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Thermal failure of the LM117 regulator under harsh space thermal environments

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ABSTRACT

In the past decades, the dramatic increase on the reliability importance of electronic systems for space applications has led to greater scrutiny of these devices for these applications, especially as reliability relates to temperature. Component failure is strongly dependent on the temperature at which the device operates. This also applies to components, electronic parts, such as diodes, resistors and capacitors. These components when used in space applications must endure the harsh thermal loads caused by space thermal environments. These thermal loads cause electronic systems to fail through such mechanisms as crack propagation of solder joints, the fracturing of mechanical joints or electric malfunction.

In this study, a thermal failure of a transponder unit in the Korea LEO (Low-Earth Orbit) Earth Observation satellite will be discussed. This thermal failure occurred in an LM117 regulator used as a microcircuit of the transponder unit during a space thermal environment test. The thermal design, analysis and test are discussed in regards to the thermal failure of the LM117 regulator.

1. Introduction

The thermal management of electronic packaging is an all-inclusive method involving the selection, analysis, testing and verification of the proper thermal designs for the purpose of producing a reliable end product. The increasing emphasis on thermal management in electronic design stems from the large number of microelectronic devices in systems, their high heat densities and the exponential nature of component failure rates due to temperature issues.

Electronic components rely on the flow and control of electrical current to perform a variety of functions in virtually every major industry throughout the world. Heat is generated by the flow of electric current in electronic components such as diodes, resistors, ICs (Integrated Circuits), hybrids, transistors, microprocessors, relays, DIPs (Dual In-line Packages), VHSICs (Very High Scale Integrated Circuits), PGAs (Pin Grid Arrays), LCCCs (Leadless Ceramic Chip Carriers) and PLCCs (Plastic Leaded Chip Carriers) [1].

The two main failure modes for the solder joint interconnections of a device are low-cycle solder fatigue due to different degrees of thermal expansions between the lead frame and the PCB (Printed Circuit Board), and brittle fracturing caused by static and dynamic loads such as impact shock and random and sinusoidal vibration.

Traditionally, the critical failure mode of these interconnections has been solder fatigue driven by a mismatch of the thermal expansion coefficients between the components and the PCBs. Temperature fluctuations caused by either power transients or environmental changes, along with the resulting thermal expansion mismatch between the various package materials, result in time- and temperature-dependent creep of the solder joint. This creep and deformation accumulate with repeated cycling and ultimately cause solder joint cracking and interconnection failures. To minimize the development costs and maximize the reliable performance of these devices, a numerical approach is a necessity during the design and development phase of a microelectronic device. Several numerical approaches have been proposed which predict the solder joint fatigue life [6,7,5,2,3].

Regarding an electric malfunction, it should be noted that there are several limitations associated with the materials and electrical functions of the devices, some electronic parts, such as military-based regulators, instigate a shutdown failure of the electrical circuit whenever the device junction temperature exceeds 150 °C.

In this study, the failure of a transponder unit of the Korea LEO (Low-Earth Orbit) Earth Observation satellite is investigated, as the cause of the failure, the shutdown thermal failure is supposed and confirmed by introducing a simple network analysis using thermal test results, and the shutdown thermal failure is elucidated as one of reasons of the failure and never occurred after the rework of the mandatory workmanship.

The thermal vacuum cycling test was conducted to verify the use of the electronic equipment of the Korea LEO Earth

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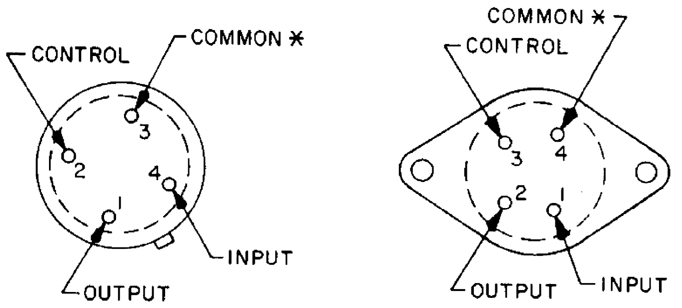

Type I Type II

Fig. 1. Basic configuration of the LM117 regulator.

Table 1
Thermocouple sensor location near the LM117 regulator.

No.	Sensor	Location
1	17	IC 1
2	18	IC 2
3	19	PCB board, near the LM117 regulator
4	20	Top side of LM117 regulator case
5	45	Transponder housing (Chassis), near the LM117 regulator
6	46	Different location of transponder housing (Chassis), near the LM117 regulator

Note: Sensor 21, Sensor 22 and Sensor 25 were not applied to the near LM117 regulator.

Observation satellite in its space thermal environment. During the thermal vacuum cycling test of the transponder as the satellite electronic unit, the transponder was shut down. To find the cause of the failure of the transponder, several tests including electrical function and thermal tests were repeatedly performed. However, determining the cause of the failure was not straightforward. The possibility that the shutdown of the LM117 regulator is the cause of the failure of the transponder was brought up because the device has the shutdown circuit to protect against the thermal failure in the event the device junction temperature exceeds 150 °C. To verify the shutdown of the LM117 regulator, the device junction temperature was obtained using the results of the thermal vacuum cycling test and the thermal network analysis. It was found that the numerical junction temperature of the LM117 regulator approaches to the device shutdown temperature, 150 °C. The thermal failure of the LM117 regulator is an electric malfunction.

The simple thermal network analysis of the numerical calculation is introduced here to obtain the device junction temperature, and this fact shows that the simple numerical analysis can be usefully applied to find the cause of the shutdown thermal failure related to this electric malfunction. And, the shutdown thermal failure of the electrical circuit in some electronic parts should be noted in determining the cause of the failure of the electronic units.

Originally, there is a thermal pad between the LM117 regulator and regulator board to increase the thermal contact performance or to decrease the thermal contact resistance between the device and the PCB board. To remove the thermal failure of the LM117 regulator, i.e., to reduce the device junction temperature, the better thermal contact performance between the LM117 regulator and regulator board was required. From our experience, this is acquired by applying the finger pressure of the mandatory workmanship on the thermal pad.

For the rework, the lead frames of the LM117 regulator were de-soldered, the thermal pad between the LM117 regulator and regulator board was re-attached and controlled by appropriate finger pressure, and the lead frames of the LM117 regulator was re-soldered. After the rework, the junction temperature of the LM117 regulator is reduced to about 126 °C from the device shutdown temperature, 150 °C. In this case, the mandatory workmanship is highlighted to reduce the thermal resistance and mitigate instances of devices failure.

2. The thermal management of the LM117 regulator

2.1. Review of the LM117 regulator

For this program, a military-based electronic part was selected. The device was protected by a thermal shutdown circuit designed to turn off the output transistor whenever the device junction temperature is in excess of 150 °C. Fig. 1 shows the basic configuration of the LM117 regulator.

As shown in Fig. 1, there are two types of LM117 regulators with different mounting conditions. However, they have the same electrical details. Type I is mounted with a solder joint, whereas Type II includes bolts for fastening. Type I is smaller in size than Type II, and the thermal performance is lower. The PCB's size is limited by the total unit size given the limited mass budget. So Type I is adopted for this electronic component. Fig. 2 shows the

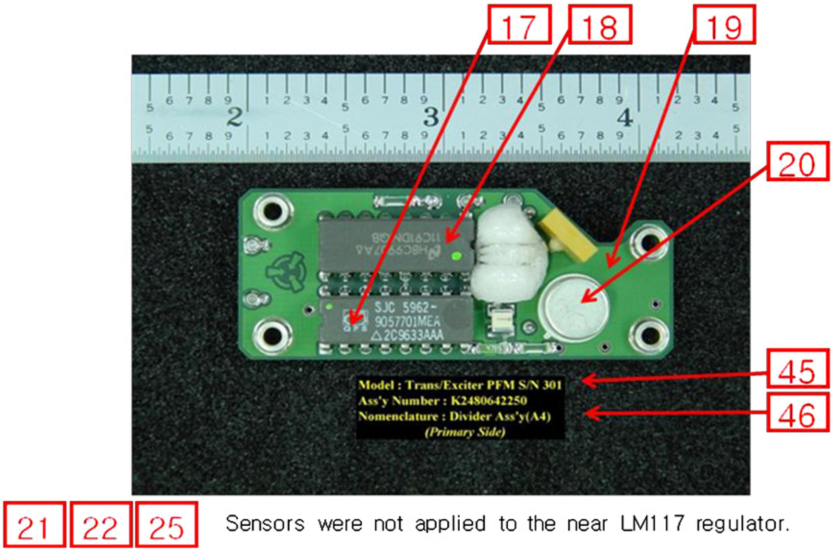

Fig. 2. LM117 regulator board and sensor locations near the LM117 regulator board of the transponder of Table 1 for the thermal vacuum cycling test.