# Reliability Report

ECE 492 – Spring 2014

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## Abstract

This document presents an analysis of the LFEV-ESCM 2014 system according to MIL-HDBK-217F to prove that the system can operate without failure for at least 1000 hours.

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# Executive Summary

## Introduction

Characterizing the performance of a system involves more than simply observing its successful operation. A system must also be operational for a useful lifetime and estimating the reliability of a system can help engineers and customers alike understand the cost of maintenance over its lifetime. In order to make sure that the LFEV-ESCM system meets the reliability standards established in ECE 492, both analysis and testing will be performed. The reliability test, a 24-hour operation of the system, will be performed according to the ATP. In this document, the potential failures of the system are identified and analyzed according to manufactures' datasheets and MIL-HDBK-217F to ensure the system can operate for 1000 hours without failure as per GPR006.

The LFEV-ESCM 2014 system deliverables consist of two major components, the battery pack and a compatible charger. These two systems will be analyzed in-depth for reliability. These two components will be integrated into the full LFEV-ESCM comprised of the Safety Controller, Load Controller, and GLV Power from the LFEV-ESCM 2013 system. Reliability figures for the 2013 subsystems will be obtained from the Reliability Memo found on the Spring 2013 team's website under the Acceptance Testing section.

## Failure Analysis

Since the likelihood of a failure in 1000 hours of operation is of primary interest, the number of expected failures in a 1000-hour period is calculated. Each failure is independent of other failures, so by adding the number of failures per million hours and converting to failures per thousand hours, our equation for number of failures per 1000 hours becomes:

$$\frac{\#\ of\ Failures}{1000\ hours} = \sum_{i=1}^{n} \left(\frac{\#\ of\ failures}{million\ hours}\right) * \left(\frac{0.001\ million\ hours}{thousand\ hours}\right)$$

Appendix A details the analysis on the probability of failure for each individual part. Based on details recorded in Appendix A, an overall calculation for the number of failures per 1000 hours could be obtained.

## Compiled Failure Rates

| Subsystem | Failures/1000 hours |
|---|---|
| **Battery Pack (All Cycles)** | 3.203 (continuous), 1.104 (4x cycle period), 0.6565 (powerlock conn. stay plugged) |
| **Charger** | 0.0304 |
| **Safety Controller** | 0.095 |
| **Load Controller** | 0.0024 |
| **GLV Power** | ≤ 0.01 |
| **All Systems** | 3.341 (continuous cycling), 1.242 (4x cycle period), 0.794 (powerlock conn. stay plugged) |

According to the failure rate analysis contained within this document, our system can successfully operate with a mean time between failure of 805.2 hours when charged and discharged at a rate of one cycle per 576 mins (8.93 hours). Although this value of reliability will not met requirement GPR006, this calculation is a worst case scenario and is a result of unplugging the powerlock connectors once per cycle. Under normal operation of the battery pack, the powerlock connectors could remain plugged in during both discharge and charging cycles, reducing the number of failures per million hours of the powerlock connectors to around 1 or 2. Using this estimation would drop the number of failures per 1000 hours to around 0.794 and thereby increase the MTBF to 1259 hours, meeting requirement GPR006. Our reliability is further verified by completion of T007 in the Acceptance Test Plan.

# Battery Pack System Failures

## Mechanical Failures

### Discharge Path

The battery pack, being an intricate mechanical assembly, depends on the integrity of its mechanical connections in order to function. Any break in the discharging or charging current paths, which have many points of connection, interrupts the current and causes a failure. By applying probability to our pack construction:

$$P(failure) = 1 - P(no\ failures) = 1 - \sum_{i=1}^{n} 1 - P_i(failure)$$

Here, n is the number of individual mechanical connections in the current path.

As per appendix A, the mean time between failure for the discharge path when considering the powerlock connectors, safety loop connectors, SCADA RS-485 connector, discharging fuse, and AIRs was 3904 failures per million hours or 3.9 failures/thousand hours. Although this calculation seems high and will therefore not meet GPR006, this calculation assumes continuous charging and discharging cycles over the entire 1000 hour period. If the system is charged and discharged with a cycle time 4 times slower than the continuous cycle model (536 mins instead of the 134 min cycle used in the calculations), a failure rate of 0.9923 failures/1000 hours will be encountered. Since the battery pack will likely not be put under a series of continuous charge and discharge cycles in its normal operation, the MTBF will most likely stay below 1000 hours as shown by the 4x longer cycle period calculation.

As of the time of system integration and ATP, there is no data available to determine the reliability of the bolted aluminum pieces which comprise the current path. Therefore, there is no accurate way to determine the complete reliability of the current path over our battery pack's lifetime. However, the Pack Management Systems and AMS are more complicated and seem to be prone to more errors than the discharging current path, so it is likely that the number of errors per 1000 hours in the Pack Manager and AMS are much higher than any errors attributed to mechanical systems and will therefore overshadow the mechanical contribution to the number of errors per 1000 hours.

### Charging Path

The battery pack's charging path contains many of the same mechanical joints as the discharge path with the exception of the powerlock connectors on the positive and negative terminal ends of the battery pack. Since the powerlock connectors were the primary contributor to mechanical failures in the battery pack, the mean time between failure for the charging path is much less. The charging path consists of the mechanical interconnects between battery cells, fuses, charge relays, Anderson plug, SCADA RS-485 connector, and wires connecting these components together. Safety loop is not considered since during charging the safety loop does not need to be closed. According to appendix A when considering the charge relays, fuses, and Anderson plug in the charging path, the number of errors per 1000 hours was 2111.29 failures/million hours or 2.11 failures/thousand hours. The primary contributor to this failure calculation is the battery cells themselves as they are only rated for around 1500 cycles of charge and discharge. If a charge/discharge cycle period 4x longer than the continuous cycling period is used, the number of failures per 1000 hours drops to 0.544. As with the calculation for the discharging path, there is no way to obtain a mean time between failure for the complete charging path as there is no reliability information for the aluminum bars connected between each of the battery cells.

### Accumulator Container

Many of the mechanical components of the battery pack were custom made. As such, it is very difficult to estimate the reliability of the mechanical components without further testing of the system in stress tests. This reliability analysis does not take into account any failures which may occur to any of the custom machined pieces of the battery pack as computer simulations might be necessary to obtain an accurate failure rate for those pieces.

## Pack Manager

The pack manager consists of both a custom-designed PCB board with soldered components and a Linux-based ARM computer. The battery pack requires both to be functional in order for the pack manager to operate correctly. As such, the probability of failure for the Pack Manager is given by:

$$P(failure) = 1 - \left(1 - P_{fail}(Computer)\right) * \left(1 - P_{fail}(Breakout\ Board)\right)$$

In Appendix B, failure analysis is recorded for each electrical component used on the Pack Manager Breakout Board. With these values, the number of errors per 1000 hours for the breakout board is 35.3 failures per million hours or 0.0353 failures per 1000 hours. This analysis does not account for any software related failures as information about the TS-8160-4200 reliability could not be found and getting an accurate estimate for software relate errors will require time and experimentation which we do not have currently at this stage in the project.

## Cell AMS Boards

In order to obtain voltage and temperature readings from each cell, a small circuit board with voltage and temperature sensors was placed on the top of each battery cell. It is dangerous to attempt to continue normal operations without knowing the current state of each cell in the pack, so the current version of the Pack Manager software will cease normal discharge and charge operations if it loses communication with at least one of the AMS boards. Therefore, all AMS boards must be functional or the system will record a failure. The probability of failure for the AMS subsystem considering each AMS failure probability is independent of each other:

$$P(system\ failure) = 1 - \left(1 - P(Individual\ AMS\ Board\ Failure)\right)^n$$

Where n is the number of cells and therefore the number of AMS boards in the pack.

Appendix C records failure analysis for each component on the AMS board's bill of materials. Using this information, the failure rate for an individual AMS board was found to be 10.43 failures per million hours or 0.01043 per 1000 hours. Taking into account all seven AMS boards increases the failures per 1000 hours to 0.073.

## Battery Pack Overall Failure Rate

| Subsystem | Failures/1000 hours |
|---|---|
| **Pack Mechanical Charging Path** | 3.904 (continuous), 0.9923 (4x cycle period) |
| **Pack Mechanical Discharging Path** | 2.11(continuous), 0.544 (4x cycle period) |
| **Pack Mechanical (All Cycles)** | 3.095 (continuous), 0.9958 (4x cycle period) |
| **Pack Manager** | 0.0353 |
| **AMS Boards (7)** | 0.073 |
| **All Battery Pack Systems** | 3.203 (continuous), 1.104 (4x cycle period) |

## Charger System Failures

The charging unit being used for the current system is relatively simple compared to the battery pack. It uses a TDK-Lambda GENH30-25 Power Supply to produce a constant charging current to the battery pack. To connect the power supply to the battery pack, a cable using Anderson connectors is utilized. In the current design, 3 sets of Anderson plugs are in the charging current path of the charger. The charger system will fail if any connection in the charging current path or the power supply itself fails. The probability of failure for the charger is given by:

$$P(failure) = 1 - \left(1 - P_{fail}(power\ supply)\right) * \left(1 - P_{fail}(Anderson\ plugs)\right)^3$$

## Charger Overall Failure Rate

The detailed failure rate for the charger components is recorded in Appendix D. Based on the component failure rates, the overall failure rate for the charger subsystem is 30.36 failures per million hours or 0.0304 failures per 1000 hours.

# Appendix A: Pack Mechanical Detailed Failure Analysis

### VEAM PowerLock Connectors (Quantity – 2)

Mating cycles: 500
Average Discharge Time 90% - 10% SOC (for avg. current ~150A) – 19.2 minutes
Average Cycle Time: 10% - 90% SOC (for current of 25A) – 115.2 minutes
Cycle time ≈ 134 minutes (charge / discharge cycle)
Cycle life = (134 minutes/cycle)*(1 hr/60 minutes)*(500 cycles) = 1117 hours
$\lambda_p$ = 895 failures/million hours

*This is a worst-case calculation that assumes the PowerLock connectors are unmated before every charge. This is not necessary with the system configuration as the system can remain connected over all charge/discharge cycles.

### Charger Anderson Connector Plug (Quantity –1)

Failure mode: 15.1 – Connectors, General (Except Printed Circuit Board)
$\lambda_p = \lambda_b \pi_K \pi_P \pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, $T_O$ = 70, insert material B – 0.015
$\pi_K$: Mating/Unmating Factor, >50 times /1000 hours – 4.0
$\pi_P$: Active Pins Factor, 6 – 2.0
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality - 21
$\lambda_p$ = 2.52 failures/million hours

### Gigavac GX14CAB, 350+ Amp Isolation Relay (AIRs) (Quantity – 2)

Mechanical Life: 1,000,000 cycles
Average Cycle Time: 134 minutes (see cycle time calculation above)
Lifetime: (1,000,000 cycles)*(134 minutes/cycle)*(1/60 minutes/hour) = 2,233,333 hours
$\lambda_p$ = 0.45 failures/million hours

### 4-pin MATE-N-LOK Connector (Quantity – 2)

Failure mode: 15.1 – Connectors, General (Except Printed Circuit Board)
$\lambda_p = \lambda_b \pi_K \pi_P \pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, $T_O$ = 70, insert material B – 0.015
$\pi_K$: Mating/Unmating Factor, 5 to 50/1000 hours – 3.0
$\pi_P$: Active Pins Factor, 4 – 1.7
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality - 21
$\lambda_p$ = 1.6 failures/million hours

### 6-pin MATE-N-LOK Connector (Quantity – 1)

Failure mode: 15.1 – Connectors, General (Except Printed Circuit Board)
$\lambda_p = \lambda_b \pi_K \pi_P \pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, $T_O$ = 70, insert material B – 0.015

$\pi_K$: Mating/Unmating Factor, 5 to 50/1000 hours – 3.0
$\pi_P$: Active Pins Factor, 6 – 2.0
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality - 21
$\lambda_p$ = 1.89 failures/million hours

### DIN Rail Terminal Blocks (Quantity – 37)

Failure mode: 15.1 – Connectors, General (Except Printed Circuit Board)
$\lambda_p = \lambda_b\pi_Q\pi_E$ failures/million hours
$\lambda_p = \lambda_b\pi_K\pi_P\pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, $T_O$ = 70, insert material B – 0.015
$\pi_K$: Mating/Unmating Factor, 0 to 0.05/1000 hours – 1.0
$\pi_P$: Active Pins Factor, 2 – 1.4
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality - 21
$\lambda_p$ = 0.441 failures/million hours

### Littelfuse 30A Charging Fuses (Quantity – 2)

Failure mode: 22.1 – Fuses
$\lambda_p = \lambda_b\pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate 0.010
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality - 8.0
$\lambda_p$ = 0.080 failures/million hours

### Zoro Tools G3475534 200A Discharging Fuse (Quantity – 1)

Failure mode: 22.1 – Fuses
$\lambda_p = \lambda_b\pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate 0.010
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality - 8.0
$\lambda_p$ = 0.080 failures/million hours

### Gigavac P105CDA, 50 Amp Charging Relay (Quantity – 2)

Mechanical Life: 1,000,000 cycles
Average Cycle Time: 134 minutes (see cycle time calculation above)
Lifetime: (1,000,000 cycles)*(134 minutes/cycle)*(1/60 minutes/hour) = 2,233,333 hours
$\lambda_p$ = 0.45 failures/million hours

### 60Ah Battery Cells (Quantity – 7)

Cycle Life (according to Spec. Sheet) ≥ 1500 cycles
Average Cycle Time: 134 minutes (see cycle time calculation above)
Lifetime: (1500 cycles)*(134 minutes/cycle)*(1/60 minutes/hour) = 3,350 hours
$\lambda_p$ = 298.5 failures/million hours

# Appendix B: Pack Manager Detailed Failure Analysis

### 4x20 Character LCD Display (Quantity – 1)

Failure mode: 6.12 – Optoelectronics, Alphanumeric Displays
$\lambda_p = \lambda_b \pi_T \pi_Q \pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, C = 80: 0.00009 + 0.00017(C) + 0.000043 = 0.0137
$\pi_T$: Temperature Factor, $T_O$ = 50°C – 2.1
$\pi_Q$: Quality Factor, Lower – 5.5
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality - 8.0
$\lambda_p$ = 1.27 failures/million hours

### 16-pin Shrouded Header (Quantity – 2)

Failure mode: 15.1 – Connectors, General (Except Printed Circuit Board)
$\lambda_p = \lambda_b \pi_K \pi_P \pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, $T_O$ = 70, insert material B – 0.015
$\pi_K$: Mating/Unmating Factor, 0 to 0.05 /1000 hours – 1.0
$\pi_P$: Active Pins Factor, 16 – 3.4
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality - 21
$\lambda_p$ = 1.071 failures/million hours

### 10-pin Shrouded Header (Quantity – 1)

Failure mode: 15.1 – Connectors, General (Except Printed Circuit Board)
$\lambda_p = \lambda_b \pi_K \pi_P \pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, $T_O$ = 70, insert material B – 0.015
$\pi_K$: Mating/Unmating Factor, 0 to 0.05 /1000 hours – 1.0
$\pi_P$: Active Pins Factor, 10 – 2.6
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality - 21
$\lambda_p$ = 0.819 failures/million hours

### 6-pin Shrouded Locking Header (Quantity – 1)

Failure mode: 15.1 – Connectors, General (Except Printed Circuit Board)
$\lambda_p = \lambda_b \pi_K \pi_P \pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, $T_O$ = 70, insert material B – 0.015
$\pi_K$: Mating/Unmating Factor, 0 to 0.05 /1000 hours – 1.0
$\pi_P$: Active Pins Factor, 6 – 2.0
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality - 21
$\lambda_p$ = 0.63 failures/million hours

### 8-pin Screw Terminal (Quantity – 2)

Failure mode: 15.1 – Connectors, General (Except Printed Circuit Board)
$\lambda_p = \lambda_b \pi_K \pi_P \pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, $T_O$ = 70, insert material B – 0.015

$\pi_K$: Mating/Unmating Factor, 0 to 0.05 /1000 hours – 1.0
$\pi_P$: Active Pins Factor, 8 – 2.3
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality - 21
$\lambda_p$ = 0.72 failures/million hours

### 2-pin Screw Terminal (Quantity – 4)

Failure mode: 15.1 – Connectors, General (Except Printed Circuit Board)
$\lambda_p = \lambda_b \pi_K \pi_P \pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, $T_O$ = 70, insert material B – 0.015
$\pi_K$: Mating/Unmating Factor, 0 to 0.05 /1000 hours – 1.0
$\pi_P$: Active Pins Factor, 2 – 1.4
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality - 21
$\lambda_p$ = 0.441 failures/million hours

### 3-pin Screw Terminal (Quantity – 4)

Failure mode: 15.1 – Connectors, General (Except Printed Circuit Board)
$\lambda_p = \lambda_b \pi_K \pi_P \pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, $T_O$ = 70, insert material B – 0.015
$\pi_K$: Mating/Unmating Factor, 0 to 0.05 /1000 hours – 1.0
$\pi_P$: Active Pins Factor, 2 – 1.6
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality - 21
$\lambda_p$ = 0.504 failures/million hours

### Chip Resistor, 1.5MΩ (Quantity – 1)

Failure mode: 9.2 – Fixed, Film
$\lambda_p = \lambda_b \pi_R \pi_Q \pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, $T_A$ = 40, Stress = 0.001: 0.00078
$\pi_R$: Resistance Factor, resistance range > 1.0M to 10 M: 1.6
$\pi_Q$: Quality Factor – Lower: 15
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality - 8.0
$\lambda_p$ = 0.150 failures/million hours

### Chip Resistor, 100KΩ (Quantity – 2)

Failure mode: 9.2 – Fixed, Film
$\lambda_p = \lambda_b \pi_R \pi_Q \pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, $T_A$ = 40, Stress = 0.001: 0.00078
$\pi_R$: Resistance Factor, resistance range ≥ 0.1M to 1 M: 1.1
$\pi_Q$: Quality Factor – Lower: 15
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality - 8.0
$\lambda_p$ = 0.102 failures/million hours

### Chip Resistor, 10KΩ (Quantity – 4)

Failure mode: 9.2 – Fixed, Film

$\lambda_p = \lambda_b\pi_R\pi_Q\pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, $T_A = 40$, Stress = 0.001: 0.00078
$\pi_R$: Resistance Factor, resistance range < 0.1 M: 1.0
$\pi_Q$: Quality Factor – Lower: 15
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality - 8.0
$\lambda_p = 0.094$ failures/million hours

### Chip Resistor, 2KΩ (Quantity – 2)

Failure mode: 9.2 – Fixed, Film
$\lambda_p = \lambda_b\pi_R\pi_Q\pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, $T_A = 40$, Stress = 0.001: 0.00078
$\pi_R$: Resistance Factor, resistance range < 0.1 M: 1.0
$\pi_Q$: Quality Factor – Lower: 15
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality - 8.0
$\lambda_p = 0.094$ failures/million hours

### Chip Resistor, 1.5KΩ (Quantity – 2)

Failure mode: 9.2 – Fixed, Film
$\lambda_p = \lambda_b\pi_R\pi_Q\pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, $T_A = 40$, Stress = 0.001: 0.00078
$\pi_R$: Resistance Factor, resistance range < 0.1 M: 1.0
$\pi_Q$: Quality Factor – Lower: 15
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality - 8.0
$\lambda_p = 0.094$ failures/million hours

### Chip Resistor, 1KΩ (Quantity – 1)

Failure mode: 9.2 – Fixed, Film
$\lambda_p = \lambda_b\pi_R\pi_Q\pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, $T_A = 40$, Stress = 0.001: 0.00078
$\pi_R$: Resistance Factor, resistance range < 0.1 M: 1.0
$\pi_Q$: Quality Factor – Lower: 15
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality - 8.0
$\lambda_p = 0.094$ failures/million hours

### Chip Resistor, 470Ω (Quantity – 2)

Failure mode: 9.2 – Fixed, Film
$\lambda_p = \lambda_b\pi_R\pi_Q\pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, $T_A = 40$, Stress = 0.001: 0.00078
$\pi_R$: Resistance Factor, resistance range < 0.1 M: 1.0
$\pi_Q$: Quality Factor – Lower: 15
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality - 8.0
$\lambda_p = 0.094$ failures/million hours

### Ceramic Chip Capacitor, 0.1uF (Quantity – 9)

Failure mode: 10.10 – Capacitors, Fixed, Ceramic, General Purpose
$\lambda_p = \lambda_b \pi_{CV} \pi_Q \pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, $T_A = 50°C$, 125°C rating, Stress = 0.001: 0.00070
$\pi_{CV}$: Capacitance Factor, C is in pF, $(0.41)C^{0.11} = 1.45$
$\pi_Q$: Quality Factor – Lower: 10
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality - 9.0
$\lambda_p = 0.091$ failures/million hours

### Ceramic Chip Capacitor, 22uF (Quantity – 1)

Failure mode: 10.10 – Capacitors, Fixed, Ceramic, General Purpose
$\lambda_p = \lambda_b \pi_{CV} \pi_Q \pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, $T_A = 50°C$, 85°C rating, Stress = 0.001: 0.00077
$\pi_{CV}$: Capacitance Factor, C is in pF, $(0.41)C^{0.11} = 2.63$
$\pi_Q$: Quality Factor – Lower: 10
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality - 9.0
$\lambda_p = 0.182$ failures/million hours

### Electrolytic Capacitor, 220uF (Quantity – 1)

Failure mode: 10.14 – Capacitors, Fixed Electrolytic, Aluminum
$\lambda_p = \lambda_b \pi_{CV} \pi_Q \pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, $T_A = 50°C$, 85°C rating, Stress = 0.001: 0.054
$\pi_{CV}$: Capacitance Factor, C is in uF: $(0.34)C^{0.18} = 0.90$
$\pi_Q$: Quality Factor – Lower: 10
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality:12
$\lambda_p = 5.82$ failures/million hours

### D1N4148 Diode Through Hole (Quantity – 3)

Failure mode: 6.1 – Diodes, Low Frequency
$\lambda_p = \lambda_b \pi_T \pi_S \pi_C \pi_Q \pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, Transient Suppressor: 0.0013
$\pi_T$: Temperature Factor, $T_J = 50°C$: 2.2
$\pi_S$: Electrical Stress Factor, Transient Suppressor: 1.0
$\pi_C$: Contact Construction Factor, Metallurgically Bonded: 1.0
$\pi_Q$: Quality Factor – Lower: 5.5
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality: 9.0
$\lambda_p = 0.142$ failures/million hours

### D1N4001 Diode Through Hole (Quantity – 1)

Failure mode: 6.1 – Diodes, Low Frequency
$\lambda_p = \lambda_b \pi_T \pi_S \pi_C \pi_Q \pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, Transient Suppressor: 0.0013
$\pi_T$: Temperature Factor, $T_J = 50°C$: 2.2
$\pi_S$: Electrical Stress Factor, Transient Suppressor: 1.0

$\pi_C$: Contact Construction Factor, Metallurgically Bonded: 1.0
$\pi_Q$: Quality Factor – Lower: 5.5
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality: 9.0
$\lambda_p$ = 0.142 failures/million hours

### B260 Schottky Diode 60V, 2A(Quantity – 1)

Failure mode: 6.1 – Diodes, Low Frequency
$\lambda_p = \lambda_b\pi_T\pi_S\pi_C\pi_Q\pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, Schottky: 0.0030
$\pi_T$: Temperature Factor, $T_J$ = 50°C: 2.2
$\pi_S$: Electrical Stress Factor, Voltage Regulator = 1.0
$\pi_C$: Contact Construction Factor, Metallurgically Bonded: 1.0
$\pi_Q$: Quality Factor – Lower: 5.5
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality: 9.0
$\lambda_p$ = 0.327 failures/million hours

### 68uH Shielded SM Inductor (Quantity – 1)

Failure mode: 11.1 – Inductive Devices, Coils
$\lambda_p = \lambda_b\pi_C\pi_Q\pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, $T_{HS}$ = 50°C, Rated for 125°C: 0.00045
$\pi_C$: Construction Factor – Fixed: 1.0
$\pi_Q$: Quality Factor – Lower: 20
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality: 12
$\lambda_p$ = 0.108 failures/million hours

### 2N2222 NPN Transistor (Quantity – 2)

Failure mode: 6.3 – Transistors, Low Frequency, Bipolar
$\lambda_p = \lambda_b\pi_T\pi_A\pi_R\pi_S\pi_Q\pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, NPN and PNP: 0.00074
$\pi_T$: Temperature Factor, $T_J$ = 50°C: 1.7
$\pi_A$: Application Factor – Switching: 0.70
$\pi_R$: Power Rating Factor, $P_r$ = 0.5W: 0.77
$\pi_S$: Voltage Stress Factor, $0.3 < V_s \leq 0.4$: 0.16
$\pi_Q$: Quality Factor – Lower: 5.5
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality: 9.0
$\lambda_p$ = 0.0054 failures/million hours

### Single Channel Optoisolator (Quantity – 1)

Failure mode: 6.11 – Optoelectronics, Detectors, Isolators, Emitters
$\lambda_p = \lambda_b\pi_T\pi_Q\pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, Phototransistor Output, Single Device: 0.013
$\pi_T$: Temperature Factor, $T_J$ = 50°C: 2.1
$\pi_Q$: Quality Factor – Lower: 5.5
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality: 8.0
$\lambda_p$ = 1.20 failures/million hours

### Dual Channel Darlington Optoisolator (Quantity – 1)

Failure mode: 6.11 – Optoelectronics, Detectors, Isolators, Emitters
$\lambda_p = \lambda_b\pi_T\pi_Q\pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, Photodarlington Output, Dual Device: 0.017
$\pi_T$: Temperature Factor, $T_J$ = 50°C: 2.1
$\pi_Q$: Quality Factor – Lower: 5.5
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality: 8.0
$\lambda_p$ = 1.57 failures/million hours

### 60V P-Channel MOSFET (Quantity – 1)

Failure mode: 6.3 – Transistors, Low Frequency, Bipolar
$\lambda_p = \lambda_b\pi_T\pi_A\pi_Q\pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, MOSFET: 0.012
$\pi_T$: Temperature Factor, $T_J$ = 50°C: 1.6
$\pi_A$: Application Factor – Power FET: $2 \leq P_r < 5W$: 2.0
$\pi_Q$: Quality Factor – Lower: 5.5
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality: 9.0
$\lambda_p$ = 1.90 failures/million hours

### 5V SPST Relay PCB Mount (Quantity – 1)

Failure mode: 13.1 – Relays, Mechanical
$\lambda_p = \lambda_b\pi_L\pi_C\pi_{CYC}\pi_F\pi_Q\pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, $T_A$ = 50°C: 0.0072
$\pi_L$: Load Stress Factor, S = 1A/5A = 0.2, Inductive Load: 1.28
$\pi_C$: Application Factor – Switching: 0.70
$\pi_{CYC}$: Cycling Factor, < 1.0: 1.0
$\pi_F$: Application and Construction Factor, General Purpose Solenoid: 12
$\pi_Q$: Quality Factor – Non-Established: 3.0
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality: 44
$\lambda_p$ = 10.22 failures/million hours

### MCP6242 Rail to Rail OpAmp (Quantity – 3)

Failure mode: 5.1 – Microcircuits, Gate/Logic Arrays and Microprocessors
$\lambda_p = (C_1\pi_T + C_2\pi_E)\pi_Q\pi_L$ failures/million hours
$C_1$: Complexity Failure Rate, MOS Linear, No Transistors 1-100: 0.010
$\pi_T$: Load Temperature Factor, $T_J$ = 50°C: 0.71
$C_2$: Package Failure Rate, Nonhermetic SMT w/Solder, 8 functional pins: 0.0034
$\pi_E$: Environment Factor, Ground Mobile ($G_M$): 4.0
$\pi_Q$: Quality Factor (best estimate, see MIL-HDBK-217F pgs 5-16): 4.0
$\pi_L$: Learning Factor, ≥ 2.0 years in production: 1.0
$\lambda_p$ = 0.083 failures/million hours

### MIC4680 Switching Regulator (Quantity – 1)

Failure mode: 5.1 – Microcircuits, Gate/Logic Arrays and Microprocessors
$\lambda_p = (C_1\pi_T + C_2\pi_E)\pi_Q\pi_L$ failures/million hours
$C_1$: Complexity Failure Rate, MOS Linear, No Transistors 1-100: 0.010
$\pi_T$: Load Temperature Factor, $T_J$ = 50°C: 0.71
$C_2$: Package Failure Rate, Nonhermetic SMT w/Solder, 8 functional pins: 0.0034
$\pi_E$: Environment Factor, Ground Mobile ($G_M$): 4.0
$\pi_Q$: Quality Factor (best estimate, see MIL-HDBK-217F pgs 5-16): 4.0
$\pi_L$: Learning Factor, ≥ 2.0 years in production: 1.0
$\lambda_p$ = 0.083 failures/million hours

### ADM1232 Watchdog Timer (Quantity – 1)

Failure mode: 5.1 – Microcircuits, Gate/Logic Arrays and Microprocessors
$\lambda_p = (C_1\pi_T + C_2\pi_E)\pi_Q\pi_L$ failures/million hours
$C_1$: Complexity Failure Rate, MOS Linear, No Transistors 1-100: 0.010
$\pi_T$: Load Temperature Factor, $T_J$ = 50°C: 0.71
$C_2$: Package Failure Rate, Nonhermetic SMT w/Solder, 8 functional pins: 0.0034
$\pi_E$: Environment Factor, Ground Mobile ($G_M$): 4.0
$\pi_Q$: Quality Factor (best estimate, see MIL-HDBK-217F pgs 5-16): 4.0
$\pi_L$: Learning Factor, ≥ 2.0 years in production: 1.0
$\lambda_p$ = 0.083 failures/million hours

### ADM2483 Half Duplex RS-485 Isolator (Quantity – 1)

Failure mode: 5.1 – Microcircuits, Gate/Logic Arrays and Microprocessors
$\lambda_p = (C_1\pi_T + C_2\pi_E)\pi_Q\pi_L$ failures/million hours
$C_1$: Complexity Failure Rate, MOS Linear, No Transistors 1-100: 0.010
$\pi_T$: Load Temperature Factor, $T_J$ = 50°C: 0.71
$C_2$: Package Failure Rate, Nonhermetic SMT w/Solder, 16 functional pins: 0.0072
$\pi_E$: Environment Factor, Ground Mobile ($G_M$): 4.0
$\pi_Q$: Quality Factor (best estimate, see MIL-HDBK-217F pgs 5-16): 4.0
$\pi_L$: Learning Factor, ≥ 2.0 years in production: 1.0
$\lambda_p$ = 0.144 failures/million hours

### HCT4002D Dual Input NOR Gate (Quantity – 1)

Failure mode: 5.1 – Microcircuits, Gate/Logic Arrays and Microprocessors
$\lambda_p = (C_1\pi_T + C_2\pi_E)\pi_Q\pi_L$ failures/million hours
$C_1$: Complexity Failure Rate, MOS Linear, No Transistors 1-100: 0.010
$\pi_T$: Load Temperature Factor, $T_J$ = 50°C: 0.71
$C_2$: Package Failure Rate, Nonhermetic SMT w/Solder, 14 functional pins: 0.0062
$\pi_E$: Environment Factor, Ground Mobile ($G_M$): 4.0
$\pi_Q$: Quality Factor (best estimate, see MIL-HDBK-217F pgs 5-16): 4.0
$\pi_L$: Learning Factor, ≥ 2.0 years in production: 1.0
$\lambda_p$ = 0.128 failures/million hours

### M74HC07 Hex Open-Drain Buffer (Quantity – 1)

Failure mode: 5.1 – Microcircuits, Gate/Logic Arrays and Microprocessors
$\lambda_p = (C_1\pi_T + C_2\pi_E)\pi_Q\pi_L$ failures/million hours
$C_1$: Complexity Failure Rate, MOS Linear, No Transistors 1-100: 0.010
$\pi_T$: Load Temperature Factor, $T_J$ = 50°C: 0.71
$C_2$: Package Failure Rate, Nonhermetic SMT w/Solder, 14 functional pins: 0.0062
$\pi_E$: Environment Factor, Ground Mobile ($G_M$): 4.0
$\pi_Q$: Quality Factor (best estimate, see MIL-HDBK-217F pgs 5-16): 4.0
$\pi_L$: Learning Factor, ≥ 2.0 years in production: 1.0
$\lambda_p$ = 0.128 failures/million hours

### LTC4151 High Voltage I2C Current and Voltage Monitor (Quantity – 2)

Failure mode: 5.1 – Microcircuits, Gate/Logic Arrays and Microprocessors
$\lambda_p = (C_1\pi_T + C_2\pi_E)\pi_Q\pi_L$ failures/million hours
$C_1$: Complexity Failure Rate, MOS Linear, No Transistors 1-100: 0.010
$\pi_T$: Load Temperature Factor, $T_J$ = 50°C: 0.71
$C_2$: Package Failure Rate, Nonhermetic SMT w/Solder, 16 functional pins: 0.0072
$\pi_E$: Environment Factor, Ground Mobile ($G_M$): 4.0
$\pi_Q$: Quality Factor (best estimate, see MIL-HDBK-217F pgs 5-16): 4.0
$\pi_L$: Learning Factor, ≥ 2.0 years in production: 1.0
$\lambda_p$ = 0.144 failures/million hours

# Appendix C: AMS Board Detailed Failure Analysis

### 6-pin Shrouded Locking Header (Quantity – 2)

Failure mode: 15.1 – Connectors, General (Except Printed Circuit Board)
$\lambda_p = \lambda_b \pi_K \pi_P \pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, $T_O = 70$, insert material B – 0.015
$\pi_K$: Mating/Unmating Factor, 0 to 0.05 /1000 hours – 1.0
$\pi_P$: Active Pins Factor, 6 – 2.0
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality - 21
$\lambda_p = 0.63$ failures/million hours

### Push-Button SPST Switch, 0.05 A, 12V (Quantity – 1)

Failure mode: 14.1 – Switches, Toggle or Pushbutton
$\lambda_p = \lambda_b \pi_{CYC} \pi_L \pi_C \pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, non-snap action: 0.040
$\pi_{CYC}$: Cycling Factor, < 1.0 cycle/hour: 1.0
$\pi_L$: Load Stress Factor, S = 0.05, Resistive Load: 1.0
$\pi_C$: Contact Form and Quantity Factor – SPST: 1.0
$\pi_E$: Environment Factor, Ground Mobile ($G_M$) – 18
$\lambda_p = 0.72$ failures/million hours

### Chip Resistor, 1.02MΩ (Quantity – 1)

Failure mode: 9.2 – Fixed, Film
$\lambda_p = \lambda_b \pi_R \pi_Q \pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, $T_A = 40$, Stress = 0.001: 0.00078
$\pi_R$: Resistance Factor, resistance range > 1.0M to 10 M: 1.6
$\pi_Q$: Quality Factor – Lower: 15
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality - 8.0
$\lambda_p = 0.150$ failures/million hours

### Chip Resistor, 324KΩ (Quantity – 1)

Failure mode: 9.2 – Fixed, Film
$\lambda_p = \lambda_b \pi_R \pi_Q \pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, $T_A = 40$, Stress = 0.001: 0.00078
$\pi_R$: Resistance Factor, resistance range ≥ 0.1M to 1 M: 1.1
$\pi_Q$: Quality Factor – Lower: 15
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality - 8.0
$\lambda_p = 0.102$ failures/million hours

### Chip Resistor, 200KΩ (Quantity – 1)

Failure mode: 9.2 – Fixed, Film
$\lambda_p = \lambda_b \pi_R \pi_Q \pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, $T_A = 40$, Stress = 0.001: 0.00078

$\pi_R$: Resistance Factor, resistance range ≥ 0.1M to 1 M: 1.1
$\pi_Q$: Quality Factor – Lower: 15
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality - 8.0
$\lambda_p$ = 0.102 failures/million hours

### Chip Resistor, 100KΩ (Quantity – 2)

Failure mode: 9.2 – Fixed, Film
$\lambda_p = \lambda_b\pi_R\pi_Q\pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, $T_A$ = 40, Stress = 0.001: 0.00078
$\pi_R$: Resistance Factor, resistance range ≥ 0.1M to 1 M: 1.1
$\pi_Q$: Quality Factor – Lower: 15
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality - 8.0
$\lambda_p$ = 0.102 failures/million hours

### Chip Resistor, 10KΩ (Quantity – 3)

Failure mode: 9.2 – Fixed, Film
$\lambda_p = \lambda_b\pi_R\pi_Q\pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, $T_A$ = 40, Stress = 0.001: 0.00078
$\pi_R$: Resistance Factor, resistance range < 0.1 M: 1.0
$\pi_Q$: Quality Factor – Lower: 15
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality - 8.0
$\lambda_p$ = 0.094 failures/million hours

### Chip Resistor, 470Ω (Quantity – 1)

Failure mode: 9.2 – Fixed, Film
$\lambda_p = \lambda_b\pi_R\pi_Q\pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, $T_A$ = 40, Stress = 0.001: 0.00078
$\pi_R$: Resistance Factor, resistance range < 0.1 M: 1.0
$\pi_Q$: Quality Factor – Lower: 15
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality - 8.0
$\lambda_p$ = 0.094 failures/million hours

### Chip Resistor, 383Ω (Quantity – 1)

Failure mode: 9.2 – Fixed, Film
$\lambda_p = \lambda_b\pi_R\pi_Q\pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, $T_A$ = 40, Stress = 0.001: 0.00078
$\pi_R$: Resistance Factor, resistance range < 0.1 M: 1.0
$\pi_Q$: Quality Factor – Lower: 15
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality - 8.0
$\lambda_p$ = 0.094 failures/million hours

### Chip Resistor, 200Ω (Quantity – 1)

Failure mode: 9.2 – Fixed, Film
$\lambda_p = \lambda_b\pi_R\pi_Q\pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, $T_A$ = 40, Stress = 0.001: 0.00078
$\pi_R$: Resistance Factor, resistance range < 0.1 M: 1.0
$\pi_Q$: Quality Factor – Lower: 15
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality - 8.0

$\lambda_p$ = 0.094 failures/million hours

### Chip Resistor, 100Ω (Quantity – 1)

Failure mode: 9.2 – Fixed, Film
$\lambda_p = \lambda_b \pi_R \pi_Q \pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, $T_A$ = 40, Stress = 0.001: 0.00078
$\pi_R$: Resistance Factor, resistance range < 0.1 M: 1.0
$\pi_Q$: Quality Factor – Lower: 15
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality - 8.0
$\lambda_p$ = 0.094 failures/million hours

### Chip Resistor, 36Ω (Quantity – 1)

Failure mode: 9.2 – Fixed, Film
$\lambda_p = \lambda_b \pi_R \pi_Q \pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, $T_A$ = 40, Stress = 0.001: 0.00078
$\pi_R$: Resistance Factor, resistance range < 0.1 M: 1.0
$\pi_Q$: Quality Factor – Lower: 15
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality - 8.0
$\lambda_p$ = 0.094 failures/million hours

### Power Resistor, 0.75Ω, 20W (Quantity – 1)

Failure mode: 9.3 – Fixed, Film, Power
$\lambda_p = \lambda_b \pi_R \pi_Q \pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, $T_A$ = 40, Stress = 7.2W/20W: 0.14
$\pi_R$: Resistance Factor, resistance range 10-100Ω: 1.0
$\pi_Q$: Quality Factor – Lower: 3.0
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality - 10
$\lambda_p$ = 4.2 failures/million hours

### Ceramic Chip Capacitor, 680pF (Quantity – 1)

Failure mode: 10.10 – Capacitors, Fixed, Ceramic, General Purpose
$\lambda_p = \lambda_b \pi_{CV} \pi_Q \pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, $T_A$ = 50°C, 125°C rating, Stress = 0.001: 0.00070
$\pi_{CV}$: Capacitance Factor, C is in pF, $(0.41)C^{0.11}$ = 0.84
$\pi_Q$: Quality Factor – Lower: 10
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality - 9.0
$\lambda_p$ = 0.053 failures/million hours

### Ceramic Chip Capacitor, 0.1uF (Quantity – 5)

Failure mode: 10.10 – Capacitors, Fixed, Ceramic, General Purpose
$\lambda_p = \lambda_b \pi_{CV} \pi_Q \pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, $T_A$ = 50°C, 125°C rating, Stress = 0.001: 0.00070
$\pi_{CV}$: Capacitance Factor, C is in pF, $(0.41)C^{0.11}$ = 1.45
$\pi_Q$: Quality Factor – Lower: 10
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality - 9.0
$\lambda_p$ = 0.091 failures/million hours

## Ceramic Chip Capacitor, 1uF (Quantity – 1)

Failure mode: 10.10 – Capacitors, Fixed, Ceramic, General Purpose
$\lambda_p = \lambda_b \pi_{CV} \pi_Q \pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, $T_A$ = 50°C, 125°C rating, Stress = 0.001: 0.00070
$\pi_{CV}$: Capacitance Factor, C is in pF, $(0.41)C^{0.11} = 1.87$
$\pi_Q$: Quality Factor – Lower: 10
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality - 9.0
$\lambda_p$ = 0.118 failures/million hours

## Ceramic Chip Capacitor, 10uF (Quantity – 3)

Failure mode: 10.10 – Capacitors, Fixed, Ceramic, General Purpose
$\lambda_p = \lambda_b \pi_{CV} \pi_Q \pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, $T_A$ = 50°C, 125°C rating, Stress = 0.001: 0.00070
$\pi_{CV}$: Capacitance Factor, C is in pF, $(0.41)C^{0.11} = 2.41$
$\pi_Q$: Quality Factor – Lower: 10
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality - 9.0
$\lambda_p$ = 0.152 failures/million hours

## Chip LED Red, 2mA SMD (Quantity – 1)

Failure mode: 6.1 – Diodes, Low Frequency
$\lambda_p = \lambda_b \pi_T \pi_S \pi_C \pi_Q \pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, General Purpose Analog: 0.0038
$\pi_T$: Temperature Factor, $T_J$ = 55°C (worst case): 2.6
$\pi_S$: Electrical Stress Factor, $V_s$ = (1.5V / 12V): $V_s^{2.43} = 0.054$
$\pi_C$: Contact Construction Factor, Metallurgically Bonded: 1.0
$\pi_Q$: Quality Factor – Lower: 5.5
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality: 9.0
$\lambda_p$ = 0.026 failures/million hours

## Chip LED Yellow, 2mA SMD (Quantity – 1)

Failure mode: 6.1 – Diodes, Low Frequency
$\lambda_p = \lambda_b \pi_T \pi_S \pi_C \pi_Q \pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, General Purpose Analog: 0.0038
$\pi_T$: Temperature Factor, $T_J$ = 55°C (worst case): 2.6
$\pi_S$: Electrical Stress Factor, $V_s$ = (1.5V / 12V): $V_s^{2.43} = 0.054$
$\pi_C$: Contact Construction Factor, Metallurgically Bonded: 1.0
$\pi_Q$: Quality Factor – Lower: 5.5
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality: 9.0
$\lambda_p$ = 0.026 failures/million hours

## Chip LED Green, 2mA SMD (Quantity – 1)

Failure mode: 6.1 – Diodes, Low Frequency
$\lambda_p = \lambda_b \pi_T \pi_S \pi_C \pi_Q \pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, General Purpose Analog: 0.0038
$\pi_T$: Temperature Factor, $T_J$ = 55°C (worst case): 2.6
$\pi_S$: Electrical Stress Factor, $V_s$ = (1.5V / 12V): $V_s^{2.43} = 0.054$
$\pi_C$: Contact Construction Factor, Metallurgically Bonded: 1.0
$\pi_Q$: Quality Factor – Lower: 5.5

$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality: 9.0
$\lambda_p$ = 0.026 failures/million hours

### Schottky Diode 20VDC, 500mA (Quantity – 1)

Failure mode: 6.1 – Diodes, Low Frequency
$\lambda_p = \lambda_b\pi_T\pi_S\pi_C\pi_Q\pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, Schottky: 0.0030
$\pi_T$: Temperature Factor, $T_J$ = 52°C: 2.3
$\pi_S$: Electrical Stress Factor, Voltage Regulator = 1.0
$\pi_C$: Contact Construction Factor, Metallurgically Bonded: 1.0
$\pi_Q$: Quality Factor – Lower: 5.5
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality: 9.0
$\lambda_p$ = 0.342 failures/million hours

### 10uH Semi-Shielded SM Inductor (Quantity – 1)

Failure mode: 11.1 – Inductive Devices, Coils
$\lambda_p = \lambda_b\pi_C\pi_Q\pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, $T_{HS}$ = 50°C, Rated for 125°C: 0.00045
$\pi_C$: Construction Factor – Fixed: 1.0
$\pi_Q$: Quality Factor – Lower: 20
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality: 12
$\lambda_p$ = 0.108 failures/million hours

### TIP102 Darlington NPN Power Transistor (Quantity – 1)

Failure mode: 6.3 – Transistors, Low Frequency, Bipolar
$\lambda_p = \lambda_b\pi_T\pi_A\pi_R\pi_S\pi_Q\pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, NPN and PNP: 0.00074
$\pi_T$: Temperature Factor, $T_J$ = 77°C: 2.9
$\pi_A$: Application Factor – Switching: 0.70
$\pi_R$: Power Rating Factor, $P_r$ = 1W: 1.0
$\pi_S$: Voltage Stress Factor, $V_s < 0.3$: 0.11
$\pi_Q$: Quality Factor – Lower: 5.5
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality: 9.0
$\lambda_p$ = 0.0074 failures/million hours

### LTV-357T Single Channel Optoisolator (Quantity – 1)

Failure mode: 6.11 – Optoelectronics, Detectors, Isolators, Emitters
$\lambda_p = \lambda_b\pi_T\pi_Q\pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, Phototransistor Output, Single Device: 0.013
$\pi_T$: Temperature Factor, $T_J$ = 50°C: 2.1
$\pi_Q$: Quality Factor – Lower: 5.5
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality: 8.0
$\lambda_p$ = 1.20 failures/million hours

### PIC16(L)F1826/27 (Quantity – 1)

Failure mode: 5.1 – Microcircuits, Gate/Logic Arrays and Microprocessors
$\lambda_p = (C_1\pi_T + C_2\pi_E)\pi_Q\pi_L$ failures/million hours
$C_1$: Microprocessor Die Complexity Failure Rate, 16 bits, MOS – 0.010

$\pi_T$: Load Temperature Factor, Digital MOS/VHSIC CMOS, $T_J$ = 50°C: 0.29
$C_2$: Package Failure Rate, Nonhermetic SMT w/Solder, 18 functional pins: 0.0082
$\pi_E$: Environment Factor, Ground Mobile ($G_M$): 4.0
$\pi_Q$: Quality Factor (best estimate, see MIL-HDBK-217F pgs 5-16): 4.0
$\pi_L$: Learning Factor, ≥ 2.0 years in production: 1.0
$\lambda_p$ = 0.143 failures/million hours

### MCP6242 Rail to Rail OpAmp (Quantity – 1)

Failure mode: 5.1 – Microcircuits, Gate/Logic Arrays and Microprocessors
$\lambda_p = (C_1\pi_T + C_2\pi_E)\pi_Q\pi_L$ failures/million hours
$C_1$: Complexity Failure Rate, MOS Linear, No Transistors 1-100: 0.010
$\pi_T$: Load Temperature Factor, $T_J$ = 50°C: 0.71
$C_2$: Package Failure Rate, Nonhermetic SMT w/Solder, 8 functional pins: 0.0034
$\pi_E$: Environment Factor, Ground Mobile ($G_M$): 4.0
$\pi_Q$: Quality Factor (best estimate, see MIL-HDBK-217F pgs 5-16): 4.0
$\pi_L$: Learning Factor, ≥ 2.0 years in production: 1.0
$\lambda_p$ = 0.083 failures/million hours

### LT1307 DC-DC Switching Regulator (Quantity – 1)

Failure mode: 5.1 – Microcircuits, Gate/Logic Arrays and Microprocessors
$\lambda_p = (C_1\pi_T + C_2\pi_E)\pi_Q\pi_L$ failures/million hours
$C_1$: Complexity Failure Rate, MOS Linear, No Transistors 1-100: 0.010
$\pi_T$: Load Temperature Factor, $T_J$ = 50°C: 0.71
$C_2$: Package Failure Rate, Nonhermetic SMT w/Solder, 8 functional pins: 0.0034
$\pi_E$: Environment Factor, Ground Mobile ($G_M$): 4.0
$\pi_Q$: Quality Factor (best estimate, see MIL-HDBK-217F pgs 5-16): 4.0
$\pi_L$: Learning Factor, ≥ 2.0 years in production: 1.0
$\lambda_p$ = 0.083 failures/million hours

### MCP9700 Linear Thermistor Temp Sensor SOT-23-3 (Quantity – 1)

Failure mode: 5.1 – Microcircuits, Gate/Logic Arrays and Microprocessors
$\lambda_p = (C_1\pi_T + C_2\pi_E)\pi_Q\pi_L$ failures/million hours
$C_1$: Complexity Failure Rate, MOS Linear, No Transistors 1-100: 0.010
$\pi_T$: Load Temperature Factor, $T_J$ = 50°C: 0.71
$C_2$: Package Failure Rate, Nonhermetic SMT w/Solder, 3 functional pins: 0.0012
$\pi_E$: Environment Factor, Ground Mobile ($G_M$): 4.0
$\pi_Q$: Quality Factor (best estimate, see MIL-HDBK-217F pgs 5-16): 4.0
$\pi_L$: Learning Factor, ≥ 2.0 years in production: 1.0
$\lambda_p$ = 0.048 failures/million hours

### 3.3V LDO Voltage Regulator 500mA (Quantity – 1)

Failure mode: 5.1 – Microcircuits, Gate/Logic Arrays and Microprocessors
$\lambda_p = (C_1\pi_T + C_2\pi_E)\pi_Q\pi_L$ failures/million hours
$C_1$: Complexity Failure Rate, MOS Linear, No Transistors 1-100: 0.010
$\pi_T$: Load Temperature Factor, $T_J$ = 50°C: 0.71
$C_2$: Package Failure Rate, Nonhermetic SMT w/Solder, 3 functional pins: 0.0012
$\pi_E$: Environment Factor, Ground Mobile ($G_M$): 4.0

$\pi_Q$: Quality Factor (best estimate, see MIL-HDBK-217F pgs 5-16): 4.0
$\pi_L$: Learning Factor, ≥ 2.0 years in production: 1.0
$\lambda_p$ = 0.048 failures/million hours

### Dual I2C Isolator (Quantity – 1)

Failure mode: 5.1 – Microcircuits, Gate/Logic Arrays and Microprocessors
$\lambda_p = (C_1\pi_T + C_2\pi_E)\pi_Q\pi_L$ failures/million hours
$C_1$: Complexity Failure Rate, MOS Linear, No Transistors 1-100: 0.010
$\pi_T$: Load Temperature Factor, $T_J$ = 50°C: 0.71
$C_2$: Package Failure Rate, Nonhermetic SMT w/Solder, 8 functional pins: 0.0034
$\pi_E$: Environment Factor, Ground Mobile ($G_M$): 4.0
$\pi_Q$: Quality Factor (best estimate, see MIL-HDBK-217F pgs 5-16): 4.0
$\pi_L$: Learning Factor, ≥ 2.0 years in production: 1.0
$\lambda_p$ = 0.083 failures/million hours

# Appendix D: Charger Detailed Failure Analysis

**TDK-Lambda GENH30-25 Power Supply (Quantity – 1)**

5-year warranty provided by manufacturer. With worst case scenario of MTBF = 5 years.
$\lambda_p$ = 22.8 failures/million hours

**Charger Anderson Connector Plug (Quantity – 3)**

Failure mode: 15.1 – Connectors, General (Except Printed Circuit Board)
$\lambda_p = \lambda_b\pi_K\pi_P\pi_E$ failures/million hours
$\lambda_b$: Base Failure Rate, $T_O$ = 70, insert material B – 0.015
$\pi_K$: Mating/Unmating Factor, >50 times /1000 hours – 4.0
$\pi_P$: Active Pins Factor, 6 – 2.0
$\pi_E$: Environment Factor, Ground Mobile ($G_M$), lower quality - 21
$\lambda_p$ = 2.52 failures/million hours