# APPLICATION OF CCD IMAGERS IN HIGH SHOCK ENVIRONMENTS

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## ABSTRACT

Charge-Coupled device (CCD) camera development has been conducted to demonstrate the feasibility of using a hardened imager for a gun or artillery launched television system and for a planetary penetrator probe imaging system. Camera components and systems were subjected to accelerations which had amplitudes of 10,000 to 20,000 g's and durations of 2 to 5 milliseconds. Survivability of CCD and optical components was demonstrated for the shock parallel as well as perpendicular to the focal plane. This paper discusses the development of the hardened CCD cameras, testing of the optical and electronic components, special fabrication considerations, and some of the particular application requirements.


## INTRODUCTION

Prior to the advent of solid-state imagers, hardening an image tube to withstand shocks of 10,000 to 20,000 g's would have been impractical, if not impossible. Charge-coupled devices (CCD) and charge-injection devices (CID) have extended the capability of using imaging systems to applications where such shocks are experienced. Development has been conducted addressing both military and space applications. The military application is for a gun or artillery launched TV system. An imaging payload for hard-landing planetary probes is the space application.

The CCD's used in this development were commercial devices with minor packaging modification. For the gun-launched effort, a 100 x 100 CCD array was used with the wire bonds between the CCD chip and the ceramic substrate encapsulated by the manufacturer. Subsequent testing proved the encapsulation unnecessary; hence, the wire bonds on the 244 x 190 arrays used for the penetrator imager were not encapsulated. The glass window usually found as a part of the CCD package was removed prior to system testing, although some device testing was done to evaluate its survivability.

The shock testing was conducted both in an air gun, which uses compressed air as the propellant, and in an 8" (205 mm) Howitzer. The air gun can produce accelerations which peak up to 35,000 g's and decay to 10% of the peak after 3 milliseconds. The acceleration produced by the Howitzer is about 8,000 g's with a duration of 3-5 milliseconds.

Testing of the gun-launched TV components was conducted with the shock perpendicular to the focal plane, i.e. the camera was looking along the axis of acceleration. For the penetrator imager, the camera is required to look at right angles to the axis of deceleration, and thus, the testing was conducted with the shock parallel to the focal plane.

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## GUN-LAUNCHED TV

A gun-launched TV system has two possible applications: as a gun-launched observation sensor (GLOS) and as a Television Guided Projectile (TVGP). The GLOS will consist of a CCD TV camera and a video transmitter mounted in a projectile quite similar to the present illuminating round. After launching, a pre-programmed delay will initiate parachute deployment, placing the system in a slow descent mode for transmission of pictures of the area over which it is descending. In the TVGP, a stabilized CCD camera will image the target area for video transmission to a remote operator. After target detection, the operator initiates lock-on of a gated video tracker located in the projectile. The tracker then provides the guidance commands for terminal homing.

To demonstrate that a TV picture can be transmitted from a gun-launched projectile, a CCD television camera and transmission system was designed, system components were tested, and, after system fabrication, gun-launch tests were conducted.

### Component Tests

Testing of the CCD and optics, which were considered high risk components, composed the majority of the component tests. The survivability of other system components including the RF, power, and clocking electronics, had been demonstrated in previous projects.

In the first series of CCD tests, three 100 x 100 CCD arrays, all electrically inoperative, were shocked at 15,000 g's in the air gun to test for structural integrity. In the second test, two CCD's, one inoperative, the other operative but unpowered, were fired from the Howitzer at 8,000 g's. After recovery, evaluation revealed that the structural integrity had been maintained and that the operative device functioned properly.

Optical components tested were a 12 mm diameter lens with a focal length of 22 mm and neutral density filters 25.4 mm in diameter with transmissions of .1% and .0001%. In the first test, a lens and the 2 neutral density filters were shocked at 15,000 g's in the air gun. The only failure was in the .0001% filter and was the result of its structure, which consisted of 2 connected .01% filters. In a second test, 2 lenses were fired in the Howitzer with no damage resulting.

### Packaging Design

The camera housing with the electronics and optics sections is shown in Figure 1. In the optics section the lens and a fixed aperture were epoxied into a lens holder inserted into the rear of the optics section. A protective glass dome made of annealed borosilicate crown glass, 44.4 mm in diameter, was epoxied to the front of the section and the assembly was threaded into the camera housing, providing a focus adjustment. To maintain the desired focal distance during the application of high-g forces, a locking ring was threaded to the optics tube.

The electronics section consisted of four printed circuit boards containing the CCD and the camera clocking, power regulation, and video processing electronics. This section was encapsulated (potted) in an epoxy resin and placed in a cup for mechanical support of the potted mass during gun-launch. The RF transmitter, amplifier, antenna and the power supply, and a thermal battery were housed behind the camera.

### System Tests

Prior to gun-launch testing, helicopter fly-over tests were conducted to evaluate the system's performance. Gun-launch tests were conducted from an 8-inch Howitzer at a nominal setback force of 8,000 g's. After two shots that were unsuccessful due to mechanical problems, several mechanical and electrical modifications were undertaken, and a third system was successfully gun-launched. At 15 seconds into the ballistic flight, the recovery system separated, suspending the camera system beneath a parachute. The camera system functioned and transmitted video for 100 seconds. The system (Figure 2) was recovered and further testing revealed no mechanical failures and no apparent image degradation.

## PLANETARY PROBE IMAGER

A hardened CCD imager has application as a payload for penetrator missions to Mars, Mercury, the Moon and the satellites of the outer planets. An imaging experiment as part of a Mars penetrator mission will contribute to landing site characterization, Martian exobiology investigations, and an understanding of Martian dynamic behavior. The camera for a penetrator will be mounted on the antenna structure about 1 meter above the planet's surface. The camera electronics, power supply, and other electronics associated with the experiment will be housed within the penetrator body below the planet's surface.

### Test Results

In this application, the CCD camera will experience a deceleration of up to 20,000 g's. Shock tests have been performed on electrical reject CCD's, lenses, and neutral density filters to determine whether they can survive such an impact. The 244 x 190 CCD arrays were fired in the air gun at 20,000 g's in the two positions as shown in Figures 3A and 3B. In Figure 3A the shock was parallel to the long dimension of the chip and in Figure 3B it was perpendicular to it. The devices were soldered to a double sided printed circuit board which was then potted into a holder. Some of the potting resin flowed onto the top of the chips, creating the dark blotches seen in Figure 3. These two devices were tested to determine whether the gold wires connecting the die contacts to the ceramic substrate contacts would remain attached. No damage was observed in any part of the chips. A second test was conducted at 22,000 g's with the covers mounted on the substrate and again no damage was observed.

Several achromat lenses, 8.5 mm in diameter, and several neutral density filters, 12.0 mm in diameter, were also tested. Both types of components, shown in Figure 4, were epoxied into a holder and shocked with the force parallel to the face of the components. Damage was sometimes observed in units not properly epoxied into their holders, but when properly mounted, shocks up to 33,500 g's produced no damage.

Electronic testing was also performed to determine whether the CCD would operate satisfactorily when separated from the camera electronics. This separation is necessary in the penetrator to minimize the weight on the antenna structure. The lens and CCD from the camera were mounted in a separate enclosure which was connected to the camera electronics by a 2.3 meter cable. Since the cable was an additional load for the electronics to drive, the clock signals reaching the CCD were altered and this produced a decrease in the video output signal. As a result, a loss in image contrast was observed at low light levels but not at high levels. By adjusting the electronics to drive the higher load of the cable, no loss in performance was observed.

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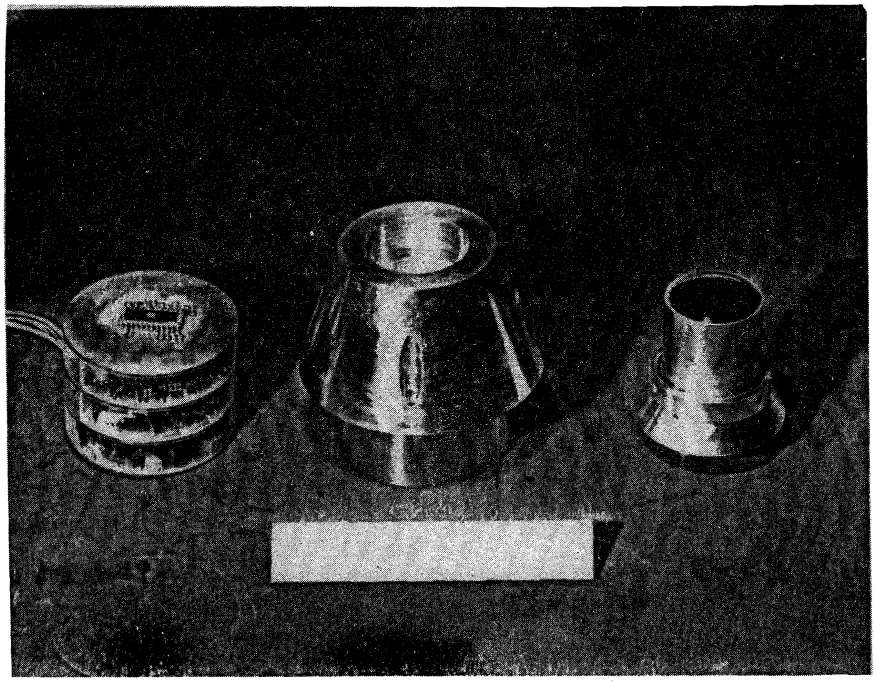


FIG 1: ELECTRONICS AND OPTICS FOR GUN-LAUNCHED TV SYSTEM

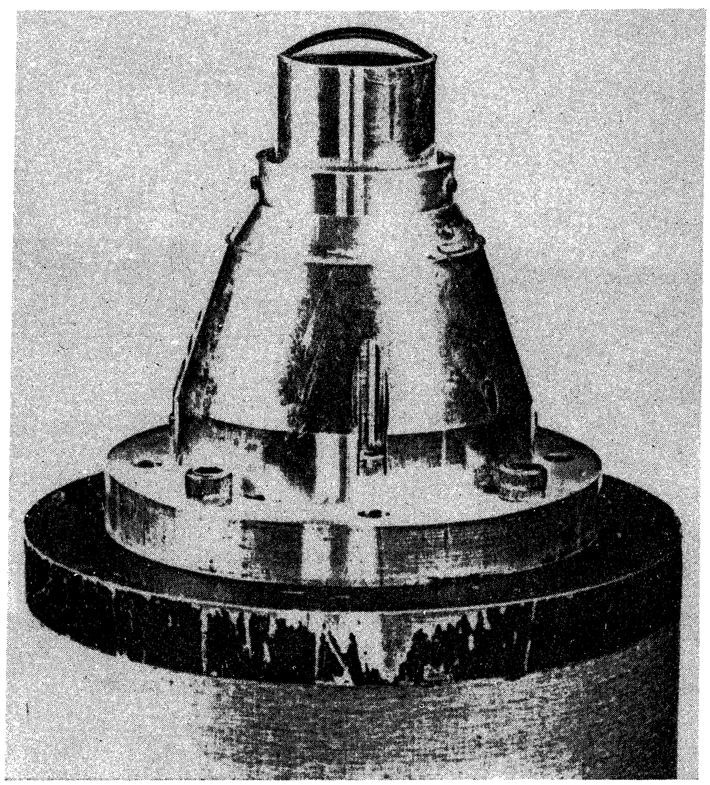
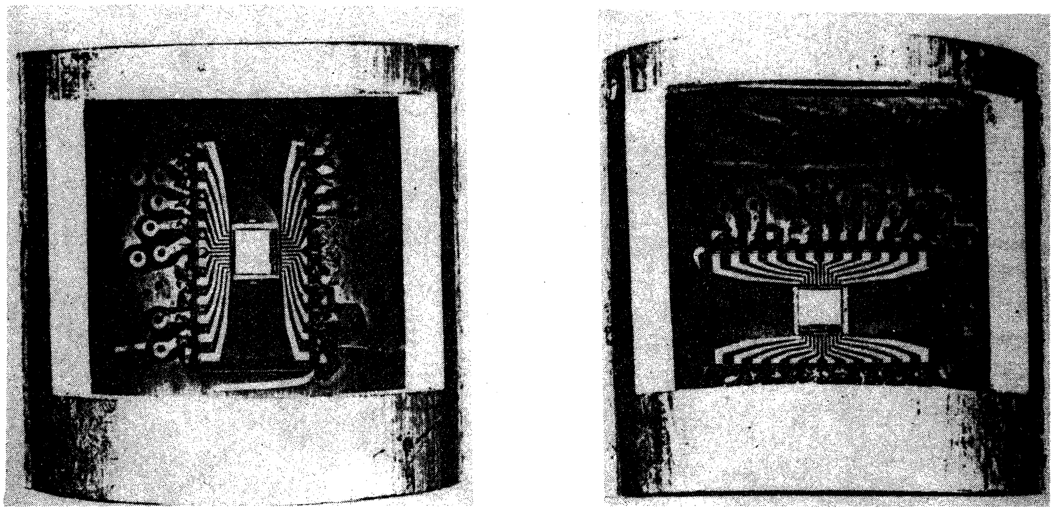
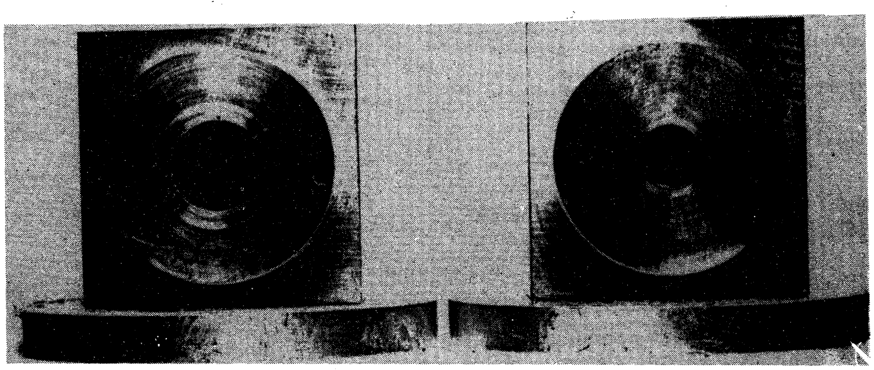


FIG 2: SYSTEM AFTER GUN LAUNCH TEST



a) b)

FIG 3: CCD's MOUNTED FOR SHOCK TESTS



a) b)

FIG 4: FILTER a) AND LENS b) MOUNTED
FOR SHOCK TESTS