

Swift BAT Instrument Thermal Control System Recovery after Spacecraft Safehold in August 2007

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ABSTRACT

The *Swift* mission Burst Alert Telescope (BAT) Detector Array thermal control system includes two propylene loop heat pipes (LHPs), eight ammonia constant conductance heat pipes (CCHPs), a radiator that has AZ-Tek's AZW-LA-II low alpha white paint, and precision heater controllers that have adjustable set points in flight. The Power Converter Box (PCB) and Image Processor Electronics (IPE) boxes (a primary and a redundant) of the BAT have Z93P white paint radiators. *Swift* was successfully launched into orbit on November 20, 2004. The spacecraft (S/C) was placed into a safehold mode on August 10, 2007 after an anomaly on inertial reference unit (IRU) #3. It was returned to inertial pointing on August 16 and instrument power up followed. This paper presents a thermal assessment of the BAT instrument thermal control system (TCS) shut down and recovery as a result of the S/C safehold mode. The recovery required starting up the LHPs manually.

INTRODUCTION

The BAT is the primary instrument on the *Swift* S/C. The *Swift* mission is part of the National Aeronautics and Space Administration (NASA) Medium-Size Explorer (MIDEX) Program, and is managed by Goddard Space Flight Center (GSFC). It is designed to detect gamma ray bursts (GRB) over a broad region of the sky in a low Earth orbit and quickly align the telescopes on the S/C to the gamma ray source. It was launched successfully from Cape Canaveral Air Force Station, Florida into an orbit of 600-km altitude and 20.69° inclination on November 20, 2004. The *Swift* mission is a first of its kind of multi-wavelength transient observatory for GRB astronomy. *Swift* has detected GRB at an average rate of approximately two per week.

The BAT telescope assembly is mounted to the instrument module optical bench through five titanium flexures. The PCB and IPEs are mounted to the S/C bus. Figure 1 shows the location of the BAT on the *Swift* observatory.

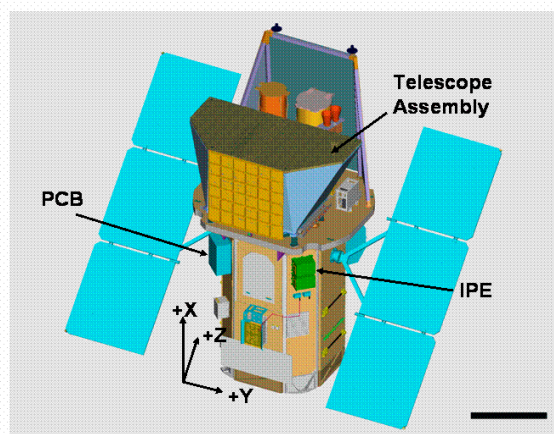


Figure 1. BAT on *Swift* Observatory.

The BAT was developed at GSFC. Its telescope assembly consists of 256 Detector Modules (DMs) in the Detector Array. There are 16 Detector Array Blocks. Each Block holds 16 DMs, 3 Block Voltage Regulator (BVR) units and 3 Block Command & Data Handling (BCDH) units. The power dissipation of each Block was measured during ground testing to be 13 W. Therefore the total power dissipation of the 16 Blocks is 208 W. The Detector Array Plate (DAP) is 1.3 m (4.3 ft) x 1 m (3.3 ft). It accommodates all the 16 Blocks. It also provides the mounting surface and the positional stability for the Blocks. The DMs are located at the top (+X side) of the DAP and is enclosed by graded-Z shields on the sides and a coded mask at the top. The BVRs and BCDHs are located at the bottom (-X side) of the DAP. Eight Blocks are located at the front (-Z side or radiator side) of the DAP, and eight are located at the rear (+Z side) of the DAP. Figure 2 shows the BAT telescope assembly. Figure 3 shows the 16 Blocks after they were integrated to the telescope assembly during instrument integration and testing in 2003.

The *Swift* S/C was placed into a safehold mode on August 10, 2007 after an anomaly on IRU #3. All the three instruments were powered off, and put into a survival mode. The LHPs on the BAT shut down. It was the first in-flight shutdown caused by a S/C safehold mode. Survival heaters maintained the BAT

temperatures above the cold survival temperature limits. The S/C was returned to inertial pointing on August 16, and instrument power up followed.

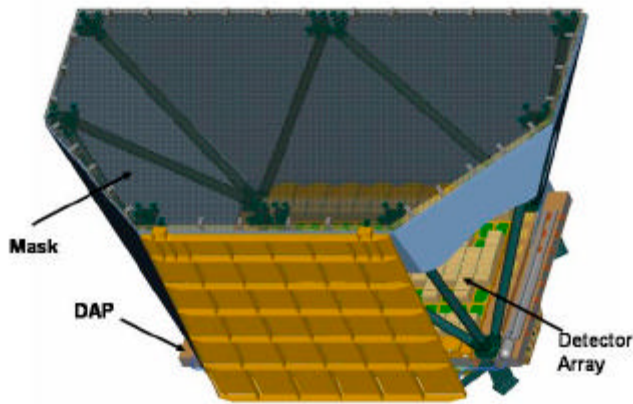


Figure 2. BAT Telescope Assembly.

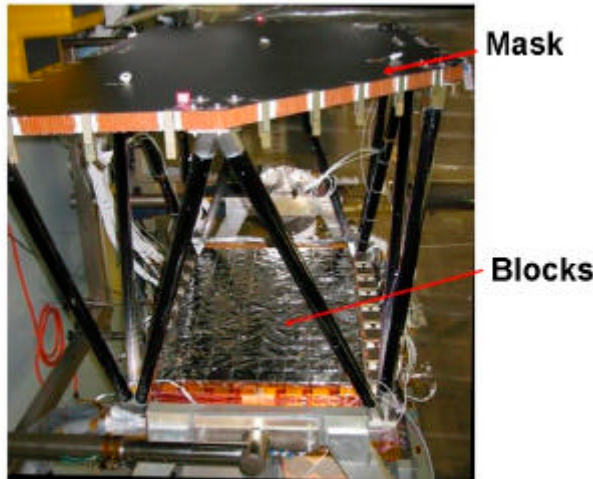


Figure 3. Detector Array Blocks.

OBJECTIVE

The objective of this paper is to present a thermal assessment of the BAT instrument TCS shut down and recovery as a result of the S/C safhold mode that occurred from August 10 through 16, 2007. It includes LHP shutdown and startup in the zero-g environment. These data are compared to those recorded in the thermal balance (T/B) and thermal vacuum (T/V) tests on the ground when there was gravity. The LHP startup thermal data are also compared to those recorded during the launch and early orbit (LAEO) phase in November/ December 2004. It also includes an evaluation of the effect of degradation over 33 months in orbit on the TCS shutdown and recovery.

BAT TCS DESCRIPTION

The *Swift* observatory is required to slew to targets within 50° in 75 seconds and to targets from 50° to 270° in 75 to 270 seconds. Because of frequent slewing, the

thermal environment for the BAT changes constantly, although direct sunlight is not permitted on the BAT radiator. Another factor that also affects the BAT thermal environment is the beta (β) angle, which is in the -44.14° to +44.14° range, and changes at approximately 2° per day.

Figure 4 shows many components of the BAT TCS when the *Swift* observatory was in the fairing in November 2004. A description of the BAT instrument TCS is described briefly below.¹

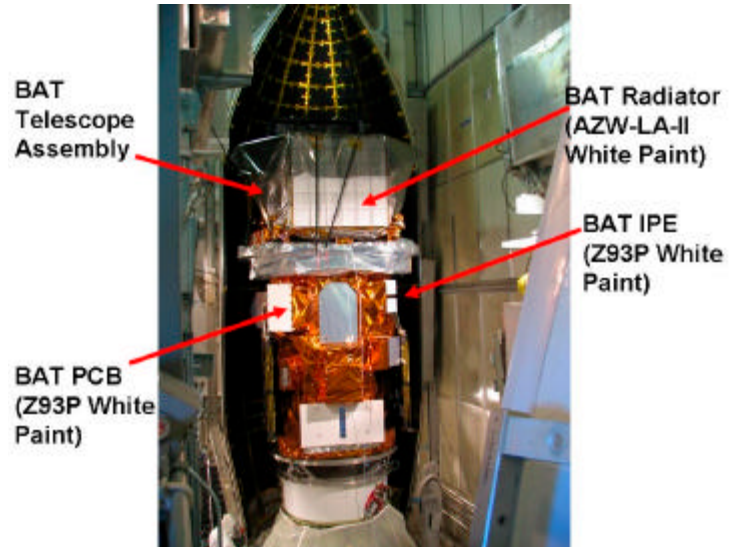


Figure 4. *Swift* in Fairing.

Telescope Assembly - The BAT Detector Array Blocks are thermally well coupled to eight CCHPs embedded in the DAP. Two LHPs (#0 and #1) transport heat from the CCHPs to a radiator, which is located on the shaded side of the observatory. They provide redundancy. Originally the numbers used by the BAT thermal system were #1 and #2. But later they were changed because the S/C used #0 and #1 for observatory integration and testing, and mission operation. The CCHPs have ammonia as the working fluid and the LHPs have propylene as the working fluid. The worst cold case safhold mode temperature prediction for the radiator was colder than -100°C. Propylene was selected to prevent freezing and maximize heat transport capacity. The LHP compensation chambers (CCs) have 0.127 mm silver Teflon as the thermal coating, and are shielded from the sun by the optical bench sunshade. Silver Teflon has a solar absorptance of 0.08 at beginning of life (BOL) and a hemispherical emittance of 0.76. The low absorptance minimizes the thermal effect of albedo flux. The LHPs vary the thermal conductance from the DAP to the radiator. As a result, they provide a nearly constant heat sink temperature for the DAP in normal operation, and minimize heater power in both normal operation and the safhold mode. Precision heater controllers are also used to control the CC temperatures. Specially made Kapton film heaters on the Blocks are controlled by precision heater controllers. All the Block and LHP heater controllers have adjustable set points in flight. The radiator has AZ-Tek's AZW-LA-II

low alpha white paint as the thermal coating. The BOL absorptance is 0.1 and the emittance is 0.9 (both measured).² This white paint is flown on a radiator of an operational S/C for the first time. It is used to minimize the thermal effect of albedo. The LHP thermal system (Figure 5), including the AZW-LA-II white paint radiator, augmented by Block heaters, was designed to meet the stringent thermal requirements of temperature gradient ($\pm 1^\circ\text{C}$ maximum) and stability ($\pm 0.5^\circ\text{C}$ maximum) for the 16 Blocks. Thermal analysis showed that if the AZW-LA-II is used, the thermal requirements are met and there is sufficient margin.¹ The LHP thermal system detailed characteristics were presented by Choi.¹

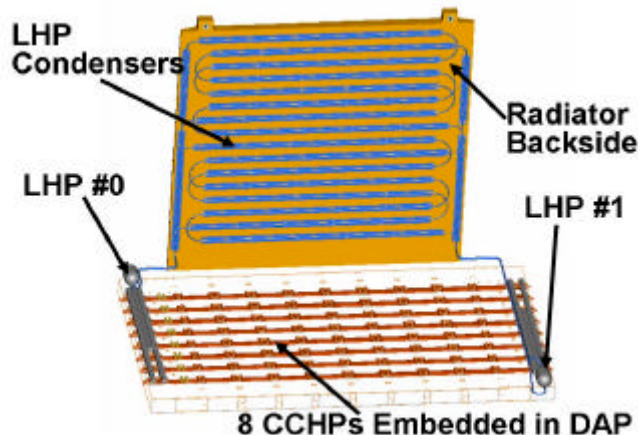


Figure 5. BAT LHP Thermal System.

A variable conductance heat pipe (VCHP) was added to each LHP to provide rough temperature control by pre-conditioning of LHP liquid line temperature. This is accomplished by heat exchange between the VCHP condenser and LHP liquid line through a heat exchanger (Figure 6). It serves to reduce the LHP CC heater power to meet the specification. This new feature is flown the first time on LHPs. The VCHP reservoirs have 0.127 mm silver Teflon as the thermal coating. It minimizes the thermal effect of albedo flux.

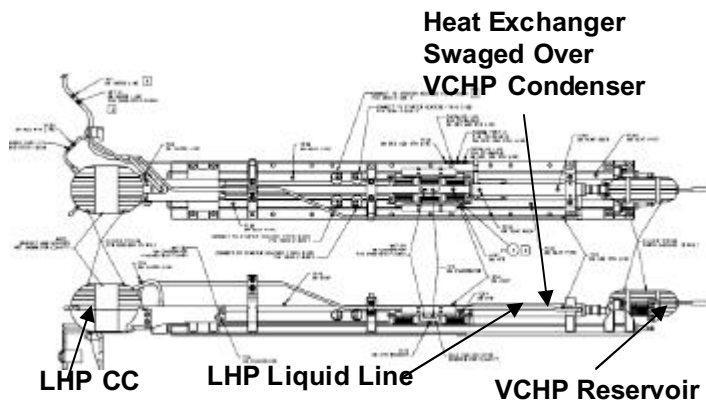


Figure 6. VCHP of LHP.

Figure 7 shows the LHP and radiator assembly during component level integration and testing in 2003.

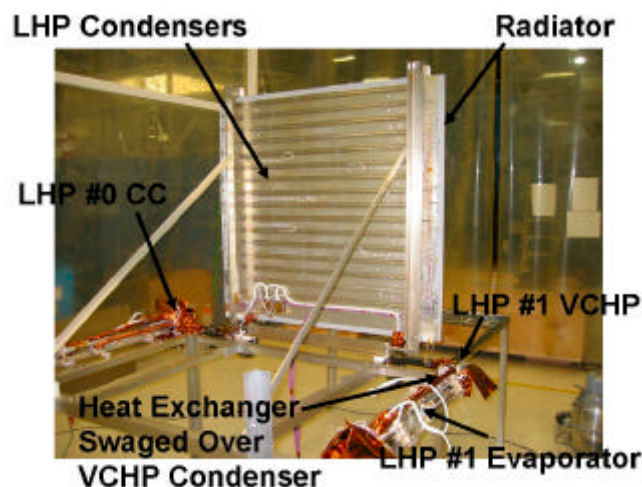


Figure 7. LHP and Radiator Assembly.

The DMs and top of the DAP are insulated with a 7-layer MLI blanket. The MLI outer cover is black Kapton. There is a 5.08 cm x 5.08 cm MLI cutout over each Block heater controller so that heat radiates from the 16 heater controllers to the mask. The purpose of this MLI thermal design is to prevent the mask, and its support structure (composite tubes and titanium joints) from being too cold, and to minimize thermal structural distortion. The exterior of the mask, graded-Z shields and bottom of the DAP is insulated with a 15-layer MLI blanket. To meet the electrical conductivity and thermal requirements, the outer cover for MLI on the graded-Z shields and DAP bottom is germanium oxide over black Kapton. There is no electrical conductivity requirement for the MLI on the mask. Two-micron silicon oxide over 0.0254 mm aluminized Kapton is the outer cover to provide a low absorptance (about 0.1) and a medium emittance (about 0.4) so that the mask has moderate temperatures. Survival heaters are located at the LHP CCs, -Y and +Y sides of the top of the DAP, and Block heater controllers. Survival heater circuits are fully redundant. Thermostat set point for the primary survival heaters is -8°C , and that for redundant units is -13°C . They are enabled all the time. During the safhold mode or when the BAT is turned off, when the DAP temperature approaches the LHP CC, the LHP will shut down.

The cost of AZW-LA-II low alpha white paint is high ($\sim \$66,000/\text{m}^2$). Unless thermal analysis showed it is required to meet the thermal requirements, Z93P white paint is used instead. The BOL absorptance of Z93P is 0.16 and its emittance is 0.9 (both measured).⁴

PCB – The PCB top plate is a radiator that has Z93P white paint as the thermal coating (Figure 4). Survival heaters and thermostats are attached to a very shallow cavity -- approximately 56 cm x 7.6 cm -- at the center of the top plate. A top cover is mounted to the top plate to cover up the shallow cavity. The exterior of the top cover also has Z93P white paint, and the interior has Kapton tape as thermal coating. Cho-therm is used to enhance heat conduction from the top plate to the top cover. The underside of the "lips" around the perimeter of the top plate