Temperature and Diode Measurements on a PXL Ladder

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Measurements of voltages at various points along the ladder in conjunction with recording of diode ADC values and temperatures were made in an attempt to develop a way of extracting temperatures from the on chip temperature diodes. The difficulty is that the diode has only one terminal available and one must determine the ground potential at the point of diode attachment.

It was decided that a way to handle this is to forfeit the west diode, S10 and ground it's ADC lead to the ground at the east end of the ladder next to chip 1 and remove the current source to this diode, S10. The ADC for S10 then gives the ground potential at the east end close to the diode ground in S1.

The diode was calibrated by putting the ladder in an oven with chip power off and recording ADC values for S1 and the S10 (grd at S1) along with the thermal couple measure of the oven temperature. The thermal couple measurement black points are shown in Figure 1 Temperatures as a function ADC difference. The black points show the thermal couple temperatures measured in the oven and the black line is fit to these thermal couple temperatures. The other points are IR camera measurements also shown as a function of delta ADC in a separate measurement with different chip power conditions different cooling condias a function of the diode voltage measured in ADC counts. The linear calibration fit is shown as a black line. The ladder was then operated with various chips powered and with different fan conditions and the temperature at the center of chip 1 and at a hot spot on the chip were recorded with an IR camera along with the thermal diode ADC values. These points are also shown in Figure 1. Note, in the figure when the chip is powered the hot spot runs 10 or 12 degrees C hotter than the diode temperature given by the black line. The hot spot in the chip is in a region that is reflective so the temperature at this location is actually higher than represented by the IR Camera reading. The center of the chip is correctly covered by a controlled emissivity and should be accurate, however the diode is located in a hotter region on the chip when the chip is powered. There are two points in the plot, Figure 1, where the chip was not powered. In this case the IR camera measurements agree quite well with the diode calibration curve. It is expected that with full cooling air the chip temperature will be more uniform across the surface as was the case with the cooling studies using silicon heater chips.

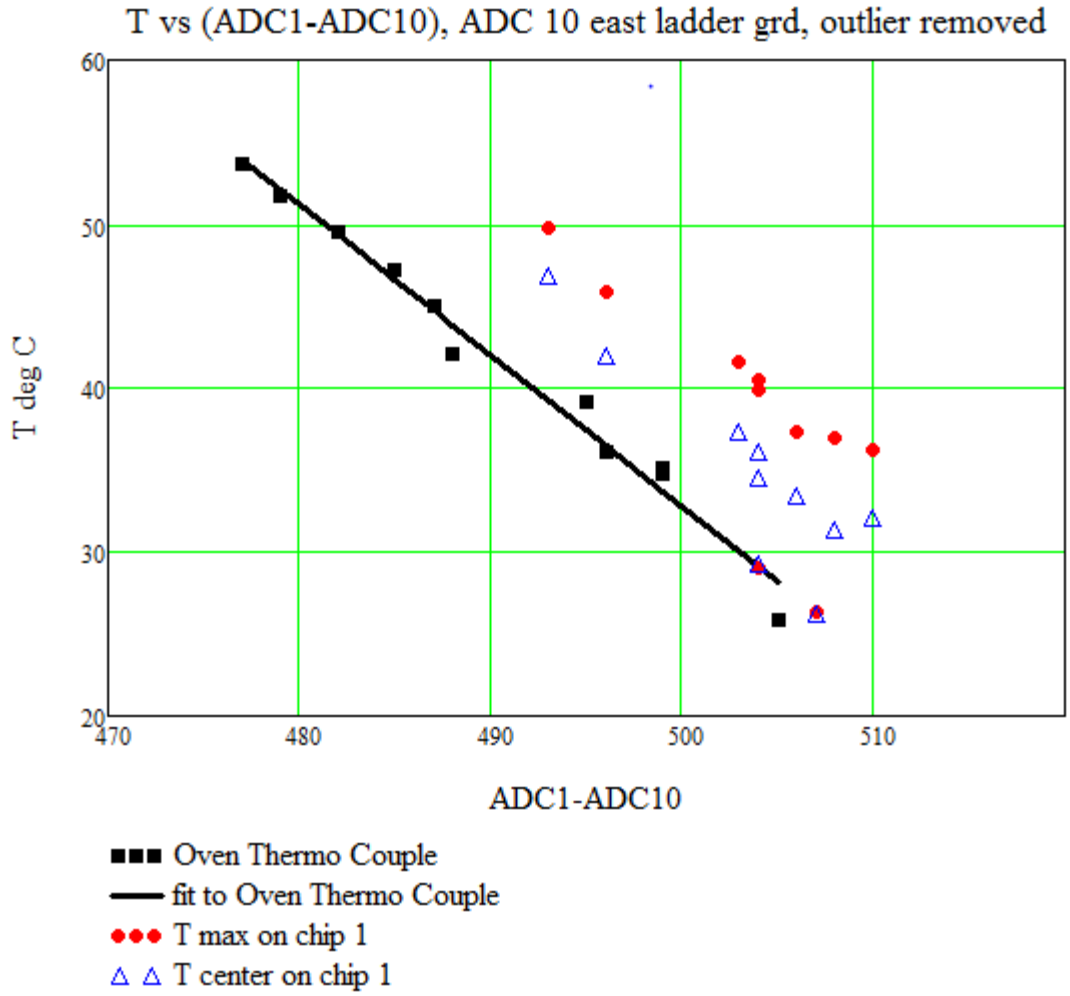

Figure 1 Temperatures as a function ADC difference. The black points show the thermal couple temperatures measured in the oven and the black line is fit to these thermal couple temperatures. The other points are IR camera measurements also shown as a function of delta ADC in a separate measurement with different chip power conditions different cooling conditions. The IR camera measurements were not done in the oven.

The calibration function in Deg C determined with the thermal couple measurements:

$$TADC(ADC1, ADC10) := 492.6 - 0.920(ADC1 - ADC10)$$

This calibration corresponds to -1.7 mV/Deg C which is not unreasonable, see http://en.wikipedia.org/wiki/Silicon_bandgap_temperature_sensor.

The accuracy of the diode determination of temperature was checked by observing the temperature at the center of chip/sensor 1 with the IR camera while leaving this chip's power off so that the temperature variation across the chip is minimal, that is the diode temperature is the same as the center. The temperature was recorded while powering on varying numbers of the other chips. The order of chip powering started at the opposite end of chip 1 and working closer to chip 1 as more chips

are powered. The results of this exercise is shown in Figure 2, where the IR measurement is shown along with the diode temperature obtained from the ADCs according to the above formula. Note, the ADCs were recorded multiple times for a number of the settings and there is a scatter in the points of several degrees. It is not clear why the spread in ADC measurements was so large in this set of measurements. In the earlier measurements shown in Figure 1 the ADC values appeared more stable.

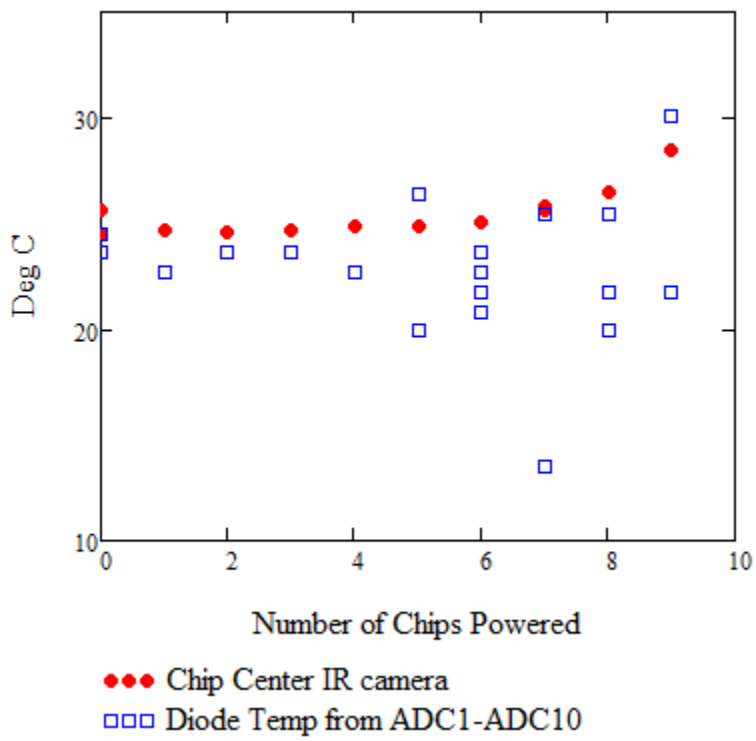

Figure 2 in red, temperature of chip center measured with an IR camera vs number of chips powered, i.e. the amount of voltage offset on the ground. In blue the diode temperature as determined by the forward bias voltage. The voltage is determined from the ADC measureing near diode ground and the ADC measureing the diode bias voltage.

Replotting this data, see Figure 3, as the difference between the IR temperature value and the diode temperature value shows a spread of up to 10 degrees and an average offset of up to 5 degrees.

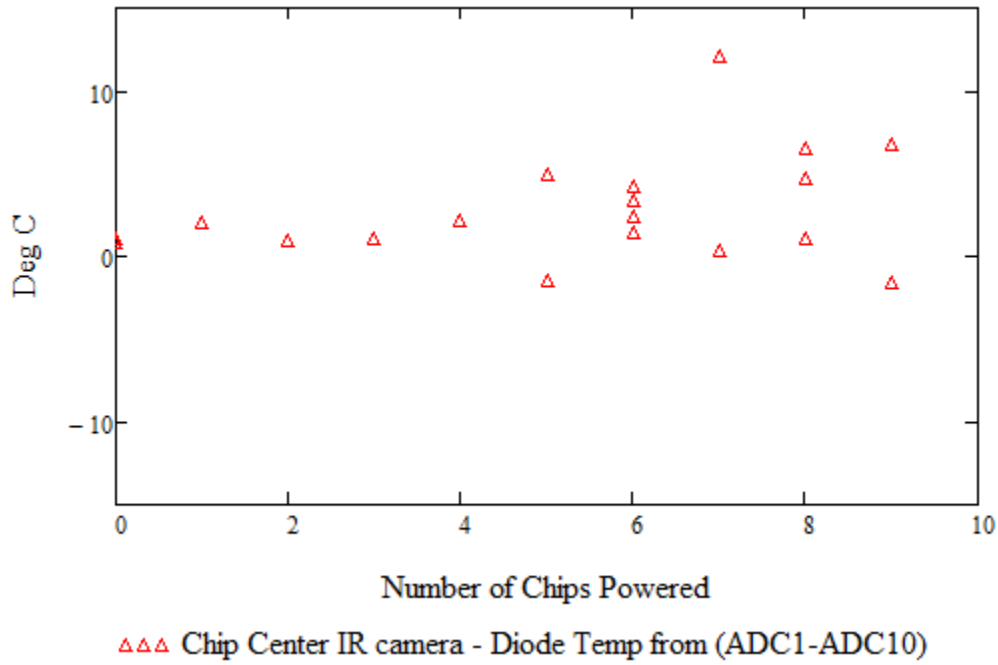

Figure 3 Difference between IR camera temperature and diode determined temperature.

The ladder that was measured is shown in Figure 4. The point where the ADC10 attached to the ground is indicated. The blue tape on sensor/chip 1 has high emissivity for IR as it appears in the IR camera the same as the black marker on the tape. The diode in chip 1 is measured with ADC1. All ADC values are referenced to ground back in the MTB board where the ADCs are located.

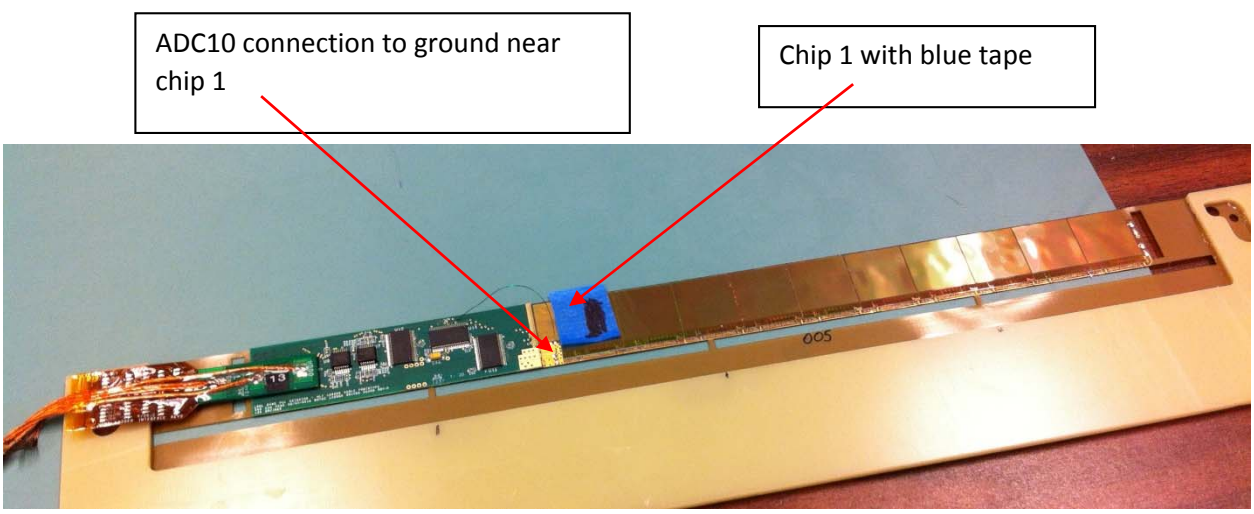

Figure 4 PXL ladder measured. The ground point that ADC10 was moved to is indicated. The chip measured is partially covered with blue tape to give a more accurate temperature reading using the IR camera.

The set of IR images used to record the temperatures plotted in Figure 2 and Figure 3 is shown in Figure 5.

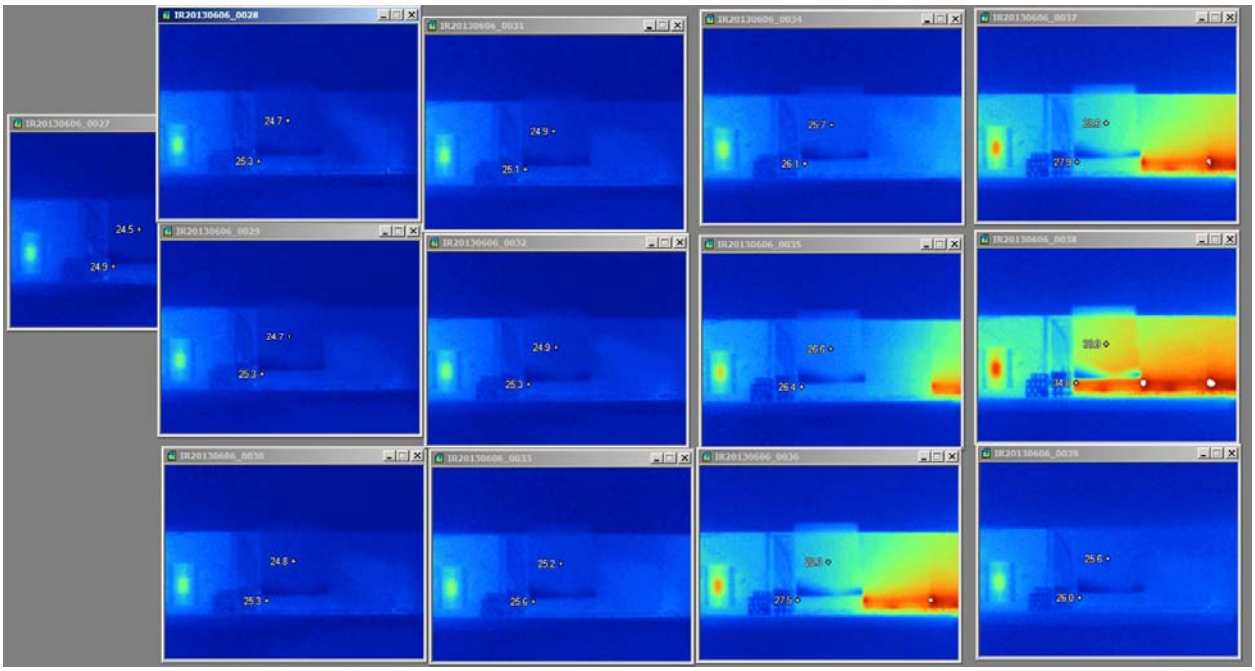

Figure 5 Thermal camera images for the measurements of the PXL ladder chip 1 that were used in Figure 2 and Figure 3.

The ADC10 calibration was checked by connecting the lead to ground at the far west end of the ladder and measure this voltage point with the ADC and a volt meter for different chips powered on. The more chips powered on the more this ground point is raised above the MTB ground potential. The result of this measurement is shown in Figure 6. The slope from the fit is 1.63 mV/cnt to be compared with an expected value of 3300mV/(2*1024) = 1.61 mV/cnt. Again is not clear why these ADC values appeared more stable than some of the other measurements.

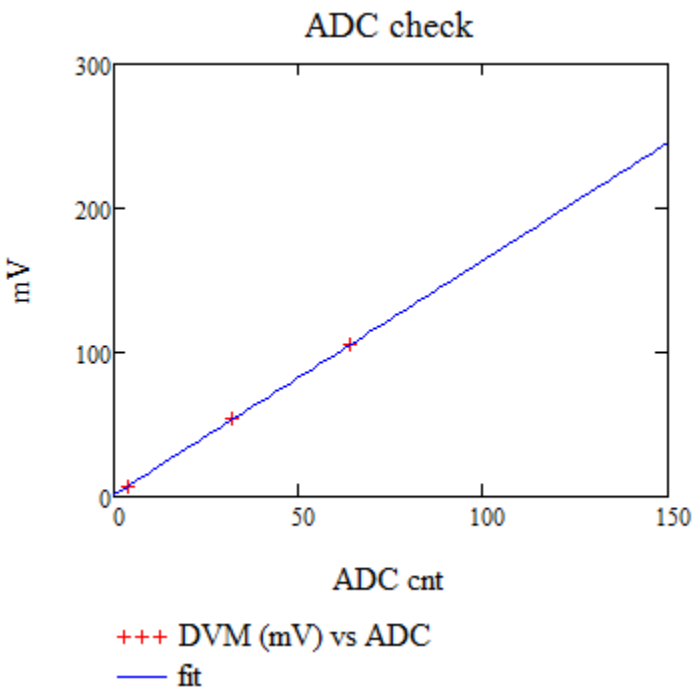

Figure 6 Meter reading of the west end ladder ground as a function of recorded ADC10 value.

Conclusion

We can get a measurement of the sensor 1 temperature that is probably good to about 5 deg C independent of the current drawn on the ladder if we move the diode10 lead to the ground point near chip 1. It may be necessary to average ADC values to get a good measure. Why these ADC values appear stable some times and not others should be explored further.