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Curiosity's Fault Tolerant Wakeup and Shutdown Design

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Abstract

Curiosity spends roughly 70% of the day "sleeping", in order to recharge the batteries from the nuclear power source. The system is designed to ensure the Rover goes to sleep and wakes back up to continue science and engineering activities. Additionally, the design is robust to off-nominal situations that may need additional actions performed by both hardware and software to ensure the Rover can communicate with the Earth. This paper describes nominal and off-nominal behavioral patterns, fault tolerance features designed into the Rover system (hardware and software), several off-nominal scenarios that are accommodated by the design, and some lessons learned from this development effort.

Keywords: Wakeup; shutdown; Mars Science Laboratory; Curiosity; robotics; spacecraft surface operations; fault tolerance; fault protection; lizard brain;

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1. The Curiosity Mission & Background

The Curiosity Rover landed on Mars in August, 2012, and immediately started to study Gale Crater. Curiosity is an ambitious design, with many instruments, a driving capability, a robotic arm, and an articulating mast, all powered by a single 114 W Multi-Mission Radioisotope Thermoelectric Generator (MMRTG).

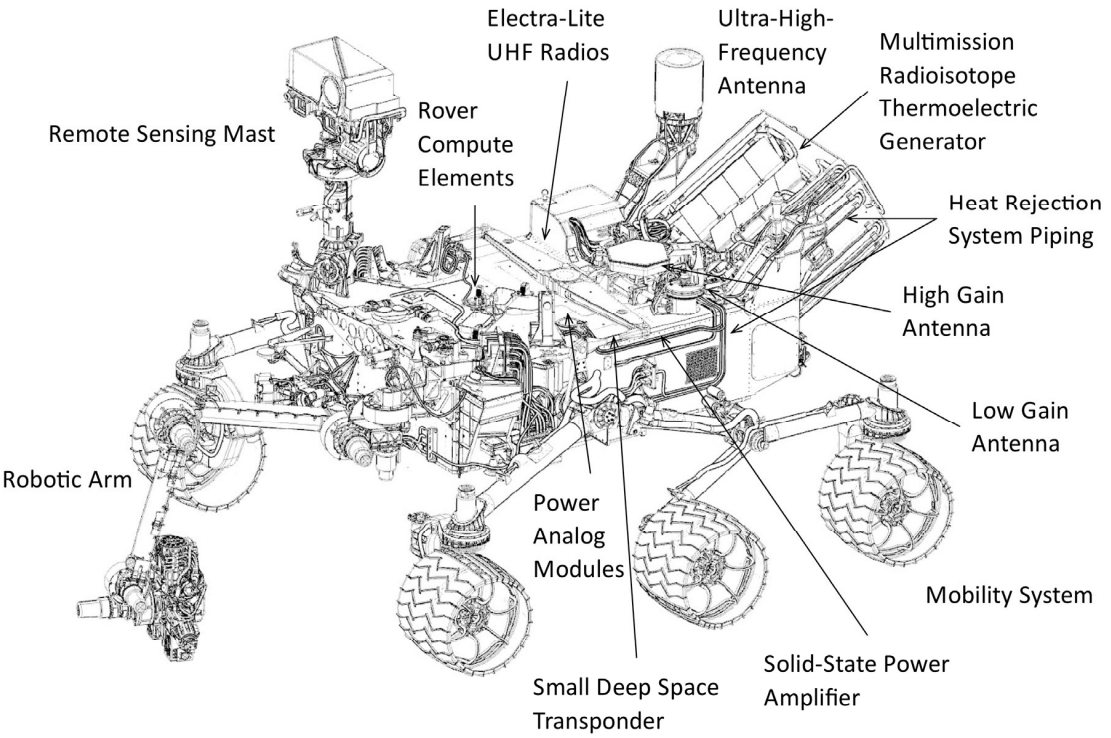

Figure 1: The Curiosity Rover

The energy demands of the Rover exceed the energy production capability of the MMRTG. This fact made it necessary to create a system that allowed the Rover to integrate and store the generated energy over periods of time when the energy demands of the Rover could be guaranteed to be less than the energy production capability of the MMRTGs. We created an operational state of the vehicle called the sleep state. In this state, most of the loads on the vehicle are turned off, including the computer that controls the normal communication sessions and science gathering activities. While the loads on the Rover are off, and the Rover is functionally quiescent (asleep), the MMRTG produces sufficient energy to charge the two 43 Amp-Hour Lithium-ion batteries. When the Rover wakes up from its slumber and resumes its activities, it draws power from the MMRTG and from the replenished (recharged) batteries.

Given this sleep capability, the design was required to have a robust wakeup design because the computer is needed to communicate with Earth and to perform science activities. Communication with the Mars Reconnaissance Orbiter (MRO) or the Odyssey orbiter must be initiated at prescribed times, based on their availability. Direct to Earth communication must be done when the Earth is above the horizon. Science gathering activities, driving, robotic arm movement and imaging are usually done in the daylight hours, when the sun provides visibility and warms the actuators.