A 1-D, HARD X-RAY PINHOLE CAMERA

FOR FLASH X-RAY PULSED-POWER ACCELERATORS*

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ABSTRACT

A time-resolved pinhole camera has been constructed to diagnose the x-ray emitting source of the SATURN accelerator. The detector for the camera is a 20-channel, linear array of plastic scintillators, placed beneath adjustable jaws; optical signals are connected by fiber-optic links to a remote bank of photomultiplier (PM) tubes. Variations in the channel-to-channel response have been reduced by exposing the complete array to a nearly uniform pulsed x-ray field (Febetron 706, e-beam tube with Ta converter) and adjusting the gains on the PM tubes. Experiments under SATURN to date have yielded information on the simultaneity of the source rings, x-ray pulse widths, and the duration of hot spots. The camera complements existing diagnostics, such as time-integrated and multiframe, gated cameras and non-spatially resolved PIN and scintillator-photodiode detectors.

INTRODUCTION

The SATURN simulator, located at Sandia National Laboratories, has been operating since the Summer of 1987. It is a radial pulsed power accelerator which can deliver a large x-ray burst to an experiment located beneath the center of the machine. Thirty-six individual modules contribute to the power flow in SATURN. Electrical energy is initially stored in Marx generators which erect on command and charge intermediate store capacitors. Gas switches discharge these capacitors, and the resulting power pulse is shaped and delivered to an x-ray emitting diode structure by means of magnetically insulated transmission lines (MITL's). Reference 1 describes this accelerator in detail.

Figure 1 shows the vacuum section of SATURN. The radial MITL's consist of a set of cones which, when nested together, connect to different numbers of high voltage modules at the top (large) end. At the bottom (narrow) end they form the electrode structure of the diode. Electrons are accelerated across the cathode-anode gaps into a tantalum converter, and the resulting bremsstrahlung source consists of three concentric rings with nominal average diameters of 7, 16, and 23 cm, respectively. Experiments are placed beneath this source.

Since the three cathode rings attach electrically to different parts of the accelerator, one cannot assume identical emission from each of them. It is, therefore, important to know how long each ring emits x-rays, whether the output from each ring is simultaneous, and what the relative spatial brightness is across the converter. We have developed two new x-ray cameras to diagnose this source. One is a multiframe pinhole camera, based on gated image intensifiers, and is described elsewhere [2]; it yields continuous spatial information over a two-dimensional field of view. The other camera, which we describe here, is based on a linear array of fast scintillators; it provides continuous time information over a discrete, one-dimensional field of view. Both cameras together have given us valuable insights into the workings of the SATURN x-ray source. We discuss here the construction, calibration, and operation of the scintillator camera and review the results of a SATURN experiment in which both cameras were used.

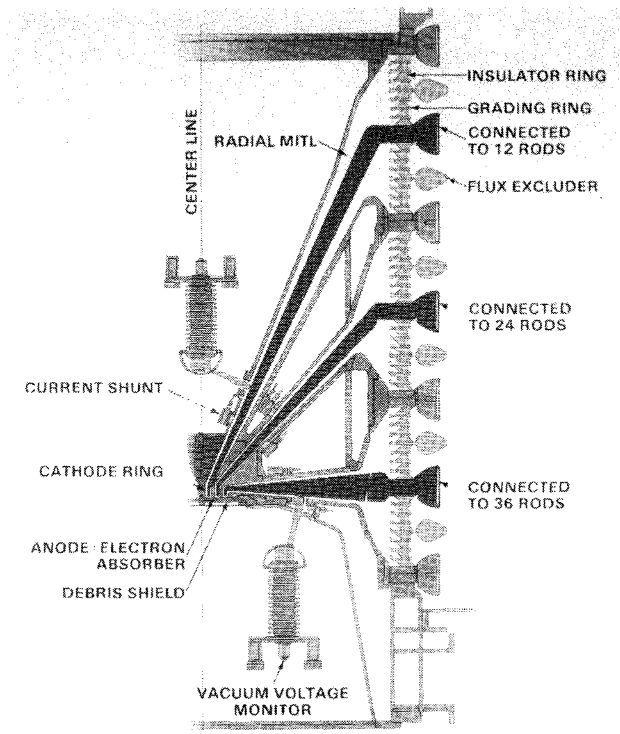

Fig 1. Vacuum section of the SATURN accelerator. The x-ray emitting diode structure, cylindrically symmetric about the centerline, is located just above the debris shield. The source contains three cathode rings, each connected electrically to different numbers of pulsed power modules by rods.

PHYSICAL DESCRIPTION

The scintillator camera designed for SATURN is sketched in Figure 2. A single, tungsten pinhole casts the image of the source on a time-integrating film plane. (Figure 3a.) Below this plane is a pair of adjustable, stainless steel jaws (5 cm thick), which restrict the two-dimensional image of the circular source to a one-dimensional slice along a diameter. Beneath the jaws is an array of 20 fast, plastic scintillators (~ 1 ns decay time)[3]; this array samples the one-dimensional image at discrete locations, giving 20 time-resolved records. The mounting block for the scintillators is made of aluminum (1.7 cm thick) and is internally polished. The scintillators are 3.2 mm in diameter, 2.5 cm long, and spaced at 6 mm increments. Another time-integrating film strip (Figure 3b) is mounted above the

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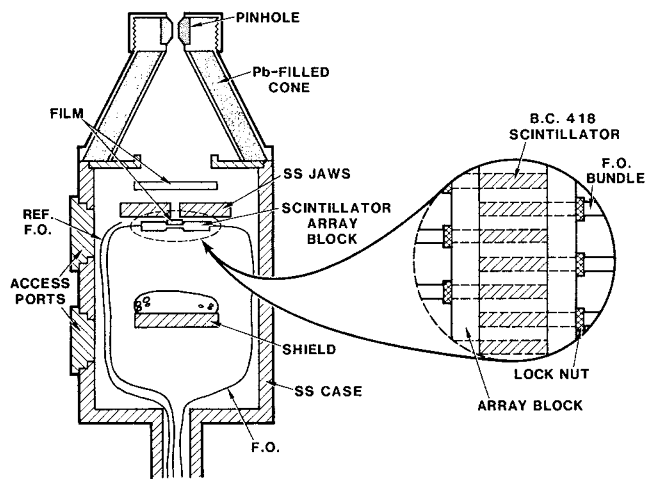

Fig 2. Internal view of the 1-D scintillator camera.

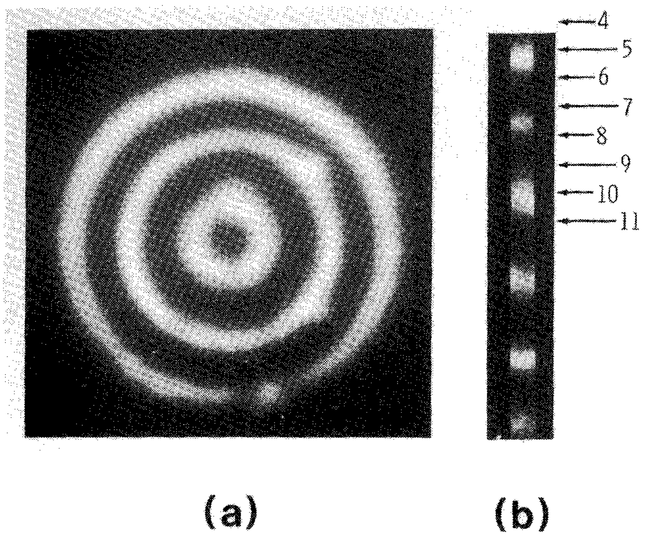

Fig 3. Time-integrated pinhole images of the SATURN standard source (Shot #537). Figure 3a shows a full two-dimensional view; figure 3b gives the truncated view beneath the jaws in the one-dimensional camera. (See Figure 2.) The numbers at the right of Fig. 3b correspond to the centers of the scintillator channels directly below this film plane. One notes a number bright spots in the images, particularly one at the top of the inner ring. The demagnification of the camera was about 1.6:1 on this shot.

scintillator array and is keyed to the array locations. This film has been useful as a cross-check of the scintillator signals. A SiO_2 fiber optic bundle [4] abuts each scintillator and conducts a fraction of its emitted visible light from the camera body. A background or reference bundle, not attached to a scintillator, is mounted near the scintillator array; this measures the background signal produced by direct interaction of x rays in the fiber optics (primarily Cerenkov radiation [5]). An internal shield (5 cm stainless steel plus about 4 cm of lead shot) protects the fibers from direct exposure to the x-ray image.

The layout of the scintillator camera underneath SATURN is shown in Figure 4. A framework, not shown, both supports and centers the camera on the elevator. Since the fiber optic bundles are just as vulnerable to Cerenkov signals outside the camera as within, they are protected by a hollow, articulated arm which conducts the fibers out of the radiation region to a screen room. The straight sections of this arm are made of steel pipe with 4 cm thick walls. Additional lead shielding is required to reduce the Cerenkov background signal to acceptable limits: lead shields (5 cm thick) are installed near the x-ray diode which shadow the arm region, and about 12 cm of lead shot in bags is stacked on the top of the arm between the wrist and the elbow.

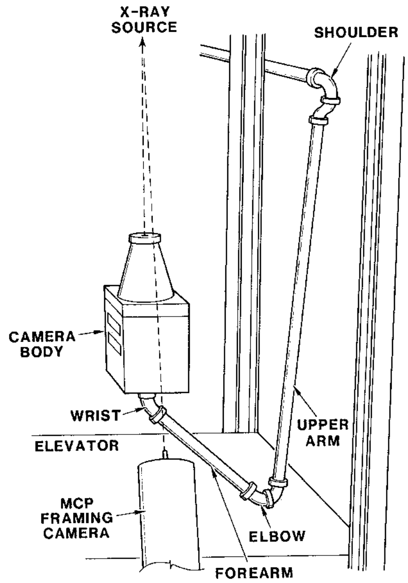

Fig4. Layout of the scintillator camera beneath SATURN. The relative location of the framing camera [2] is also indicated.

In a radiation-protected screenroom, the 21 fiber optic bundles connect to an equal number of Amperex 2020 photomultiplier tubes. The incoming signals can be attenuated with neutral density filters to extend the signal range without adjusting the photomultiplier tube voltages. At present each electrical signal is recorded on a transient waveform digitizer with a 250 MHz bandwidth.

RELATIVE CALIBRATIONS

Since the photomultiplier tubes produce different electron gains as a function of voltage, it is important to expose them simultaneously to a uniform x-ray field. This procedure yields a relative calibration from channel to channel. Such calibrations are obtained with a Hewlett-Packard 706 Febetron pulser (3 ns Blumlein pulse-forming line [6]) and an electron-beam tube with a tantalum converter foil. The whole apparatus is aligned with the scintillator block on the camera. (The shielding cone and the pinhole are removed.) Measurements with thermoluminescent detectors have indicated that at the calibration position, the free-field exposure across the array dimension is uniform to about 10%.

Figure 5 shows the pulsed response for the first six channels in a recent calibration. Although the peak responses vary from channel to channel, the full-width-at-half-maximum of the pulses averages about 6.2 ns across all 20 channels. Taking the Febetron pulse width to be 3 ns, we estimate the system response to be about 5.4 ns. For the 15-20 ns wide pulses from SATURN, this impulse response represents roughly a 4-6% correction. Contributers to this broadening include the scintillator, fiber optic cables, photomultiplier tubes, and the recording system.

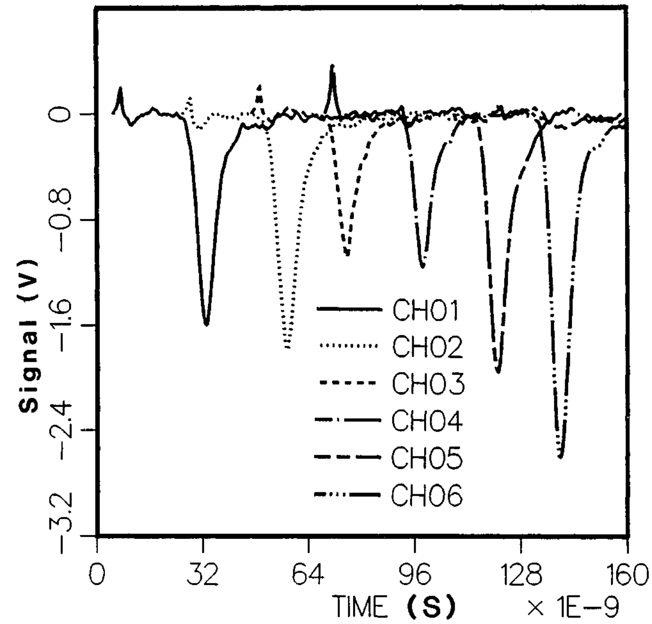

Fig 5. Pulse responses from the first six scintillator channels in a recent calibration. The signals are shifted in time for clarity.

Several such relative calibrations have been made with the Febetron. The net response for each channel varies by 5-10% for a given series of calibration pulses. Figure 6 shows two calibrations taken with the same set of PMT voltages but separated in time by nearly a year. The drift in calibration we attribute to the PM tubes; reseating of the fiber optics barely affected the calibration. It is clear that for critical SATURN experiments, it may be desirable to calibrate the system before and after the shot.

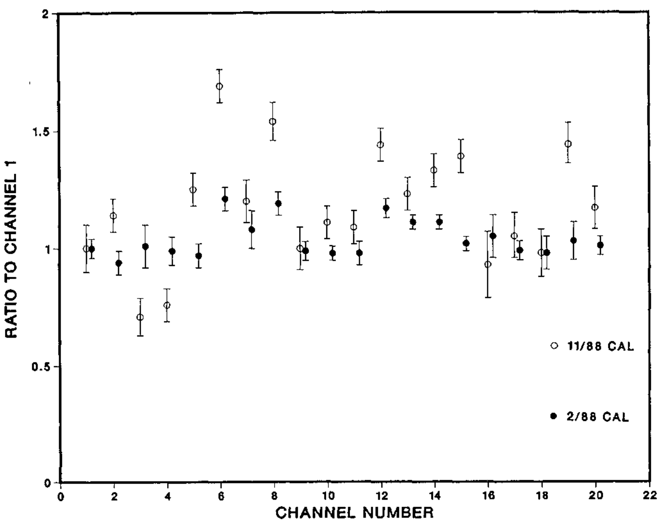

Fig 6. Comparison of two relative calibrations.

RESULTS AND DISCUSSION

Figure 7 shows raw data for two channels on SATURN shot 537. The first peak on the left of each trace we attribute to Cerenkov signals generated in the fiber optics. This Cerenkov signal arises in the upper part of the articulated arm which holds the camera and is strongly influenced by shielding over this member. For comparison, the (scaled) signal from the background fiber, which has no scintillator attached, is

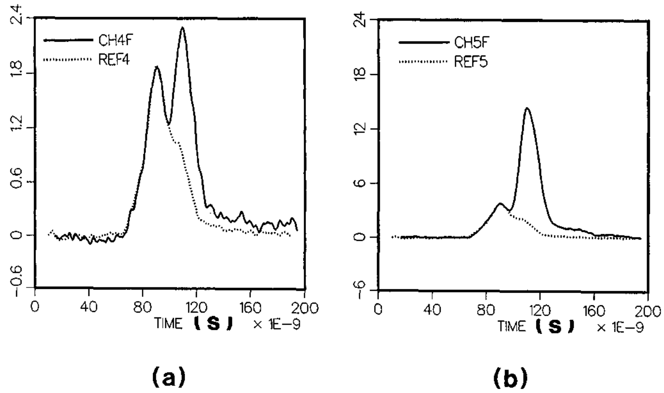

Fig 7. Raw data for two channels in Shot #537.

superimposed on each figure. The second peak in the raw traces is the signal from x rays imaged onto the array; it correlates with the time-integrated film image.

Processing these raw data traces requires removing the background and correlating the signals in time. For this purpose a small amount of (early-time) Cerenkov background signal (as shown in Figure 7) is useful as a time marker since all the fiber optic bundles run closely together and are all exposed simultaneously. Thus, the actual procedure is first to shift the raw signals in time to the reference channel and then to subtract off the scaled Cerenkov backgrounds. Depending on the noise level, the remaining x-ray data signals can have a common time reference to within about 2-3 nanoseconds. Of course, some caution must be applied to any pulse-width estimates if the background represents as large a fraction of the total raw signal as shown in Figure 7a.

Not all 20 channels were available for SATURN shot 537, so we shall discuss here only the scintillator signals which pertain to the image in Figure 3b above the center. (This somewhat atypical shot illustrates the utility of these new diagnostics.) Channels 4 through 6 bracket the outer ring (top), 7 and 8 bracket the middle ring, and channels 9 through 11 sample the inner ring. Figure 8 summarizes the time history of the three rings at the indicated locations. At these

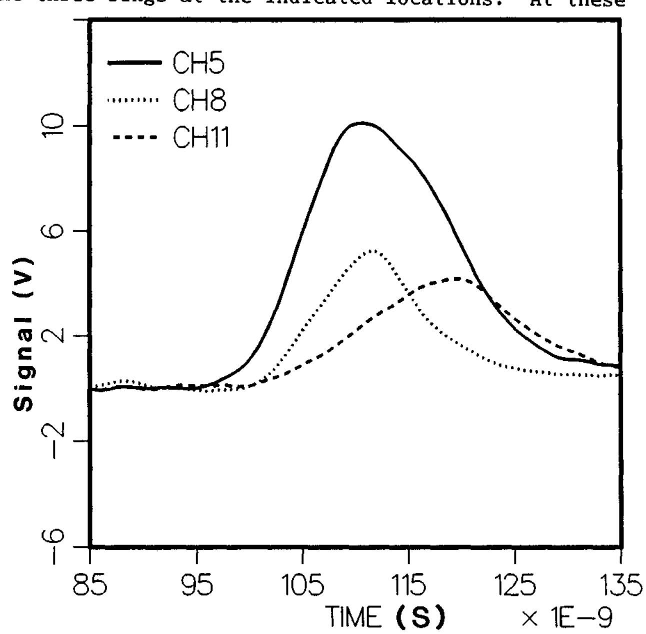

Fig 8. Comparison of the turn-on time and duration at selected positions on the three SATURN rings.

image positions the outer and middle rings turned on nearly simultaneously while the inner ring turned on about 9 ns later. The full widths at half maximum were respectively 16, 11, and 17 ns. Although not shown in Figure 8, channels 4 and 6 showed traces similar to channel 5 and peaked within 3 nanoseconds of its maximum. Likewise, channel 7 matched the trace of channel 8 closely.

However, the three channels which sampled the inner ring were remarkably different (Figure 9). The bright spot shown at the top edge of this ring on the time-integrated image (Figure 3b) is located between channels 9 and 10, while channel 11 is on the bottom edge of the image (inner radius). We believe that the x-ray emission from this part of the ring had two components: at the inside edge (channel 11) the output peaked and relaxed within 17 ns (as noted in Figure 8), whereas at the outside edge some bright discharge (the hot spot) varied in intensity for over 25 ns.

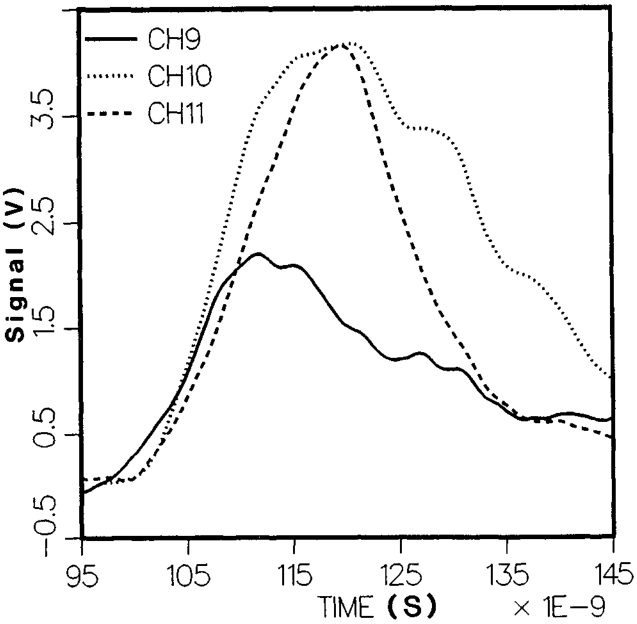

Fig 9. Corrected x-ray signals for scintillator channels 9 - 11 in Shot #537. Channels 9 and 10 correspond spatially to the location of the hot spot shown in Figure 3b.

The framing camera observed the same shot with 1 time-integrated and 4 time-resolved channels. Shown in Figure 10 are the time-resolved images. The inter-frame separation is 10 ns, and the effective gate is approximately 6 ns. It is clear from frames 2 through 4 that the outer and middle ring turned on nearly together, and that emission from the innermost ring peaked one frame later -- both observations in agreement with the scintillator camera results. The time-resolved framing camera pictures, however, do not show the hot spot on the top edge of the the inner ring; however, the time-integrated frame on this camera does show it. This result is consistent with the interpretation from the scintillator data that the hot spot came late in time.

CONCLUSIONS

In summary, the scintillator-array camera and the framing camera together yield a clearer view of the operation of the SATURN accelerator and of its x-ray converters than one would obtain with time- or spatially-integrated detectors alone. The scintillator camera has demonstrated the ability to determine the duration and alignment in time of the signals from various parts of the diode (consistent with its one-dimensional field of view). More difficult to obtain with this camera is a quantitative measure of the peak emission across the field. This goal depends on the alignment of the camera with the diode, the jaw gap, the curvature of the rings in the image, the registration of the scintillator positions with the image rings, and the relative calibration of the PM tubes. Future calibration plans include an experimental determination of the impulse response of the channels determined with a short-pulse (50 ps) LINAC.

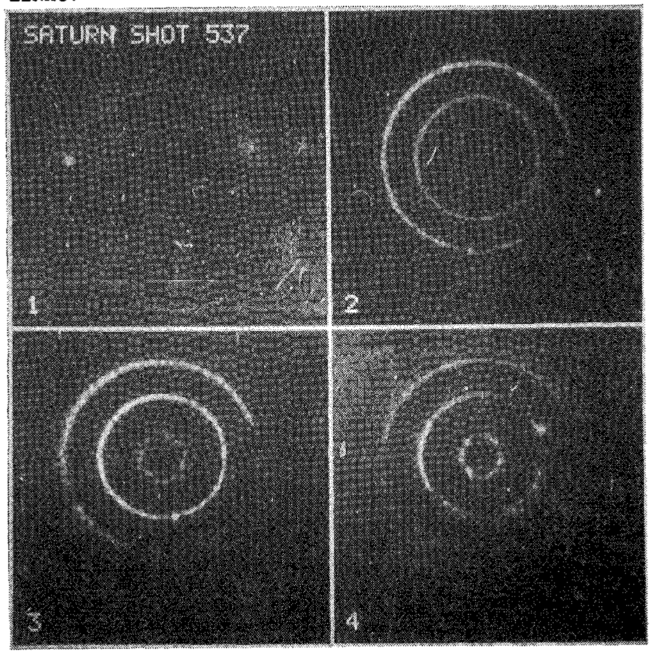

Fig 10. Time-resolved images for Shot #537. The orientation is the same as in Figure 3.

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[4] Ensign-Bickford Optics Corporation, 16-18 Ensign Drive, Avon, CT 06001. Use of this product by Sandia National Laboratories does not necessarily constitute an endorsement.

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