A HIGH SPEED IMAGING SYSTEM FOR NUCLEAR DIAGNOSTICS*

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ABSTRACT

A high speed imaging system based on state-of-the-art photosensor arrays has been designed for use in nuclear diagnostics. The system is comprised of a front-end rapid-scan solid-state camera, a high speed digitizer, and a PCM line driver in a downhole package and a memory buffer system in an uphole trailer. The downhole camera takes a "snapshot" of a nuclear device created flux stream, digitizes the image and transmits it to the uphole memory system before being destroyed. The memory system performs two functions: it retains the data for local display and processing by a microprocessor, and it buffers the data for retransmission at slower rates to the LLL computational facility (NADS). In the talk, the impetus for such a system as well as its operation will be discussed. Also discussed will be new systems under development which incorporate higher data rates and more resolution.

I. INTRODUCTION

All nuclear devices designed at Lawrence Livermore Laboratory are subjected to extensive field testing during their design and development phase. This is performed primarily to confirm that the actual device performance conforms to that predicted during device design. A secondary, but perhaps just as important, reason for testing, however, is to develop new experimental techniques capable both of answering some of the chronic problems of nuclear design and of testing more sophisticated design concepts.

Since the device to be tested must be sealed in the ground during test, the only method the designer has of observing its performance is by monitoring the various radiation and particle fluence emitted from the device during its detonation, particularly the neutrons, gamma rays, and x-rays. Device parameters that are of particular interest to the designer are:

1. The intensity of the flux.
2. The energy of the flux.
3. The spatial distribution at the birth of the flux.
4. The intensity, energy, and spatial distribution of the flux as a function of time.

II. NEW DIAGNOSTIC DEVELOPMENTS

Almost all of the available data are from two-parameter measurements. That is they are space or time averages over the entire device. Spatial distribution of the intensity of the neutron flux has commonly been obtained by using pinhole camera techniques with a recoverable film plane. The x-ray energy spectrum is usually obtained by using a recoverable film plane to record the intensity as deflected by a bent crystal. Time distribution is normally recorded by using radiation detectors to drive an uphole oscilloscope.

The new experimental techniques which are being developed are multi-parameter measurements. In these, source parameters such as intensity and energy are measured as functions of space and time. To affect this, the experiment must be placed in close proximity to the device under test and, in order to insure complete data retrieval, the data must be recorded and readout within several milliseconds. Solid state photosensor arrays provide the fast record/readout capability that is essential for these multi-parameter measurements. They also improve some of the existing experimental techniques by making them cheaper and safer. Some of these experiments are briefly described below.

A. TIME-INTEGRATED ELECTRONIC PINHOLE EXPERIMENT

Figure 1 illustrates the concept. X-rays, gamma rays, and neutrons from the device stream through the assembly of pinholes to excite a plastic scintillator. The intensity patterns are "photographed" with a solid state camera system. The x-ray or gamma ray image can be distinguished from the neutron image with a fast shutter that is opened at the appropriate time. For redundancy and/or economy, images can be multiplexed onto more than one camera by using fiber optics or mirrors. This diagnostic has two unique advantages over the existing method: (1) It eliminates problems (mostly containment) and hardware associated with recovery of radioactive plates, and (2) it can obtain both x-ray and gamma ray images.

B. TIME-INTEGRATED HIGH RESOLUTION X-RAY SPECTROMETER

Figure 2 illustrates the concept. X-rays from the device are diffracted by a crystal onto a scintillator that is optically coupled to a linear solid state camera system. The x-ray emission and absorption characteristics of elements of the device can be differentiated.

C. ULTRAFAST DOWNHOLE SIGNAL RECORDING

1. Solid State Transient Recorder

By taking advantages of the analog shift register property of charge coupled devices, ultrafast shifting (i.e., signal sampling) can lead to a very economical downhole oscilloscope with >1 GHz bandwidth. This exceeds the bandwidth of existing detector-cable-equalizer-oscilloscope systems by a decade or more. Such a capability would allow downhole recording of the signal at places where subnanosecond time resolution is most important.

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2. Streaking Camera Recording

The concept is illustrated in Figure 3. Fast scintillators are coupled through fiber optics to a streaking camera. Routine data with high dynamic range can be obtained with one detector. Time resolution with newly developed fast scintillators or Čerenkov radiators is approximately 0.1 nsec.

D. LASER TIME-RESOLVED PINEX (LTRP)

Figure 4 illustrates the concept. The experiment will obtain device x-ray, gamma ray, or neutron images that are continuous in space and discrete in time. Ultimate time resolution is less than 100 psec. Radiation streams through a pinhole and interacts in a cell containing a fast-response ($\tau \lesssim 100$ psec) scintillator producing a time-dependent optical opacity that is proportional to the instantaneous flux. The scintillator is strobed during irradiation by a long sequence of mode-locked pulses that are spatially uniform upon entering the cell, but which are spatially non-uniform upon exit. The resulting non-uniform pattern contains the desired image information. The laser pulses propagate about 50 to 100 feet, are collected by telescopes and are fed through gated image intensifier tubes to solid state camera systems. The image intensifiers serve as fast shutters to prevent the many spatially uniform pulses containing no information from activating the solid state cameras. Spatial profiles recorded on each camera (images are multiplexed for economy) are read out in <3 msec, before ground shock arrives.

E. STREAKING CAMERA IMAGING

Figure 5 illustrates the concept. This experiment will obtain images that are discrete in space and continuous in time. X-rays, gamma rays and neutrons stream through a pinhole and interact in the fast scintillator. The time-dependent opacity pattern is focused onto a 2-dimensional fiber optic array. As the 2-dimensional image information passes through the array, it is converted into a time-dependent 1-dimensional pattern. The streaking camera converts this into a 2-dimensional pattern that is recorded on a solid state camera. A movie of the device emission is constructed from this pattern. With adequate signal to background ratios, spatially resolved alpha data can be obtained from a gamma-ray movie.

F. TIME-RESOLVED HIGH RESOLUTION X-RAY SPECTROMETRY

By focusing the scintillator intensity pattern obtained in crystal diffraction onto the streaking camera photocathode, time resolved x-ray spectra can be obtained.

III. HIGH SPEED IMAGING SYSTEM

The performance requirements for a nuclear diagnostics imaging system differ from those for a TV system or a low light level imaging system. Basicly, the requirements imposed on a nuclear diagnostics imaging system are:

1. A linear response to light durations as short as 5 ns.
2. A dynamic range of at least 200:1.
3. No blooming at ten times saturation.
4. No lag.
5. Capability of a scan rate as high as 5 MHz.
6. Capability of being reset within 1 μs and of being held reset for up to one hour.

A 45 megabits/second system (Figure 6) which satisfies most of these performance requirements has been developed at Lawrence Livermore Laboratory. It consists of two subsystems: An expendable downhole system (Figure 7) and an uphole buffer system (Figure 8).

A. DOWNHOLE CAMERA SYSTEM

The photosensor array is scanned at a 5 MHz rate thereby producing a 5 MHz video signal which is then sampled and held. The sampled and held video is then submitted to a high speed digitizer/serializer where it is converted into an eight bit data word. Parity is added and the data is serialized and transmitted uphole in the form of a 45 megabits/second BiΦ PCM bit stream.

B. UPHOLE BUFFER SYSTEM

Images transmitted uphole are received and stored in an uphole buffer system prior to transmission to the computational facility. The need for a forward area buffer stems from two considerations. First, the uphole transmission rate exceeds the maximum rate capability of the computational facility. Second, the images must usually be encrypted prior to microwave transmission, further reducing the maximum bit rate to 154 kilobits/second.

The uphole buffer system consists of a synchronizer and a memory system. the synchronizer receives the serial digital bit stream from the downhole camera and converts it to parallel digital words for the memroy. The memory system determines when the uphole image is valid and then stores it in a matrix identical to the sensor array (i.e., Row 4, column 33 of the sensor is stored at address row 4, column 33 of the memory). This makes it simple to select a specific area or location of the image for close examination.

A local readout system (Figure 9) is included in the bunker design to aid in system setup. This capability allows images to be displayed both as buffered by the memory system and in real time. The buffered display allows wide range gray scale hard copy reproduction of images as they are stored in the memory system. The real time display allows for viewing the camera output while focusing, setting light levels, etc.

The image stored in the uphole memory system is encrypted and transmitted (or directly transmitted when encryption is not required) to computational facility where it is recorded to await entry into the computer. Upon ingestion into the computer, software routines correct the data for dark current noise and other calibrated variables and then produce half tone dot plots, isometric projections, contour plots, gray level photographs, and data tables.

IV. RESULTS

The 45 megabits/second system is presently based on the Reticon 50 X 50 and 100 X 100 photodiode arrays. However, both the Fairchild 100 X 100 CCD (CCD 201) and the General Electric CID, both epitaxial and bulk, have been field tested in the past.

The CCD suffered from two serious problems: first, they produced "ghost" images as a result of crosstalk between pixels and adjacent shift registers during illumination; and secondly, they exhibited serious line blooming.

The problems associated with the epitaxial CID camera were a result of using short light pulses. These problems resulted from the high currents produced in the thin epitaxial layer causing a loss of bias and the resultant collapse of the pixel depletion regions. This resulted in a nonlinearity and nonuniformity across the chip. The bulk CID arrays, on the other hand, exhibited none of the light pulse problems associated with the epitaxial arrays but did suffer from a serious crosstalk problem.

The Reticon photodiode arrays have, in tests to date with pulsed light sources, exhibited none of the problems that degraded the performance of the photosensors.

Acknowledgements

The design and development of this system required the expertise of many people of several different disciplines. The Electro-Optics and Digital Systems Group headed by T. Wieskamp, the L Division R&D Group headed by P. Ebert, the L Division Data Analysis Group headed by R. Neifert, and the Mechanical Technician Section of the Nuclear Test Engineering Division headed by L. Talbot were all necessary for the success of the project.

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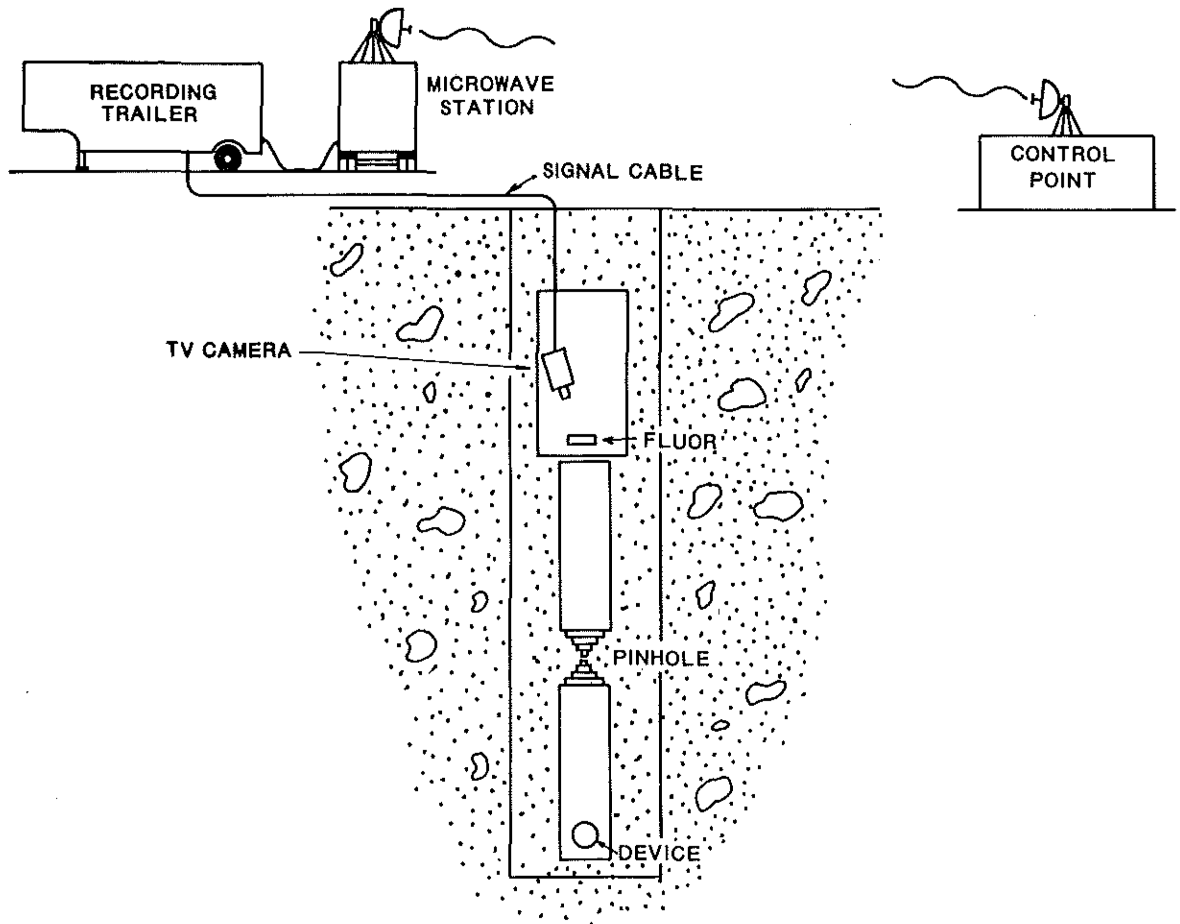

FIGURE 1 TIME–INTEGRATED ELECTRONIC PINHOLE EXPERIMENT

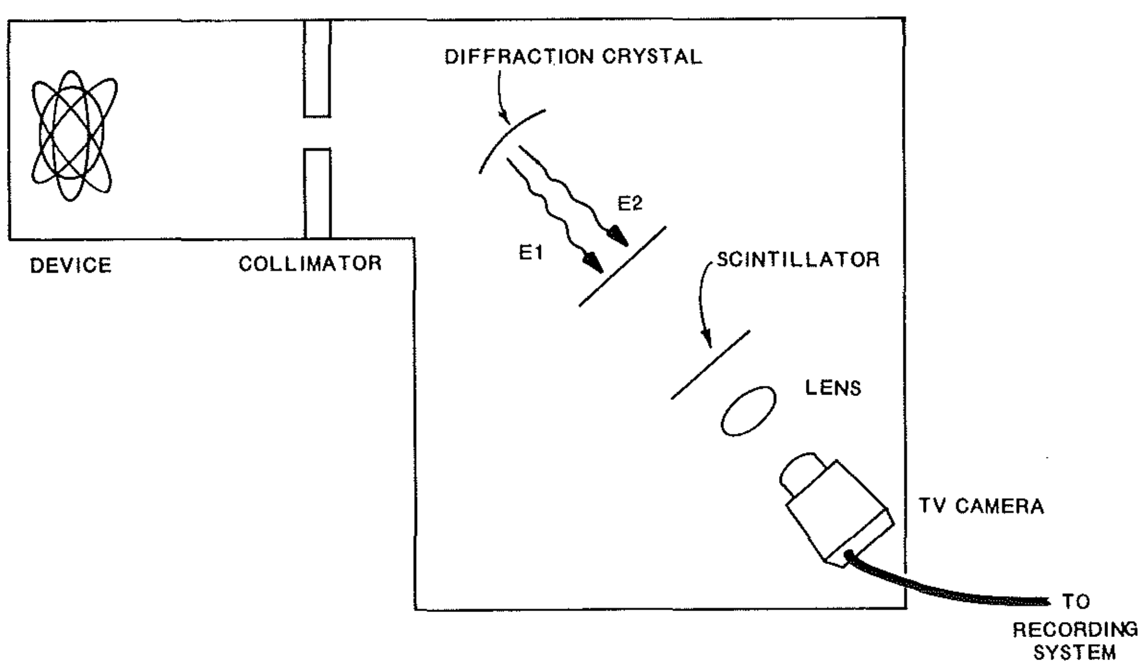

FIGURE 2 TIME– INTEGRATED HIGH RESOLUTION X–RAY SPECTROMETER

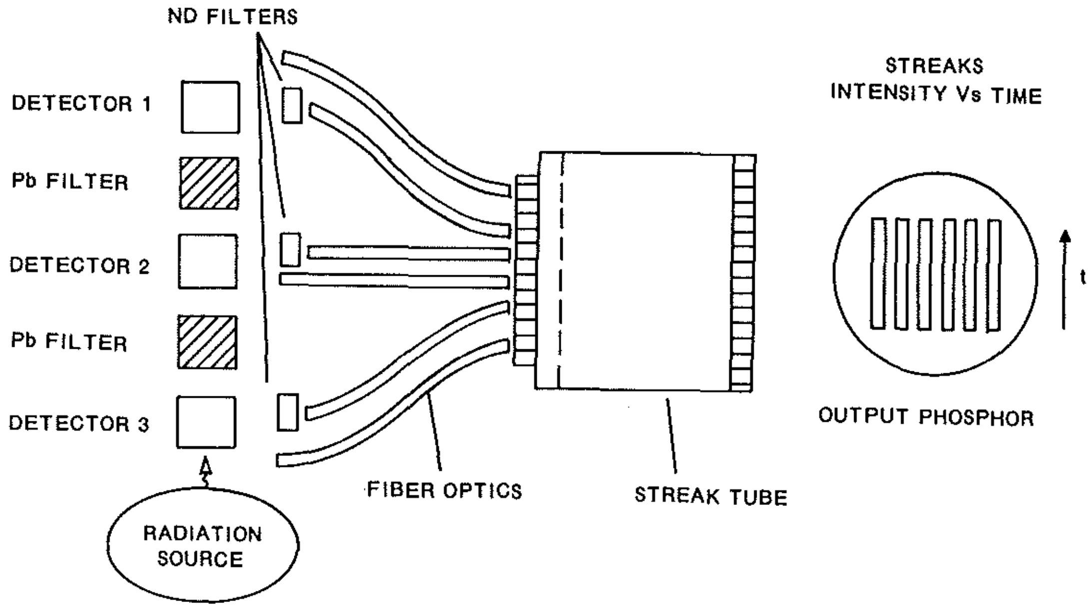

FIGURE 3 STREAKING CAMERA RECORDING

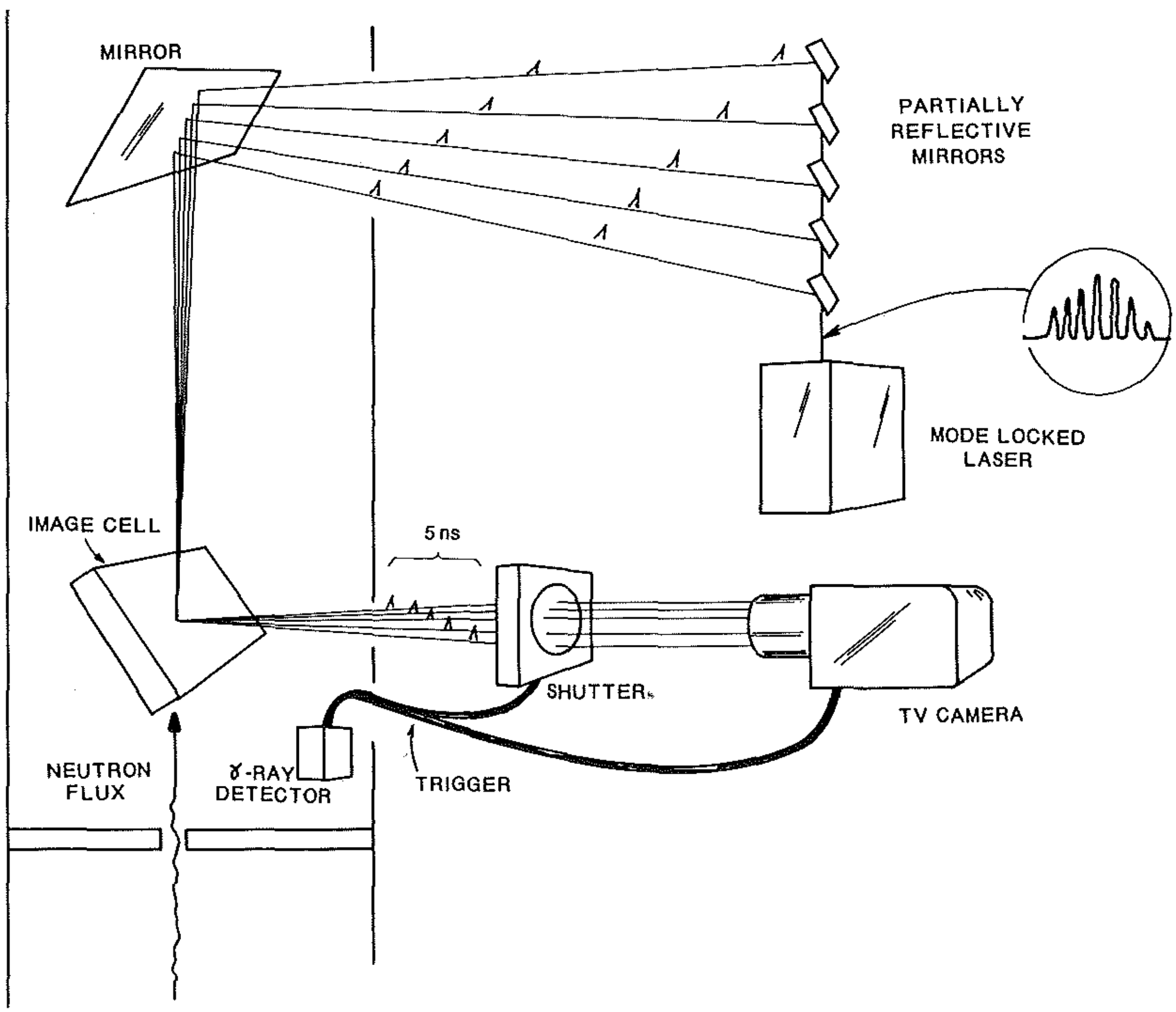

FIGURE 4 LASER TIME-RESOLVED PINEX (LTRP)

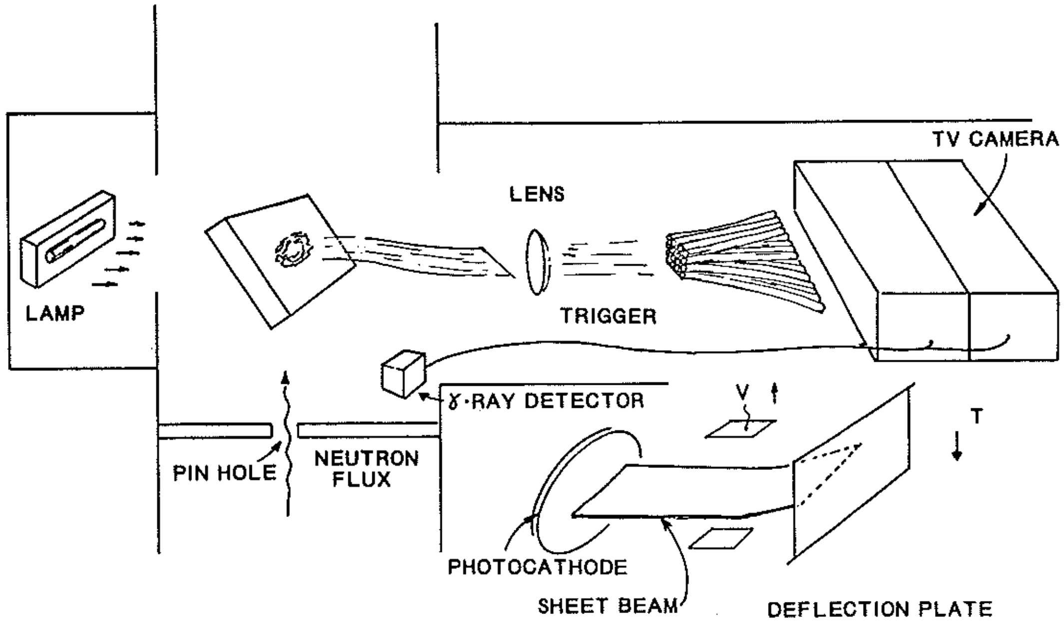

FIGURE 5 STREAKING CAMERA IMAGING

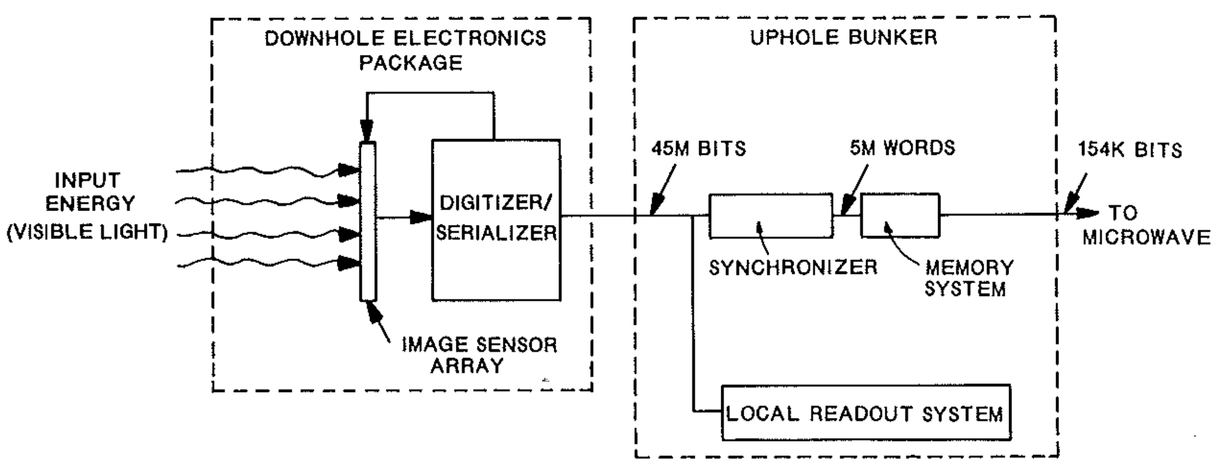

FIGURE 6 45 MEGABITS/SECOND IMAGING SYSTEM

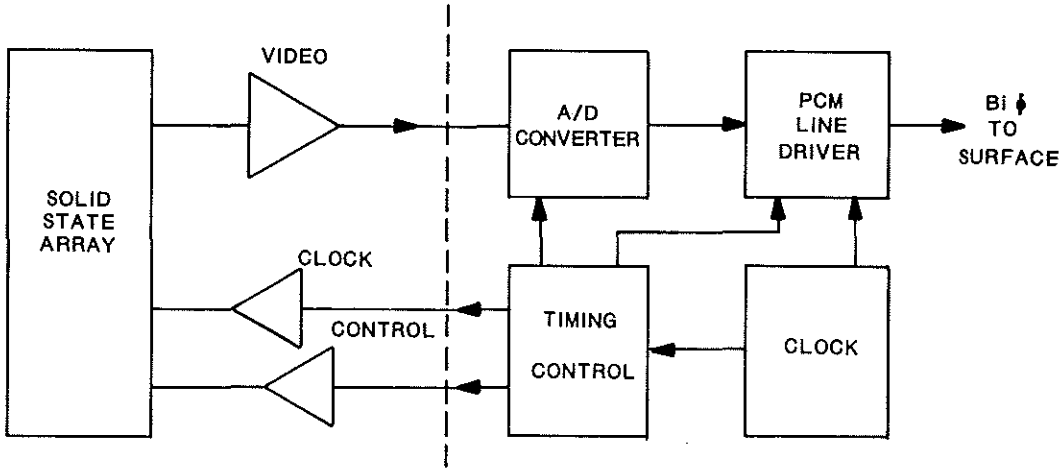

FIGURE 7 DOWNHOLE BUFFER SYSTEM

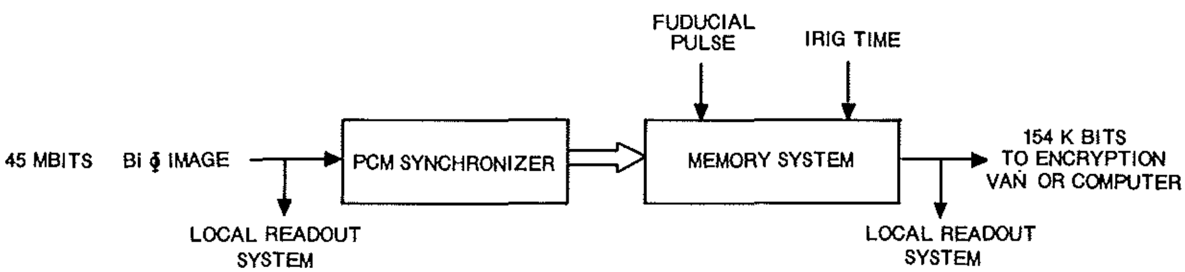

FIGURE 8 UPHOLE BUFFER SYSTEM

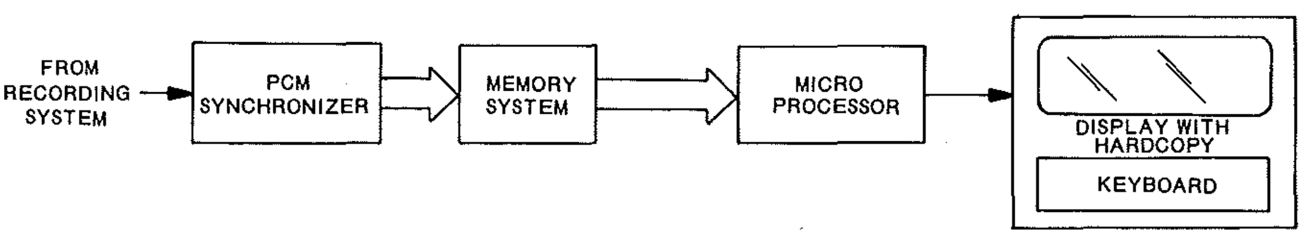

FIGURE 9 LOCAL READOUT SYSTEM