The Characterization and Minimization of Noise in a Charge Coupled Device for the Magellan Telescopes

by

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Submitted to the Department of Electrical Engineering and Computer Science in Partial Fulfillment of the Requirements for the Degrees of Bachelor of Science in Electrical [Computer] Science and Engineering and Master of Engineering in Electrical Engineering and Computer Science at the Massachusetts Institute of Technology

December 7, 2001

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BACKGROUND

The motivation for my thesis stems from the Magellan Project. The Magellan Project's purpose was to build two 6.5 meter optical telescopes which are now located in the Las Campanas Observatory in Chile. First light for these telescopes occurred on September 15, 2000, and since then research has been done on how to improve the images that are produced from these telescopes.

Adaptive Optics is one direction to look into for improving images on the telescopes. This technology development measures and corrects for optical effects from the Earth's atmosphere. The idea is that if the optical path length from the object to the viewing source is the same, then one would expect the image produced from the telescope to be perfect. However, light must travel through the atmosphere and so is diffracted by wind and temperature gradients. In order to correct for these effects, one can use a reference star as a standard and correct for the imperfections in the atmosphere by controlling the secondary mirror of the telescope.

The sample rate for the current Charge Coupled Devices used for the Magellan Telescopes is two samples per minute. In order to compensate for atmospheric conditions such as wind and temperature gradients that are found to change more rapidly, a much faster sample rate is needed. In addition, this new device must have low noise for two reasons. First, in order to correct for earth’s atmosphere, a reference star needs to be established for calibration purposes. If data is being taken at a faster rate, the amount of charge that is allowed to collect on a pixel is greatly decreased. Thus, even for a very bright star, sampling at the faster rate will make it faint and finding the centroid of the star becomes a difficult task as the read noise approaches the magnitude of the data collected. Secondly, the Charge Coupled Device used for detecting the atmosphere can also be used for collecting data on the object under observation. The Magellan telescopes were built for the purpose for observing objects at the edge of the universe (6.5 meter mirror is bigger than other telescopes and allows more light to collect). Since these images will be very faint, low read noise becomes very important in improving the image.

RESEARCH TECHNOLOGY

New technology has been developed to improve on detecting low-light-level signals for Charge Coupled Devices (CCD). Robert Reich from Lincoln Labs has fabricated a Charge Modulation Device (CMD) grown from the buried-channel silicon region of a CCD. This device allows better detection for low-level signals because it amplifies the output by lowering the effective capacitance of the device.

The currently documented performance of this device is under a 60 Khz sampling rate. It also uses the Correlated Double Sampling (CDS) technique to get rid of the reset noise, the primary source of on-chip noise. Reset noise is a floating voltage that is present when even when the device is off, caused from thermal noise and the non-zero resistance of the reset FET. To correct for this error, a sample is taken after the reset (i.e. before charge is allowed to collect) and after the charge has been transferred. The difference between these two values can correct for most of the on-chip noise.

In addition, lowering the temperature and slowing the sampling rate are also techniques that can be used to reduce noise on the output.

PROJECT TASKS

Although the device as been developed, computer simulations of the device implies that more changes are necessary to improve the performance of the JFET amplifier. This work can be broken down into two parts: familiarization with and testing of the current technology, and research and development to improve upon the existing technology. The latter would include lowering of the electron noise through research technology, testing of the new design, and fabrication and incorporation of the optimized device to the Magellan Telescopes.

My first task would be to complete the low-noise CCD testing of the devices. Additional testing needs to be done at the 60 KHz sampling rate, in particular that of cold temperature conditions. I would have to become familiar with the CCD, electronic equipment, test equipment, and data analysis software that are currently used in Lincoln Labs. In addition, the previous testing of the device used the CDS to correct for reset noise. Experimentation with other techniques, for example, Dual Slope Integration, may further decrease the read noise.

My second task is to optimize performance of these low-noise CCD at a slower sample rate. It is expected that these devices are capable of running at low speed with lower noise. Adaptive optics research believes that 30 samples per second is an appropriate frequency for sensing differences in the atmosphere. I will test the devices under slower frequencies and try to minimize the noise at these frequencies. This requires modifying the output band pass filters and optimizing the timing the sample pulse on the standard signal.

FUNDING

The Spring 2001 UROP will probably be funded through the Marble Adaptive Optics account. Funding for work done this summer still needs to be investigated. Current potential sources include funding from the Space Grant Consortium or an RA position. Professor Schechter said that I could probably get one semester funded through an RA position. I will either TA or find another RA position for the other semester.

RISKS

This project is a collective effort, which adds to the complexity. Adaptive optics is the measurement and correction for effects of the Earth's atmosphere. My project deals with measurement of the atmosphere while another thesis student will deal with the correction part. Since our efforts can be developed independently, no problems seem to be present at the current time. I will be meeting with this student in the near future to discuss our roles and possibility of potential problems.

Adaptive optics is a fairly new field, making most of its technological development in the last decade. Thus, the actual instrumental success with adaptive optics is small. While success of my objective in finding optimal conditions for lowering the read noise of the CCDs is favorable, the overall aim of the adaptive optics project may fail.

TIME LINE

I plan to UROP eight hours a week in Spring 2002 at Lincoln Labs. This is primarily so I can familiarize myself with the equipment as well as begin the characterization of the CMD. During Summer 2002 I will continue the work full time at Lincoln Labs and finish characterization of these devices as well as begin research on how to decrease the electron noise for the 30 kHz sampling. By Fall of 2002, I aim to complete and test the new design. During the Spring of 2003, I plan on writing my thesis. If all goes well, there might even be opportunity for me to visit the Magellan Telescopes in Chile to see the results of this thesis.