ICC CCD CAMERA PROJECT: MOTIVATION, DESIGN, AND STATUS

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Abstract

The Internet CCD Camera (ICC) project attempts to design a 512 x 512 pixel imaging CCD camera using a low cost version of the world class Tektronix TK512CB CCD sensor. This paper describes the motivation behind the effort, the current design and design goals, and the project status.

1. Introduction

CCD camera systems intended for the amateur astronomer in general suffer from small array sizes, low S/N ratio, and non-symmetric pixel geometry and pixel array geometry. These conditions make those cameras less suited for scientific imaging and photometry than are desirable by advanced amateur and small college investigators. This paper describes a low cost, high quality, research-grade CCD camera that is currently under design.

The ICC CCD camera project is intended to fill the gap between the one-of-a-kind professional research grade CCD cameras and the existing amateur astronomer CCD cameras by providing a proven CCD camera design capable of supporting the amateur astronomer's and smaller observatory research programs. Construction of the camera is within the budgets and skills of the target group. The estimated cost of the prototype camera is $5000.00, with a target cost of $3000.00 for follow-on cameras. The camera will use a low cost version of a state-of-the-art CCD chip intended for astronomical imaging, with the capability to upgrade without modification to a prime grade device for critical applications.

2. Instrument Design Goals

This camera is designed to be modular to the extent that wide choices may be made in device selection and subsystem design. Those choices will allow a specific implementation to be optimized to meet the needs of the target observatory and the intended observational programs. Specific choices include the selection of frontside or backside CCD devices in standard, multi-pinned-phase (MPP), or mini-channel variants, wide control of clock parameters via the use of a microcontrol-loop clock generator, a removable analog subsystem that allows for upgrades to precision, and a camera head that can be cooled by a Peltier junction with air or water dissipation or a liquid nitrogen (LN2) coolant. In summary, Table 1 is a list of the features this camera will support.

3. Device Selection

The design of a CCD camera revolves around the CCD imaging device selection. Numerous parameters and options determine the characteristics of a CCD device and thus the instrument's capabilities and limits. See Janesick and Elliott (1992) and the references therein cited for a comprehensive description.

Table 1. ICC CCD Camera Design Features

Construction	modular with options
CCD Device	Tektronix thinned backside TK512CB
Cooling system	Peltier junction, air dissipation
	Peltier junction, water dissipation
	LN2
Telescope attachment	2" flange
Head weight	< 20 pounds, 10 pounds target
Readout rate	50 kilo pixel per second
DAC	16 bits with 14 bit accuracy
Video processing	Analog Double Sampling (ADS)
Clock generation	microcontroller
Digital comm	high speed RS232 (115 kbps) TCP/IP Ethernet
Host software	multi platform written in C
Control and Command	ASCII text Diagnostics modes

Initially, commercial CCD camera devices were considered. CCD cameras currently available to the amateur astronomer at modest cost (DiCicco 1990; 1991; 1992) are based on CCD devices that were not designed to the needs of research astronomy. In fact, these devices were typically designed for mass-produced TV or medium-volume realtime imagers in medicine, space, nuclear physics, and astronomy (Buil 1991). That these cameras are quite useful stands as an indicator of the power of CCD technology. These cameras can be implemented using frontside or thinned-backside sensors in standard, MPP, and mini-channel (when available) variants. The CCD may be an engineering grade or a grade 1 device as budget allows and observational program requires. Engineering grade thinned-backside devices are available for $750.00, with the grade one device for $6000.00 (Tektronix 1991 price list). Tektronix is re-engineering the TK512 and expects to sell grade 1 devices for $3000.00 (Baxter 1992).

After evaluation of available devices the Tektronix TK512 CCD was selected. This sensor is a full frame 512 x 512 pixel device. Each pixel is 27 x 27 microns. The square pixel and pixel array reduces the complexity in data reduction over non-square pixel CCD devices (Tektronix 1991 price list). Tektronix TK512 CCD devices are available in frontside and thinned backside, in grade 1 and an engineering grade. Additionally, these sensors are available in standard, MPP, and micro-channel variations (Lindley 1991). MPP devices are optimized for ultra-low dark current (Stephens 1992) and thus can operate at higher temperatures, reducing the need for a complex cooling system.

4. TK512CB Specification

The TK512CB is a 512 x 512 pixel silicon Charge-Coupled Device designed for scientific imaging under low light conditions from UV to near infrared. Each pixel is 27 x 27 microns, yielding an active image area 13.8 x 13.8 mm.

Typical dark current measured at 20° C is 1.0 nA/cm^2 for this backside device. Readout noise is 8 electrons, with a full well capacity of 500,000 electrons. Charge transfer efficiency exceeds 0.99999 (Tektronix 1991, TK512 CCD Imager Specification Sheet). The quantum efficiency (QE) of the selected thinned-backside device without anti-reflection coatings is greater than 50% between 550 and 850 nm. QE between

400 and 1000 nm is greater than 20%. Anti-reflection coatings increase the QE to 80%, peaking at 640 nm and extending the UV 20% limits to 330 nm (Tektronix 1991, Quantum Efficiency Measurements on CCDs). See Figure 1.

Tektronix Engineering grade devices are only guaranteed to image. The dark current, readout noise, and defects are unspecified and are the luck of the draw (Woody 1992). With this said, how do we get better-than-luck-of-the-draw devices? At the time we selected a TK512, there were 21 devices in stock in the engineering grade, backside, non-mpp type to choose from. Working with Tektronix engineers, we were able to select one of those devices that gave the best fit for astronomical imaging. Maximum grade 1 readout noise, for example, is 10 electrons with the OPO TK512 #1 device, failing grade 1 at 12.7 electrons readout noise. This engineering grade device selection is not normally available from Tektronix but was extended as a courtesy due to our proximity to Tektronix and because of past employment at Tektronix.

To understand Tektronix engineering grade CCD devices, I will describe the Tektronix testing sequence. First, basic DC and AC tests are performed to remove the truly dead devices as well as the devices with shorts and opens. These devices become mechanical samples and are non-functioning. Next, the device under test (DUT) has a quick test of its imaging. Non-imaging devices become electrical samples that are used to test clock and other support hardware with an otherwise good part. The DUT has the readout noise measured and if it fails the grade 1 spec it becomes an engineering grade part and testing is stopped. Next, the dark current is measured and if it fails the grade 1 spec it becomes an engineering grade part and testing stops. Next, pixel defects are measured. Any device that has 10 or more adjacent pixel defects is said to have a column defect and is becomes an engineering grade part. Also, if there are more than some number of individual pixel defects the device becomes an engineering grade part. Any part that passes all these tests becomes a grade 1 sensor (Baxter 1992; Stephens 1992; Woody 1992). In short, for devices that do image, failing any grade 1 specification halts the testing sequence and causes the device to be marked as an engineering grade sensor.

The OPO TK512 #1 CCD is an engineering grade Tek TK512CB. This thinned-backside device came with minimal test results. However, the image tests show a minimum of hot and cold defects concentrated in four locations and in general a uniform across-the-device sensitivity. With the exceptions of the four hot and cold defect areas (which can be removed prior to image processing), the test bias frame looks very much like an outstanding bias frame described by Massey and Jacoby 1992. It is expected that the OPO TK512 #1 device will produce good data not too unlike that obtainable with a grade 1 device. This will be subject to analysis after the completion of the ICC CCD camera prototype.

5. Design of the Instrument

The ICC CCD camera is broken down into 3 major assemblies and 7 subassemblies (Figure 2). The major assemblies are the camera head, camera controller, and the host computer.

The camera head (Figure 3) consists of a base plate with a 1.5" window in the center to allow light to reach the CCD sensor. The CCD is mounted to a socket board using a Zero Insertion Force (ZIF) socket that has had the center area milled out to allow the cold finger to contact the CCD. The socket board contains driver circuits for each of the CCD clocks based on a driver recommended by Tektronix (Tektronix 1992, The Imaging CCD Array, 6), a low-noise preamplifier with DC restore based on the well-known 'Spacecraft Preamplifier' (Tektronix 1992, The Imaging CCD Array, 10), and power supply decoupling components.

The socket board is mounted to a spring-loaded alignment board that causes the CCD to contact the cold finger. A heat shield isolates the socket board from the cooling assembly. The inner chamber of the camera head is held in vacuum to prevent the formation of frost on the CCD, to allow the optical window to be heated to prevent the formation of frost where it is in contact with outside air, and to form a dewar for the containment of the liquid nitrogen coolant.

The cold finger is attached to the LN2 chamber yet is isolated thermally from it by insulating screws and gaskets. LN2 is transferred to the cold finger by a copper wick. Inside the cold finger is a temperature sensor and a resistive heating element, providing closed loop control of the CCD operating temperature. The LN2 chamber is completely within the vacuum outer chamber, forming a dewar. Connected to the LN2 chamber are a fill cap and a vent tube. The planned capacity of the LN2 chamber is 1 liter LN2. There is no estimate at this time of the operational duration per LN2 charge.

Other cooling system options are Peltier Junction devices with air or water dissipation of the system heat.

The camera controller consists of a motherboard containing a Motorola 68000 series-based microprocessor, the clock generator microcontroller, the CCD temperature controller, and the power supplies. Daughter boards mount on the motherboard and include the analog board and a host interface board. By using a standard set of control signals for each of the daughter boards, individual implementations may implement analog and host interface boards suited to their needs.

OPO's analog board is implemented using correlated double sampling (CDS) based on a Dual Slope CDS circuit provided by Tektronix (Tektronix 1992, The Imaging CCD Array, 15) coupled to a 16-bit analog-to-digital converter (ADC) based on the Analog Devices AD675 ADC chip or Analog Devices AD1876 (Analog Devices 1992). CDS was selected to eliminate kTC noise (equipartition noise of the CCD's FET reset switch) and reduce digital feedthrough noise (Tektronix 1992, The Imaging CCD Array, 10). The image transfer time from the CCD sensor to the camera controller's image memory is 5.243 seconds at 50 kilo-pixel per second (kps). This equates to a 100-kbps transfer rate to the camera controller's memory, well within the 68000 family specifications.

The clock generator is a state machine implemented in high speed CMOS integrated circuits and controlled by a 87C751 microcontroller. Twenty four clocks are implemented in the prototype with expendability in increments of 8 clocks. The clock edge resolution is 100 nS (24). Using a 50 kilopixel-per-second readout rate gives 200 clock generator cycles (of 100 nS each) per pixel. This yields a clock edge control of 0.5% of the pixel cycle. The clock generator is crystal-controlled, thus clock jitter is not expected to be a source of problems.

Host interface options include serial RS232 communications to a host computer or thinwire ethernet using the TCP/IP communications protocol. RS232 would best be used where the host was an IBM PC class machine with a high-speed RS232 communications adaptor. Even then, RS232 would be slow, taking over 37 seconds to transfer a 512 x 512 by 16 bit image (4,194,303 bits) at 112 kbps. Image compression techniques could be implemented to reduce the image transfer time to the host computer.

6. Future Directions

Once the camera is functional, additional work remains to bring it to an operational state. Using a commercially available filter wheel such as those available from Optec (199 Smith Street, Lowell, MI 49331) or CompuScope (3463 State Street, Suite 431, Santa Barbara, CA 93105) leads to the selection of a filter set. See Boltwood (1992) for a discussion of the difficulties involved.

Significant additional work remains to be done on the host processor. An interface to IRAF or SPS (Janes and Heasley 1993) will be created to allow image processing and stellar photometry.

7. Internet Team Members

The camera design team is composed of a project leader, subsystem design team members, and advisory team members. Of special note, each of the team members are from diverse geographic locations, including Australia and England. Communications among the team has occurred through the internet.

Table 2. Camera Design Team

Team Member	*Function*
Ethan VanMatre	Project leader
Dave Garnett	Clock generator
Robert Mutel	Camera head
Linas Petras	Alternate camera head
Mike Collins	Advisor
Tom Glinos	Advisor
Kurt Hillig	Advisor
Mike Anderson	Advisor
Art Wetzel	Advisor

8. Conclusions

We have shown that a research quality CCD Camera can be designed and is being constructed by advanced amateur astronomers for use in their observing programs and for use by smaller university astronomy programs. The availability of engineering grade CCD sensors reduces the cost of designing an astronomy-specific CCD camera while allowing for the upgrade to a leading edge sensor. Spectral response of the selected CCD sensor allows UBVRI photometry.

We are especially grateful to Bill Stephens of Photonics Marketing Associates for his assistance in selecting an engineering grade Tektronix CCD and for his liaison with the Tektronix CCD Engineering staff. We also thank Dr. Fred Ringwald for his encouragement and support of amateur astronomers.

References

Analog Devices 1992, *Data Converter Ref. Manual*, **2**, 2-283.
Baxter, A. 1992, Tektronix, private correspondence.
Boltwood, P. 1992, *IAPPP Communications*, **46**, 48-56.
Buil, C. 1991, *CCD Astronomy*, Willman-Bell Publishing, 57.
DiCicco, D. 1990, *Sky & Telescope*, **80**, 250.
DiCicco, D. 1991, *Sky & Telescope*, **81**, 257.
DiCicco, D. 1992, *Sky & Telescope*, **82**, 395.
Garnet, D. 1993, private correspondence.
Janes, K. A., and Heasley, J. N. 1993, *Publ. Astron. Soc. Pacific*, **105**, 527-537.
Janesick, J., and Elliott, T. 1992, *Astron. Soc. Pacific Conference Series*, ed. S. B.

Howell, 23, 1-67.
Lindley, C. A. 1991, *Practical Image Processing in C,* 427,429.
Massey, P., and Jacoby, G. H. 1992, *Astron. Soc. Pacific Conference Series,* ed. S. B. Howell, 23, 245.
Stephens, B. 1992, Photinics Marketing Assoc., private correspondence.
Tektronix 1991, TK512 price list.
Tektronix 1991, TK512 CCD Imager Specification Sheet.
Tektronix 1991, Quantum Efficiency Measurements on CCDs.
Tektronix 1992, The Imaging CCD Array, 6.
Tektronix 1992, The Imaging CCD Array, 10.
Tektronix 1992, The Imaging CCD Array, 15.
Woody, T. 1992, Tektronix, private correspondence.

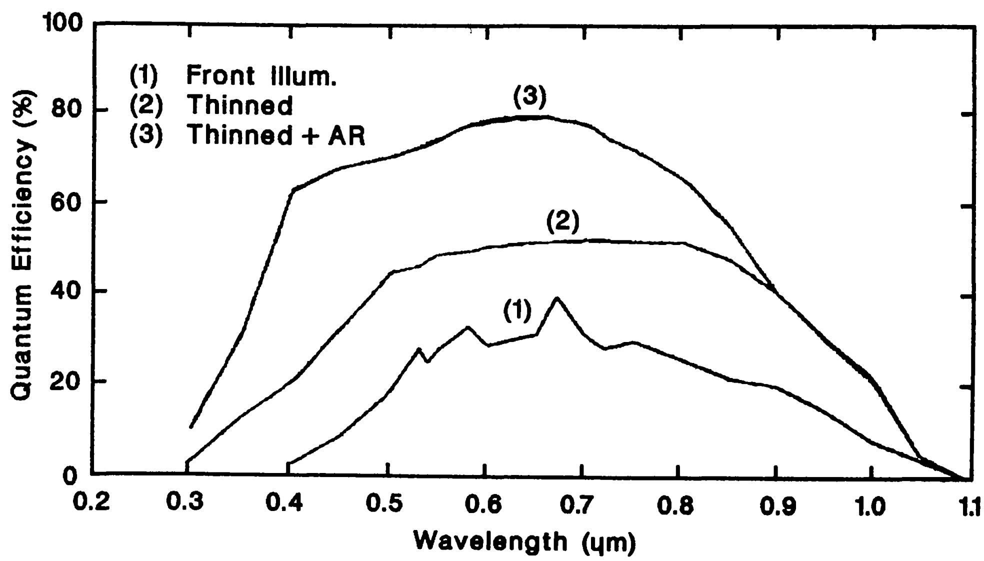

Figure 1. Quantum efficiency curve of selected Tektronix thinned-backside device with and without anti-reflection coatings.

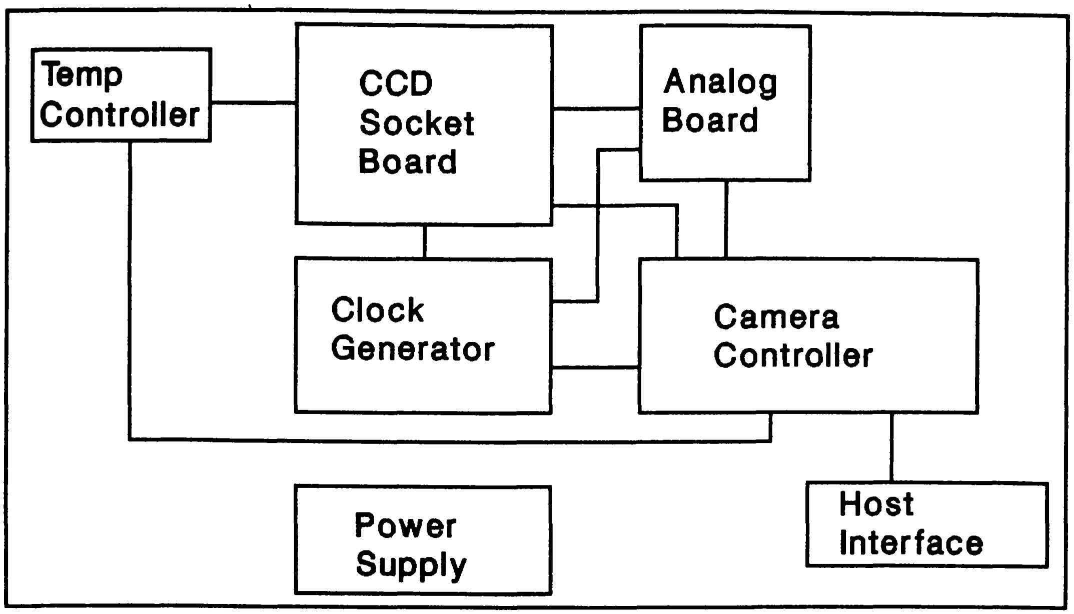

Figure 2. The ICC CCD Camera is broken down into 7 subassemblies.

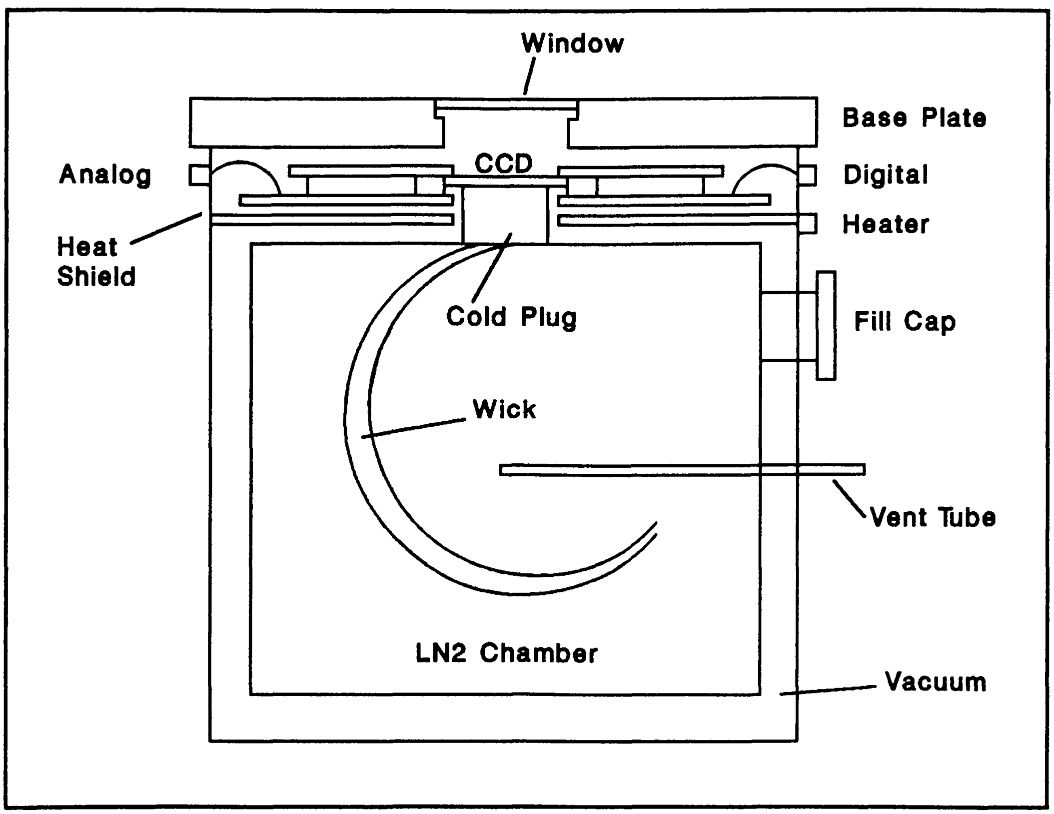

Figure 3. The ICC CCD Camera head.