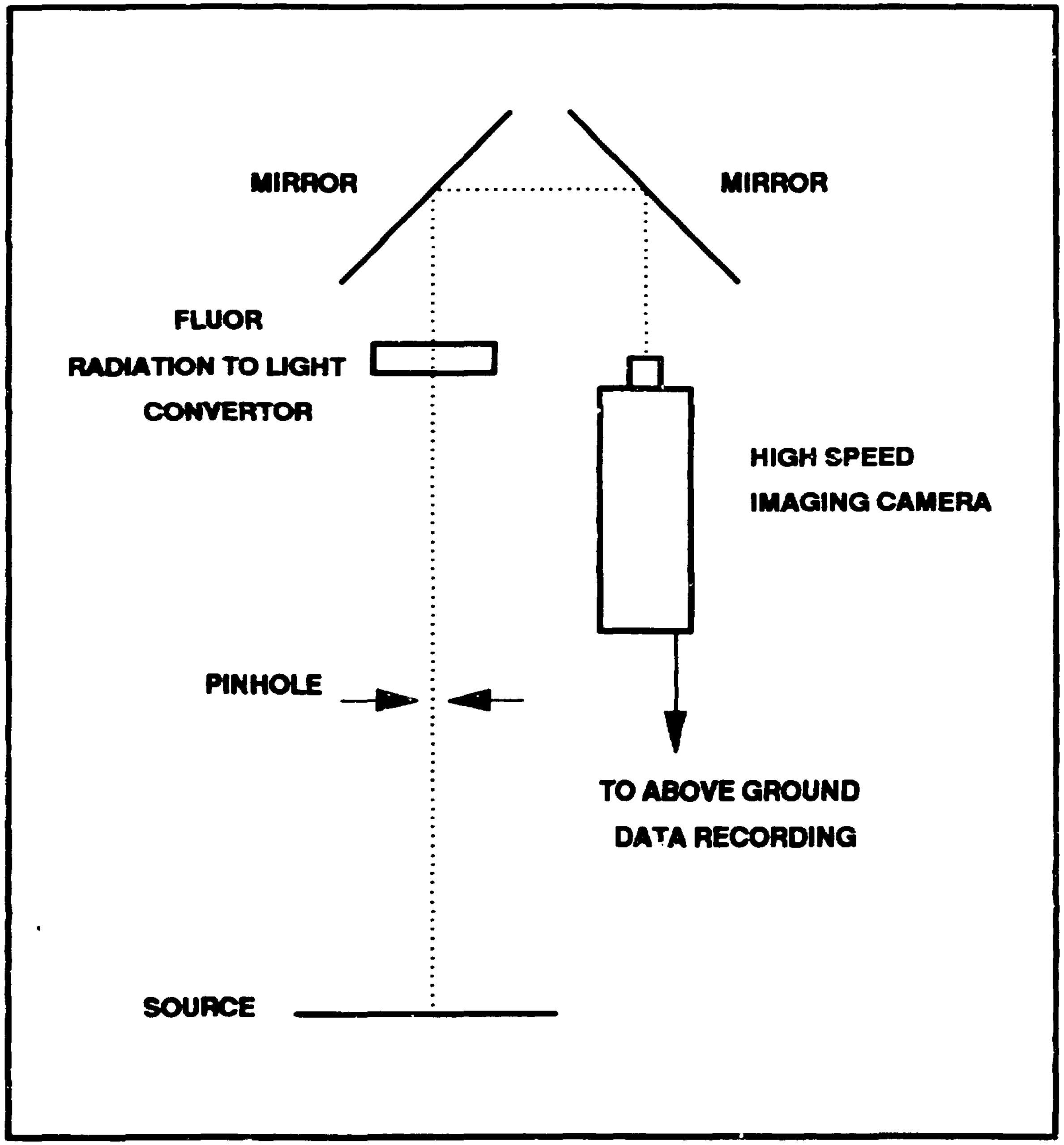
MIRROR
MIRROR
FLUOR
RADIATION TO LIGHT
CONVERTOR
HIGH SPEED
IMAGING CAMERA
PINHOLE
TO ABOVE GROUND
DATA RECORDING
SOURCE

Figure 1

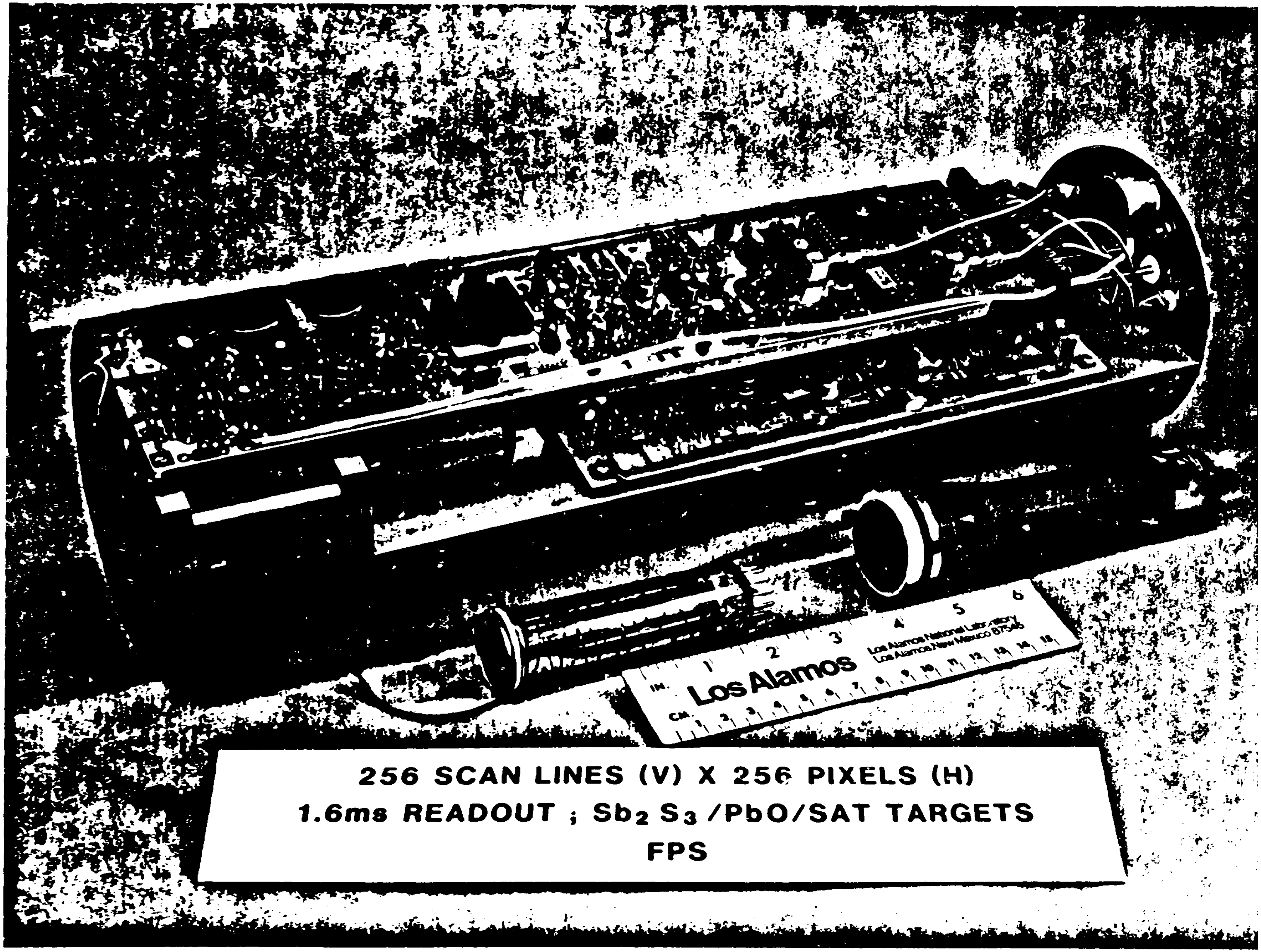
Los Alamos
256 SCAN LINES (V) X 256 PIXELS (H)
1.6ms READOUT ; Sb_2S_3/PbO/SAT TARGETS
FPS

Figure 2

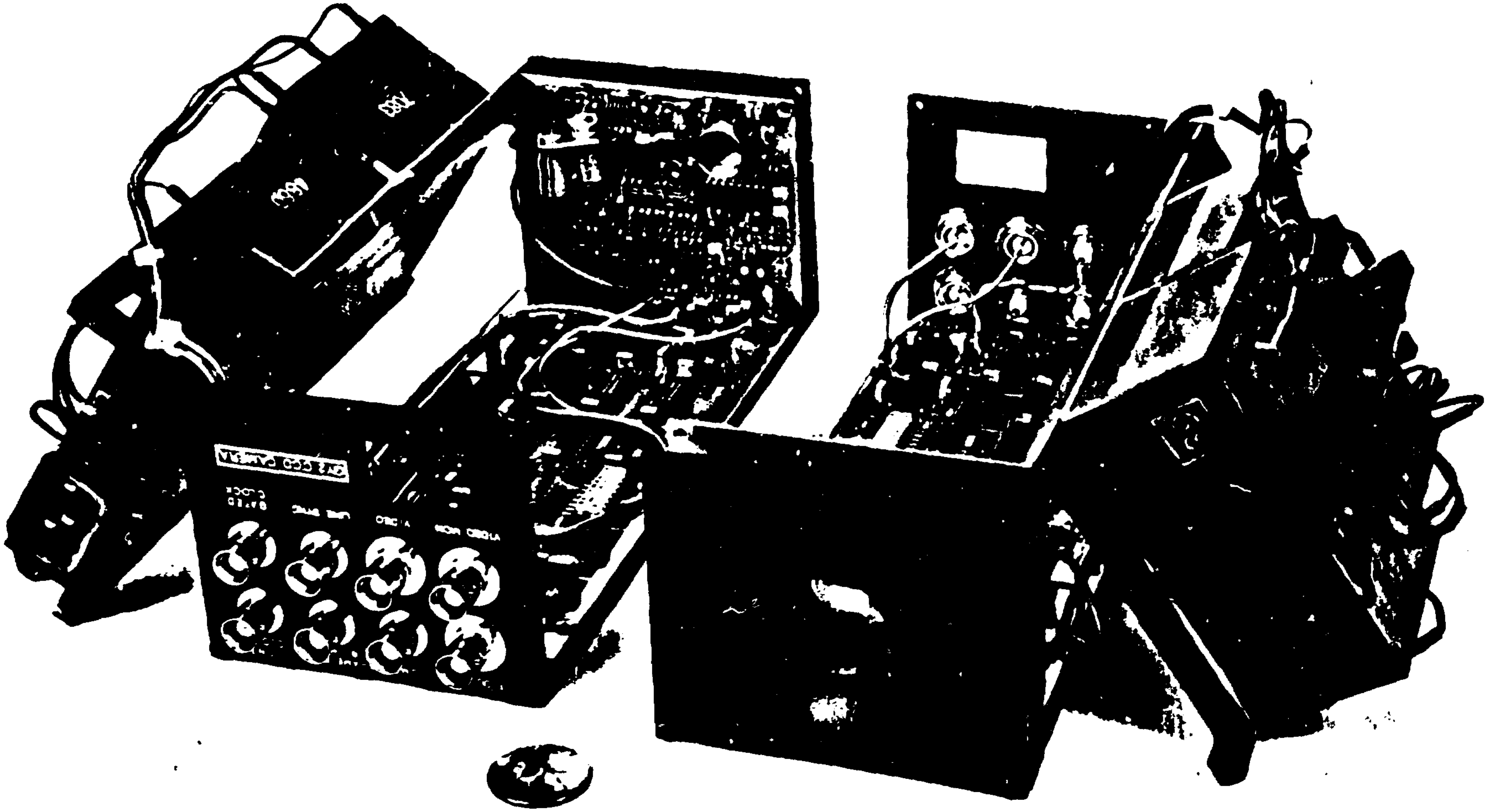

Figure 3


9200
9200
9200