Thermal management for CCD performance on the Advanced Camera for Surveys (ACS)

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ABSTRACT

The Advanced Camera for Surveys, an instrument containing two CCD cameras and a MAMA detector, is being build by Ball Aerospace and Technologies Corporation for NASA. The instrument will be placed in the Hubble Space Telescope during a space shuttle mission in December 1999. The CCD detectors need to operate at a temperature below -80°C in order to avoid unacceptable dark current. This cooling is achieved through detailed thermal design which minimizes the parasitic load to a 4K x 4K array with 15 micron pixels (61.4mm x 61.4mm) and cools this Wide Field Channel (WFC) detector with a combination of thermo-electric coolers (TECs).

This paper will describe the innovative thermal design necessary to maintain the WFC CCD at its cold operating temperature while providing the means to reject the heat generated by the TECs. It will focus on optimization techniques developed to manage parasitic loads including material selection, surface finishes and thermal isolation. The paper will also address analytical techniques developed to characterize TEC performance. Finally, a comparison with the STIS CCD design currently operating in the Hubble Space Telescope will be made.

Keywords: HST Advanced Camera, CCDs, thermal design, cooling techniques

1. REQUIREMENTS

The most significant requirement driving the CCD design is operating temperature. With some knowledge of the performance characteristics of the selected CCD, -80°C was established as the warmest temperature that would allow the detector to meet its performance requirements. Colder temperatures have been set as goals. For analysis margin, -83°C was established as the required design temperature for the worst case hot environment.

Another thermal requirement involves allowable gradients. The temperature gradient across the CCD die can be no greater than 1°C due to dark current limitations. An additional requirement is that the CCD must be at least -5°C when the TECs are turned off in order to allow annealing of any radiation induced damage.

2. ENVIRONMENTS

Because the ACS is contained within the aft end of the Hubble Space Telescope, no external solar or earth flux is incident upon the instrument. Temperature variations which exist within the telescope are due to single orbit day/night transients, spacecraft slews for observations, power changes within the aft shroud as other instruments are turned off and on, and gradual seasonal changes. The temperature within the instrument optical bench is maintained at 20°C with the use of thermostatically controlled heaters.

Since the primary requirement is to maintain the CCD no warmer than -80°C, the critical design environment is the hottest one that can be expected during the mission lifetime. That occurs at the end of the design life in 2004, as a result of degradation of thermal control surfaces and the incorporation of a new instrument during the last scheduled servicing mission in 2002, with higher power consumption than the array of instruments in place in 1999.

The plot which follows is typical of the temperature distribution inside the aft shroud as it varies over time.

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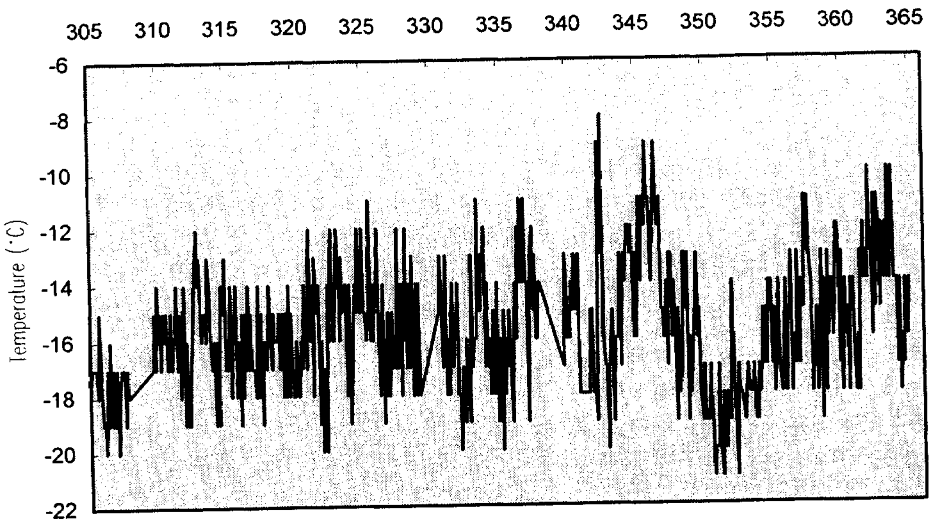
Typical Aft Shroud Sink Temperature Variation



3. COOLING METHODS

The Wide Field Camera (WFC) uses three distinct cooling methods that combine to maintain the CCD below its required operating temperature in the environment described above. Thermo-electric coolers (TECs) attached directly to the CCD chip carriers lower the temperature to the required CCD operating level. The heat generated by these devices is removed from the detector housing by flexible heat pipes. The heat pipes transport the heat to an interface plate on the external surface of the instrument. Finally, the Aft Shroud Cooling System (ASCS), including a Capillary Pumped Loop (CPL) carries heat from the interface plate to an external radiator, where it is rejected to space.

3.1 Thermo-electric coolers

TECs are small and relatively inefficient (~10%) cooling mechanisms. So long as the output power can be adequately rejected, these compact devices are ideal for achieving the level of cooling required. The WFC detector assembly employs two different types of TECs—a four stage device and multiple two stage devices.

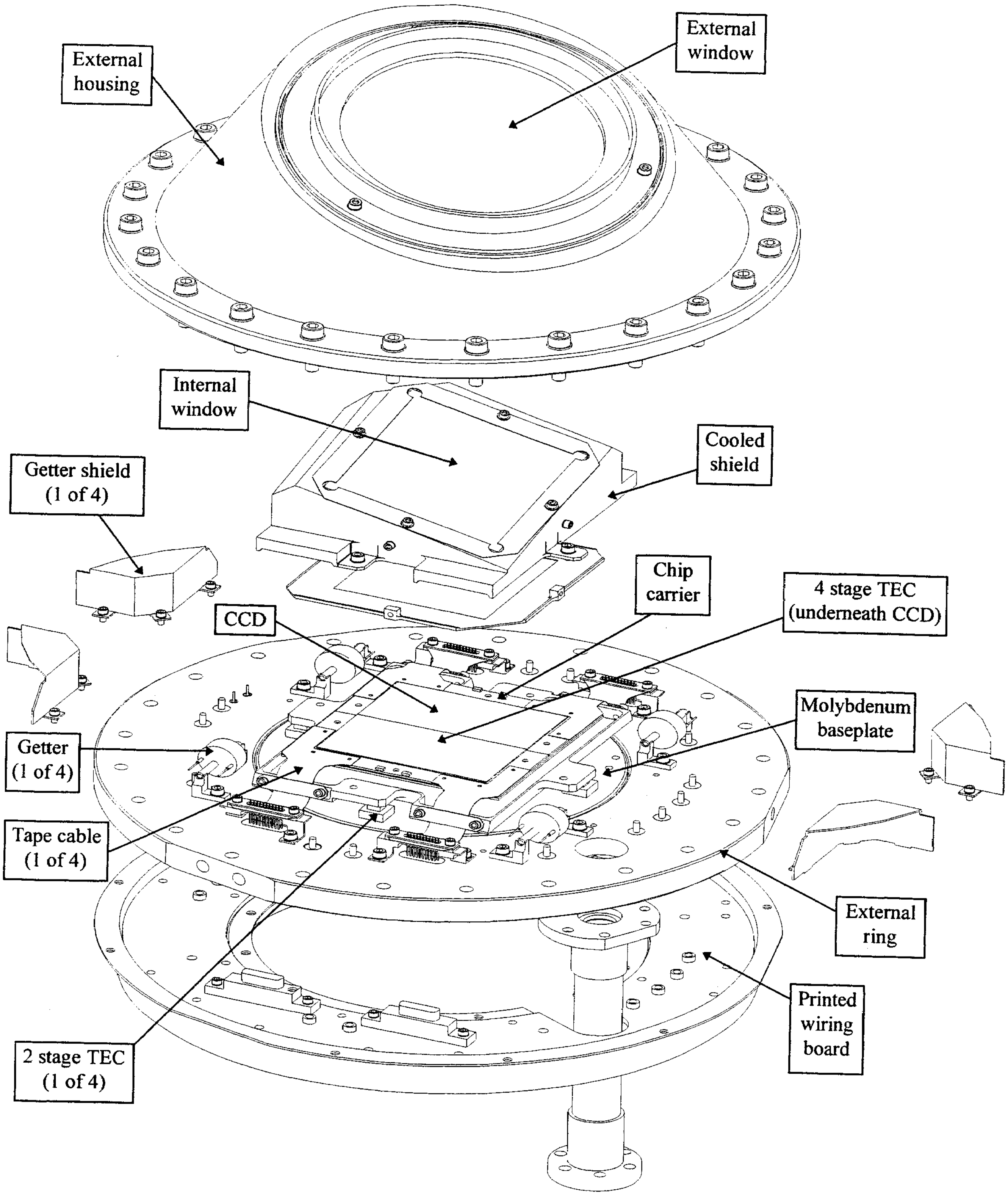
3.2 Flexible heat pipes

This heat transport mechanism couples the outside of the WFC detector assembly to the instrument external surface and removes the heat generated by the TECs. The heat pipes themselves are stainless steel pipes with an internal fluid and wicking material which allow reasonable quantities of heat to be transported over several feet with only a small temperature gradient (< 1°C) within the fluid itself. In this case they must be flexible because rigid pipes would transfer structural loads to the sensitive detector assembly which would adversely impact optical alignment. It is important to have an efficient heat transfer mechanism here, because the cooler the hot side of the TEC can be maintained, the lower the operating temperature of the CCD.

3.3 Aft shroud cooling system

This is a multi-component transport system which transfers heat from several sources within the Hubble Space Telescope aft shroud to an external radiator, where it can be efficiently rejected to space. It consists of Capillary Pumped Loop subsystems, which are similar in theory to heat pipes but allow active temperature control at the evaporator end where the heat is being generated.

WFC DETECTOR ASSEMBLY (EXPLODED VIEW)



Scale: 1 inch on page = 2 inches on detector