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"A Historical Perspective, design, fabrication, and performance of the CASSINI Huygen's Probe DISR CCD imager"

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Abstract

Space exploration missions can entail significant amounts of time. The original CCD's for the NASA/ESA CASSINI space mission were initiated in 1990 when our group at Ford Aerospace was approached by Dr. Uwe Keller to provide a custom imager for the Descent Imager/Spectral Radiometer (DISR) experiment aboard the Huygens probe. The instrument was launched in 1997 and seven years later the Huygens probe descended thru atmosphere of the Saturnian moon Titan. Startling pictures returned to Earth from over 750 million miles away revealed a strange new world.

We will describe the technology, design rules, and system trades used to create a CCD imager uniquely qualified for this mission. Performance in a deep space radiation environment during the 7 year travel to Titan will be reported. The instruments' successful performance upon landing will also be detailed.

Introduction

In the early 90's production silicon lithography was moving below 1 micron to the 0.8-0.5 micron regime. When we began this program at Ford Aerospace our CCD technology used a nominal 2-3 micron geometry. The multiple science requirements of the DISR dictated integration of a variety of CCD functions to meet their goals. The CCD's surface is divided into nine separate regions, with the light collected by different fore optics and brought to the detector by fiber optic bundles and ribbons. These include imagers looking in three different directions with different fields of view and angular resolutions, two regions fed by light collected by upward- and downward-looking grating spectrometers for flux measurements and for making spatially-resolved spectra of the surface at 480-960 nm, and four regions devoted to measurements across the solar aureole in two colors and in two different polarization states.

Design

The CCD is a front side illuminated device qualified for space applications. Buried channel technology is employed with 2 phase MPP clocking. The gate dielectric is oxide-nitride for improved radiation tolerance. The frame transfer type CCD consists of two sections of 256 lines and 520 columns each. The image section contains eight additional columns at the beginning which are covered by a metal mask for calibration reference, Figure 1. Pixels in the image section contain an anti-blooming structure to remove excessive charge from overexposure, Figure 2. The image section requires anti-blooming drains to provide protection from the excess charge produced when the Sun flashes through the solar aureole section. The anti-blooming drain takes up 6 μm on the side of each pixel. The individual pixels are 17x23 μm (sensitive area) on 23 μm centers. The pixel exhibits a pixel capacity of more than 125 000 e-. The anti-blooming gate can be adjusted to optimize the full well capacity. Line transfer of up to 2μsec/line during the image shift allows operation with minor shuttering. Compared with actual exposure times (7-50 msec), the shift time is small so that no significant image smear occurs. The optical resolution of the imager was set as a compromise between the scientific objectives and the data transmission capability of the spacecraft-ground link.

The quantum efficiency of the CCD material is also typical for front side illuminated silicon and quite good (- 50%) at peak.

A simple single stage source follower, W/L 60/6, provided a noise of 5-8 electrons rms at a readout rate of 14μsec/pixel.

The CCD is mounted on a ceramic substrate in a PGA kovar tub with mounting bracket on back for a thermal strap, Figure 3.

The CCD input is via a coherent fiber optic bundle with 6 μm core size and 8 μm centre-to-centre spacing. The CCD is fed by optical fibers from nine optical subsystems: HRI, MRI, SLI, ULVS, DLVS and the 4-channel SA radiometer (two colors in each of two orthogonal polarization states), Figure 4.

Electronics

The CCD pixel signals are pre-amplified by an OP-16 JFET-input operational amplifier in the Sensor Head (SH) to minimize the possibility of noise. After amplification, the signals are relayed over a short connecting cable to the Electronics Assembly (EA), where they undergo video processing, including correlated double sampling. A fast 12-bit AD7672 A/D converter and AD585 S/H digitizes the pixels, which are clocked to the bus. After A/D conversion, a pseudo-square root algorithm reduces the imaging data from 12 to 8 bits/pixel. The image data is then compressed in a lossy hardware compressor. The compression factor is programmable, and will be between 20:1 and 30:1 for different images. This compression reduced the data for Huygens-to-Cassini data link of 8 kbits/sec. The dark current from the CCD is measured by the signals from the column of masked pixels along the chip's edge. These data are read out and transmitted to the ground once every data cycle (about every 1/3 min). At Titan entry, the chip is at a temperature of some 260K, and the dark current is a few per cent of typical signals. After some 40 min, the detector cools to < 180K, and the dark current is essentially negligible.

The full well capacity of the CCD pixels is about 125 000 electrons. This is digitized to 12 bits for 4096 levels of some 30 electrons/step (before square root compression). The read noise of the system (CCD, electronic amplifiers, sample and hold, A/D conversion and subsequent handling) is < 23 electrons. The data is shot-noise limited for all but the lowest signals.

The DISR thermal design must maintain interface constraints, cool and maintain the detectors' temperature within limits, maintain all other components within their temperature limits, and minimize mass and power consumption. In particular, it is important that the detectors are cooled as rapidly as possible from their temperatures near 260K at Titan entry to below some 180K, Figure 5. In order to minimize the influence of dark current and to ameliorate the defects in CCD pixels that may have been damaged by energetic particle impact during cruise. The detector cooling system includes a thermal strap to provide a heat sink to the atmosphere via an attachment to the Probe. A heater ensures that the detectors will remain above their minimum temperature limit, thermostatically controlled to maintain > 160K.

Radiation

The long flight to Saturn and proximity of radioactive sources the DISR CCD in the Sensor Head resulted in elevated dark current and CTE degradation during the mission. Figure 6 shows an increase in dark current between the delivery to UofA in 1994/5 and 2005 of 60x. In addition, CTE degradation was noted, but not yet measured.

By design, the detector assemblies were surrounded by a tungsten radiation shield 4 mm thick, sufficient to prevent protons of <64 MeV from reaching the detectors, significantly reducing the radiation dose. Initial system tests of the CCD showed degraded performance. It was found that the plutonium heater for the system was mounted a distance of 5 to 10 cm from the CCD. It appears this contributed to the overall degradation of the CCD over the life of the mission. Fortunately, the exposure times were short, (7 msec) in the upper atmosphere at the warmer beginning of descent, and up to 50 msec close to the landing when the CCD was cold. As a result, the dark current did not contribute significantly to system noise.

Because of the overall small size of the CCD, the reduced CTE also did not cause any significant problems with the imagery.

Summary

After a 7-year journey from Earth and a 3-week cruise from its mother ship, NASA's Cassini orbiter, the European Space Agency's Huygens probe plummeted through Titan's thick atmosphere to a successful landing. During the 2.5 hour descent the DISR CCD imager/ electronics performed flawlessly, recording startling data from a total alien outpost in our solar system. DISR surface images show small rounded pebbles in a dry riverbed. Spectra measurements (color) are consistent with a composition of dirty water ice rather than silicate rocks. However, these are rock-like solid at Titan's temperatures, Figure 8. The astounding data will be studied for years, giving scientists a greater understanding of our solar system and the universe.

Acknowledgements

The authors are proud to be a part of one of the most outstanding science missions of this generation. We would like to dedicate this paper in memory of Elwood Thompson who tireless managed our portion of the program at Ford Aerospace.

References

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FIGURES

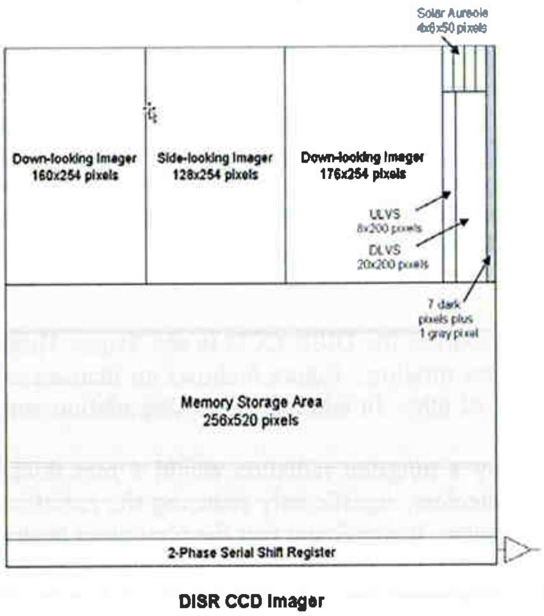

Figure 2 Schematic Diagram

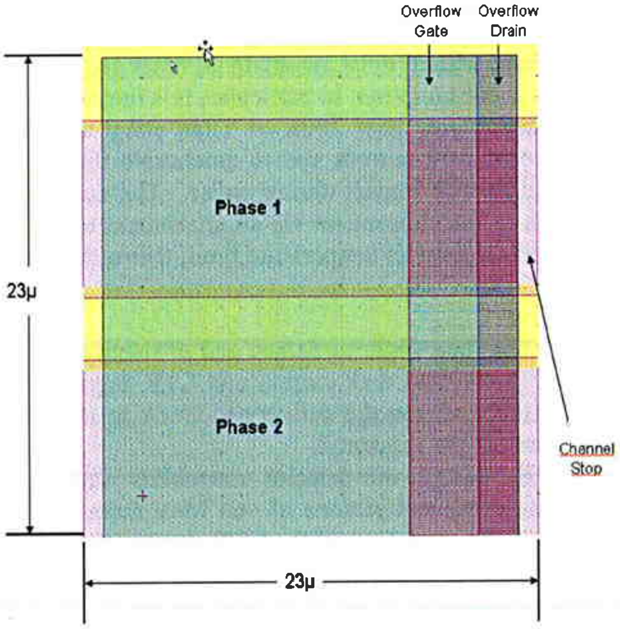

Figure 2 CCD Pixel

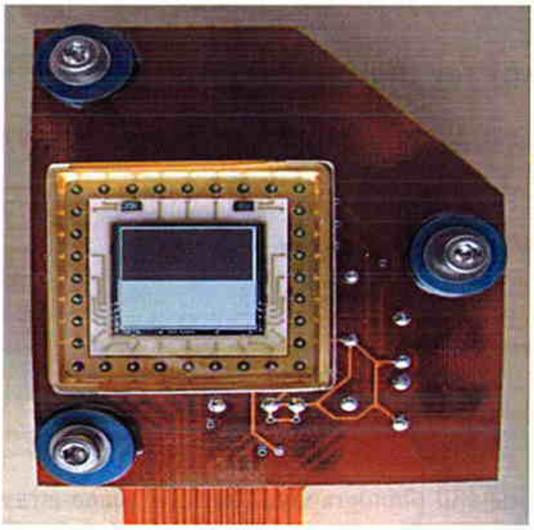

Figure 3 CCD mounted on flex cable

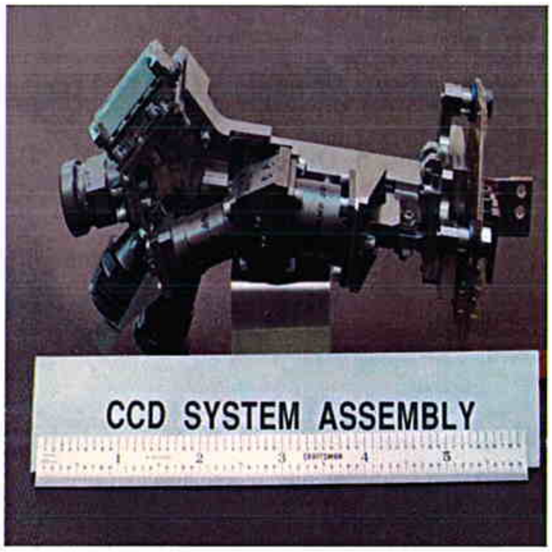

Figure 4 CCD Sensor Assembly

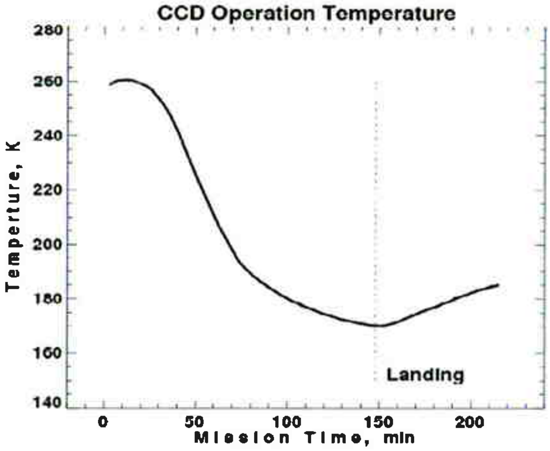

Figure 5 CCD temperature during descent and after landing

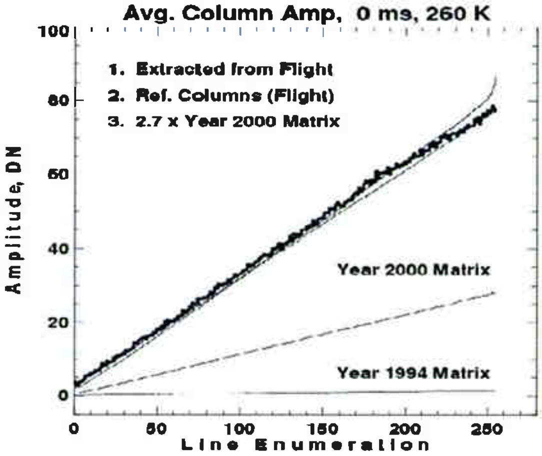

Figure 6 Vertical dark charge distribution upon readout at 260k

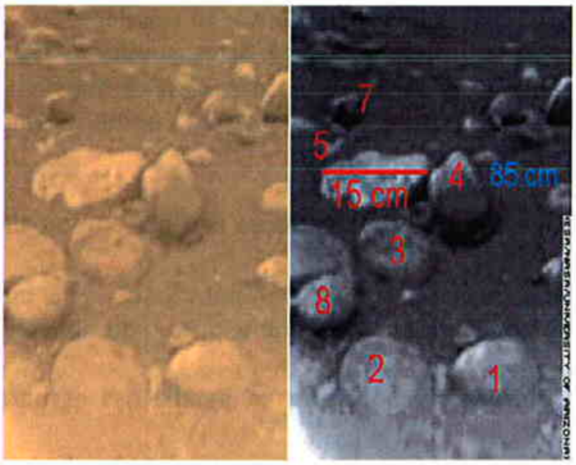

Figure 7 Surface features of Titan acquired with the Side Looking Imager.