A New Infra-Red Camera for COAST

The Cambridge Optical Aperture Synthesis Telescope

COAST is a long-baseline 5-element interferometer, which has the ability to measure closure phases. It can obtain images by Earth-Rotation Aperture Synthesis. The baselines may be configured to be up to 100 m, providing a maximum resolution of 1 milliarcsecond. In 1997, COAST obtained the first infra-red image from an aperture synthesis array. [This image of Capella is shown in the background, right panel.]

COAST operates in the Red and near Infra-Red between 600 nm – 2.3 µm. The limiting magnitude is 6.4 in the I-band. Each siderostat is a 40 cm Cassegrain telescope, with a moveable flat mirror for pointing. Light from up to 4 of the 5 beams may be combined simultaneously. COAST is also used as a test-bed for MROI development.

[The background images show one of the siderostats with its cover removed (top), and all 5 of the telescopes in front of the thermally isolated beam-combining laboratory (bottom).]

Introduction

We have designed and constructed a new Infra-Red camera for the COAST telescope in Cambridge, which is currently undergoing testing, and which is also a prototype hardware design for use at the forthcoming Magdalena Ridge Observatory in New Mexico.

The camera uses a Rockwell Hawaii HgCdTe Focal Plane Array sensor in place of the NICMOS device from our previous camera, and is able to sample the temporal fringe patterns from the four outputs of the COAST IR beam combiner at frame rates up to 10 kHz. (It is capable of exceeding this rate by some margin, or of being used for many multiple reads.) Use of non-destructive multiple reads should allow an effective read noise of 3 electrons to be attained. The camera can also be configured for spectroscopic and imaging readout modes.

The camera controller uses custom-designed hardware, and derives its timing signals from a 'PulseBlaster' FPGA card. The advantages of this are flexibility, ease of use, and rapid reconfiguration of the clocking scheme. The data capture is performed via a 'QuickUSB' module on a Linux host. The new system should improve the IR sensitivity of COAST by around 2 magnitudes.

[The background image is a detail from the Analogue PCB, showing the ADC and input amplifier for two of the quadrants. The AD7677 ADCs, are visible, with 0.6 mm pin spacing!]

Magdalena Ridge Observatory Interferometer

MROI is a facility class optical and near infra-red interferometer, whose design is based upon our experience at COAST. The observatory site is in New Mexico, at an altitude of 3.2 km above sea level. MROI is scheduled for completion in 2008/9.

MROI will have 10 elements, with 1.4 m diameter mirrors, on baselines up to 400 m. The resulting array will have an extremely high sensitivity (H=14) and will have an angular resolution of approximately 1 milliarcsecond.

Applications of MROI will include the study of the formation of planets, stellar accretion and mass loss, and active galactic nuclei.

Please see the talk by J.S. Young in the "New Astronomical Instrumentation" session for more details.

Circuit Description

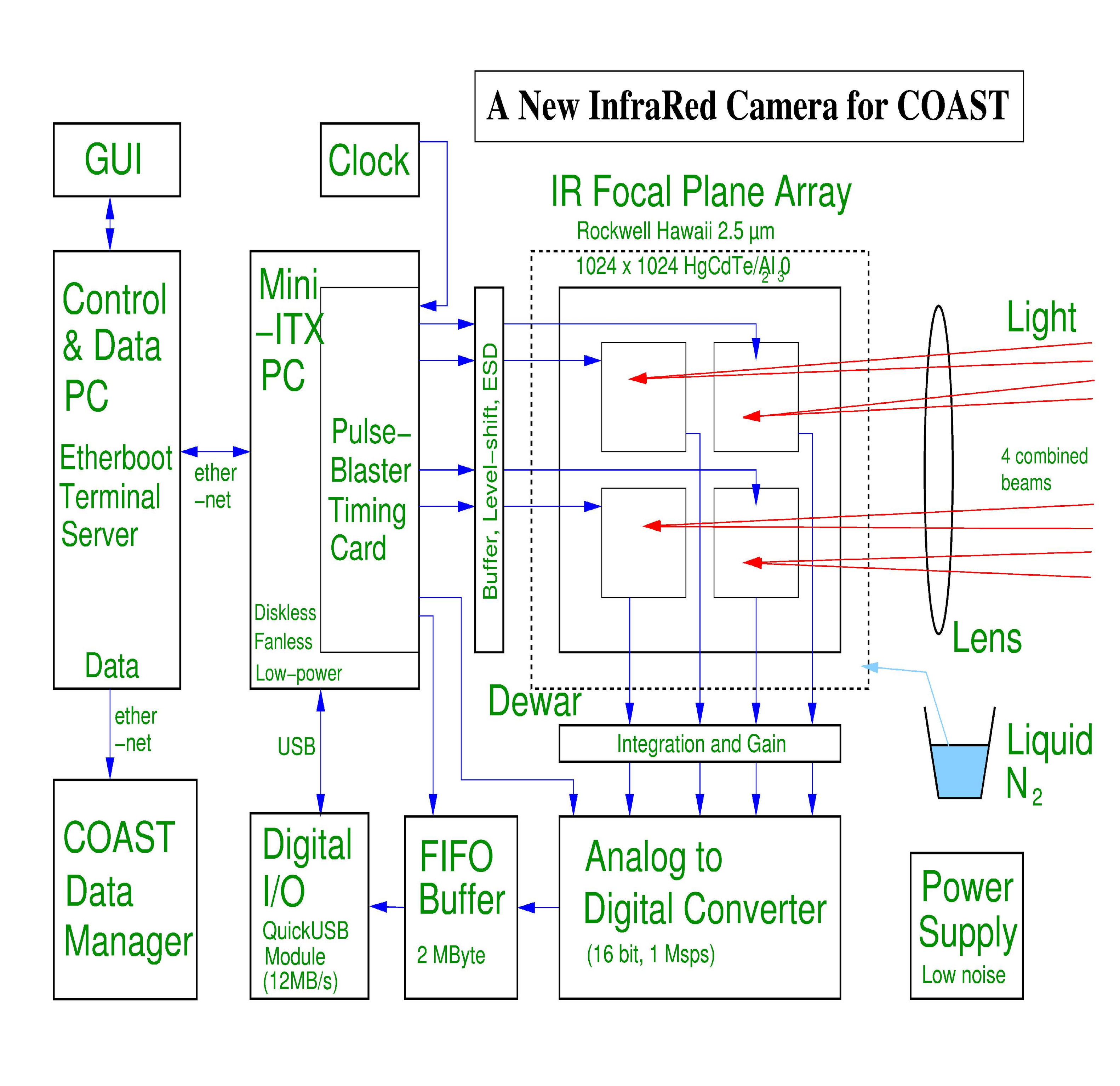
Most of the hardware is custom-designed, with the exception of the commercially available PulseBlaster and QuickUSB modules. There are 3 main circuit boards, described below.

The Digital Circuit Board runs at 48 MHz, and buffers the incoming data from the ADCs. The digital circuit controls the peripherals (filter-wheel and shutter), and the timing: PulseBlaster → Array clock → Read → Integration → S/H hold → ADC trigger → ADC readout → Serialised quadrants → FIFO → PC.

The ADC Circuit board digitises the incoming 0-2.5 V signal at 16 bits, and up to 1 Msample/s. This is achieved using AD7677 converters from Analog Devices. The synchronous parallel data from all 4 quadrants is then serialised into one stream before it is sent to the FIFOs.

The Analogue control board interfaces directly to the Hawaii FPA in the Dewar. It buffers and level-shifts the PulseBlaster's clock signals to protect the array from transients, and match the FPA's CMOS supply (which is adjustable and set to about 4.3 V, rather than 5 V in order to minimise glow). The output from the sensor is buffered, and amplified with a variable gain. This amplified signal is then integrated, and passed through a sample-and-hold circuit before it is buffered again, and sent to the ADC board. Analog FET switches (ADG712) are used to select the variable gain, and to insert and remove capacitors from the integrator; these are essentially ideal. SP720 "Littelfuse" diode arrays are used to "prevent the 'smoke' from being accidentally released" from the Hawaii sensor!

[The background image shows the Digital PCB, which contains the all control logic. The QuickUSB module is on the right.]



Hawaii 2.5µm IR FPA

The camera is based upon a Rockwell Hawaii 2.5µm CMOS HgCdTe Focal Plane Array. This is an array of 1024x1024 pixels, each 18.5 µm across, arranged in 4 independent quadrants. It is designed to minimise glow and dark current, at a running temperature of 78 K and a cut-off wavelength of 2.5 µm.

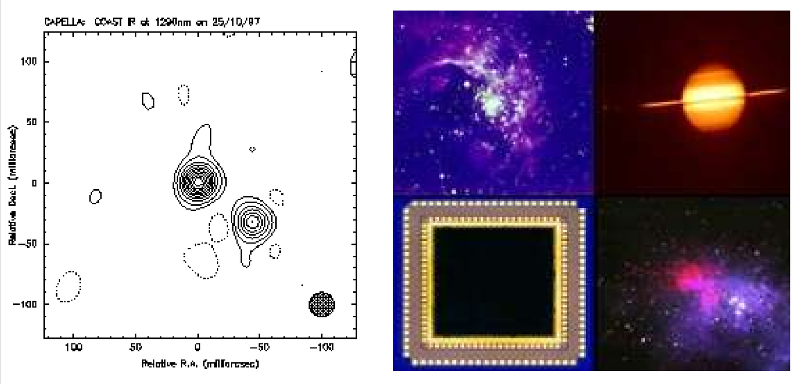
Each well has a capacity of 10^5 electrons and a gain of 3-6 µV/e. 16 bits of A-D conversion covers almost the entire range without the need for adjustment of the gain. The read noise is < 3 electrons for Fowler Sampling (multiple reads).

Comparison of the New (Hawaii) Sensor with the Old (NICMOS) Camera

The existing, NICMOS/Astromed-based camera was "state of the art" 15 years ago. Using correlated double sampling (CDS), it is capable of reading 4 pixels once each at 1 kHz, or 16 multiple reads of a single pixel at 1 kHz. This is insufficiently fast to obtain closure phases when using all the available light (i.e. all 4 combined beams) at COAST. The read noise is 16 electrons for single reads; up to 8 multiple reads are possible on a single pixel, at a cost of reduced dynamic range. We have made observations at an H-magnitude of 2.5.

The Hawaii sensor has a read noise below 3 electrons (for multiple reads with CDS), and will be able to be read out much faster. At COAST, we use a frame rate of 10 kHz with many multiple reads; faster at MRO. Spectroscopic readouts will be possible by using multiple pixels and a diffraction grating. The 4 quadrants are read simultaneously, each with their own ADCs for greater speed; the ADCs are the latest high speed 16-bit parts from Analog Devices (AD7677). The new system is based on Linux instead of DOS, and has improved software and networking.

[The background images are: Hawaii array (top), IR image of Capella (COAST, 1997) (left), Hawaii sample images (Rockwell) (right).]



Software Development

To generate the camera clocking signals, we are using *Spincore's PulseBlaster* digital timing card. This emits a programmable stream of pulses on 24 channels with 10 ns resolution. An instruction parser has been written for this, so that the PulseBlaster can be programmed using a more Human-friendly language than the native raw opcodes. Because the PulseBlaster is a sequencer which has no conditional branches (i.e. it is not Turing-complete), writing an instruction translator is a relatively straightforward process. It was supplied with a GPL driver for the Linux 2.4 kernel.

For fast Digital I/O, we use a *BitwiseSystems QuickUSB* module which implements a fast (16 Mbyte/sec continuous) parallel port via USB 2.0. This uses the LGPL libusb, but has a proprietary A.P.I. and firmware.

The Mini-ITX computer is a VIA EPIA ME6000 system; it requires only 4 Watts, and is booted over the network via Etherboot. It is the host for the PulseBlaster, and also serves to relay incoming data from the ADC/FIFO/QuickUSB over Ethernet to the Data Manager. Etherboot has proved to be an ideal solution to the problem of keeping the local heat-load sufficiently low: convection from a normal PC would disrupt the optics.

All the software we have written will be released under the *GNU* General Public License.

[The background image shows the QuickUSB module under test.]

Electronic System Overview

The Hawaii FPA is cooled to 78 K in a Dewar using Liquid Nitrogen. Light from the beam-combiner is focussed onto it: each of the 4 beams contains the same information and ¼ of the total light, and is concentrated onto a single pixel, one beam per quadrant. The quadrants are controlled in parallel, providing a factor of 4 improvement in read rate.

The array clocking sequence is programmed into the PulseBlaster in advance (it can be reprogrammed in a few seconds), and every sweep of the trolleys, (usually 250 ms) the PulseBlaster is reset, and the clocking sequence is restarted. The PulseBlaster resets the array addresses, and then initiates a correlated double sampling scheme (Reset, Read, Wait, Read) with multiple reads. During each read, the array output is integrated to reduce high frequency noise; it is then held by a sample-and-hold circuit while it is digitised. The clocking scheme, integration time and gain may be varied. Although transients, and noise-coupling are undesirable, provided that they are exactly repeatable from one read to the next, they may be compensated for. The array response is non-linear, and must be calibrated.

The FIFO buffer is comprised of 4 IDC 72V2105 FIFOs in series, which can store up to an entire frame (1 Mpixel, 16 bit) of image data if desired, and this is then read into the computer via the QuickUSB module. After attaching headers, the data are then sent on over the network to the Data Manager. If desired, a sustained 1 Mbit/s throughput is attainable, although in practice longer integration times are usually preferable.

The Mini-ITX system was chosen to minimise heat emissions in the vicinity of the optics. The Pulseblaster has its own FPGA which is programmed with the clocking scheme: it is independent of its host while running. This minimises jitter, and eliminates the need for a hard-real-time Operating System. It also allows for quick changes to the readout mode if desired, simply by uploading a new set of instructions.

[The background image shows testing of the Analogue and Digital circuit boards; the Mini-itx P.C. containing the PulseBlaster is behind; on top is the clock generation box.]

Further Information

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http://www.mrao.cam.ac.uk/telescopes/coast/index.html

The Magdalena Ridge Observatory:
http://www.mro.nmt.edu/

MRO is a collaboration between the Cambridge Astrophysics group, teams in New Mexico and Puerto Rico, and the Naval Research Laboratory in Washington DC.

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