



Reliability Analysis

12 Inch LED Crossing Signal

Models 1607-508-02 and -04

Revision 1.0

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EXECUTIVE SUMMARY

Two versions of a 12 Inch LED Crossing Signal, one with an integrated power supply (model # 1607-508-02) and a second without (model # 1607-508-04), were analyzed using MIL-HDBK-217 as a guide to determine system reliability. Included in this analysis are the 6-LED side lights on each version of the signal. In addition, a field reliability calculation was performed on a previous version of this signal (model # 1607-400), using actual shipping and failure data. It was assumed that this older version of the signal would perform in a similar manner to the new signal (the designs are similar), and thus illustrates how the new signal may be expected to perform in the field.

The failure rate of the 12 Inch LED Crossing Signal with integrated power supply was calculated to be 1.06 failures per million hours, giving a Mean Time Between Failure (MTBF) of 946,022 hours. The version of the signal without the power supply was found to have a failure rate of 0.677 failures per million hours, giving a MTBF of 1.48 million hours.

Using the field data for the 1607-400 signal, the actual failure rate experienced in the field was found to be 0.078 failures per million hours, giving a field MTBF of 12.7 million hours. Since the 1607-400 signal is quite similar to the new signals under analysis, it is assumed that similar field behavior will be exhibited by the new system configuration.

1. INTRODUCTION

This reliability analysis documents the process and results of determining reliability of a Light Emitting Diode (LED) signal product using the methods in MIL-HDBK-217F [2] for component reliability and MIL-STD-756B [1] for system reliability. This document also illustrates a field reliability calculation for a similar signal analyzed herein.

1.1 PURPOSE

The Reliability Analysis identifies the failure rate of the 12 inch LED Crossing Signal along with the failure rates of each of the hardware components comprising the system. In addition, the reliability analysis was performed on two versions of the signal, one with an integrated power supply, and one without. The side light option was included in the analysis of both versions. In addition, a field reliability calculation was performed on the actual historical data of a Rail Development Group (RDG) signal with a similar design. This field reliability analysis is intended to provide some insight into the expected field behavior of the new signals.

1.2 SCOPE

The scope of this document is to define and predict system failures. Specifically, this document details the number of system failures within a lot of n units, each operating in an independent and simultaneous manner. The analysis is limited to the 12 inch LED Crossing Signal (model # 1607-508-02 & 1607-508-04), power supply (if referring to the model with integrated power supply), and side lights. The analysis does not include potential hazards which could occur from faults external to the system.

1.3 DEFINITIONS AND ABBREVIATIONS

LED	Light Emitting Diode
MTBF	Mean Time Between Failures
RDG	Rail Development Group
Parts Stress Analysis	Standard methodology for estimating electronic component failure rate based on component type and quantification of electrical stress experienced by that component while in use.
Chi-Square Distribution	Statistical function which consists of k normal distributions, summed together. Each of the normal distributions has an identical mean and standard deviation. The parameter k is typically referred to as the number of <i>degrees of freedom</i> of the Chi-Square distribution.

1.4 REFERENCES

The following items are referenced in this document or are listed to provide more information on a particular system subject:

- [1] MIL-STD-756B, Reliability Modeling and Prediction
- [2] MIL-HDBK-217F, notice 1, Reliability Prediction of Electronic Equipment
- [3] Miller Felpax Corp, Drawing No. 1607-506-01, "Schematic, 12 Inch Flashing Signal PCB, Power Supply Assembly"
- [4] Miller Felpax Corp, Drawing No. 1607-504-01, "Schematic, 12 Inch Flashing Signal PCB, Side Light Assembly"
- [5] Miller Felpax Corp, Drawing No. 1607-502-02, "Schematic, 12 Inch Flashing Signal PCB, 12 Inch Flashing Signal Assembly"
- [6] Miller Felpax Corp, Drawing No. 1607-508-02, "12 Inch LED Comp. Power Supply & Side Lights"
- [7] Miller Felpax Corp, Drawing No. 1607-508-04, "12 Inch LED Comp. Side Lights, No Power Supply"
- [8] Miller Felpax Corp, Drawing No. 1607-504-01, "12 Inch LED Comp. Side Light Complete"
- [9] Miller Felpax Corp, Drawing No. 1607-506-01, "12 Inch LED Comp. Power Supply Comp."
- [10] Rail Safety Engineering LLC., 12 Inch Flashing Light Signal Reliability Analysis, Document #017-001, Rev. 1.0, June 2000.

1.5 ORGANIZATION OF THIS DOCUMENT

This document consists of four (4) main sections:

- Section 1. Defines the overall purpose, scope, nomenclature, and general reference material for the remainder of the Reliability Analysis.
- Section 2. Defines the analysis methods used and the calculated failure rates of system components.
- Section 3. Describes the field reliability calculation for the 1607-400 signal, a similar device to the signals analyzed in this document.
- Section 4. States conclusions, including overall system reliability and estimated field reliability.

2. COMPONENT RELIABILITY ANALYSIS

2.1 ANALYSIS METHOD

The analysis was conducted on two LED signals (Model #1607-508-02 & 1607-508-04) in accordance with MIL-STD-756B [1], Method 1001, to determine subsystem and system reliability and MTBF. The failure rates of system and subsystem components (such as LEDs, resistors, diodes, etc.) were calculated based on the Parts Stress Analysis method given in MIL-HDBK-217F [2]; these failure rates are utilized throughout the analysis. A synopsis of the component failure rates appears in Table 1, below. For a detailed list of component failure rates see Table A-1, Appendix A.

Table 1. Component Failure Rates

Component Type	Failure Rate (failures/hour)
Resistor (all part numbers)	2.07×10^{-8}
6.8 μ F Capacitor	1.16×10^{-7}
10 μ F Capacitor	1.22×10^{-8}
Rectifier (all part numbers)	3.28×10^{-7}
Surge Protector (Zener Diode)	3.76×10^{-8}
LED	9.94×10^{-9}
Voltage Regulator	3.91×10^{-7}

2.2 FORMAT OF ANALYSIS

In this subsection, the assumptions of the analysis are first defined. Next, the criterion for system failure and the scenarios that can lead to system failure are established. Finally, descriptions of the subsystems that make up the system under analysis are described, along with the quantitative analysis.

2.2.1 Assumptions Made During Analysis

Each component must exhibit the following characteristics:

- Uniformity. Every LED, resistor, diode, rectifier, and capacitor must be statistically identical (within the same part number).
- Independent trials. The success or failure of any component must not affect the outcome of the next trial.
- Constant rate of failure. The rate of failure from one trial to the next must remain constant. (The component must be statistically identical from the first hour it is used to the last.)

Assumptions for the parts stress analysis:

- Ground fixed environment
- Ambient temperature of 30° C (typical of ground fixed environment)
- Electrical stress of 0.5
- Junction temperature of 60° C.

2.2.2 Criterion for Determining System Failure

System failure is defined as an outage (“stuck off”) of at least 20% of the main signal head LEDs (32 or more) OR failure of one of the two side signals.

2.2.3 Scenarios Leading to System Failure

The following scenarios will cause the 1607-508-02 signal to exhibit the criterion for system failure:

- Failure of the power supply
- At least three LED clusters fail (see 2.2.4 for definition of LED cluster)
- At least one side light fails or R1 fails (R1 is the resistor that feeds into the two side lights, see drawing [5]).

The following scenarios will cause the 1607-508-04 signal to exhibit the criterion for system failure:

- Failure of one or both rectifiers
- At least three LED clusters fail
- At least one side light fails or R1 fails (R1 is the resistor that feeds into the two side lights, see drawing [5]).

2.2.4 Subsystem Partitioning and Analysis

There are two LED signals in the 1607-508 product line under analysis. The first of the LED signals to be analyzed is model 1607-508-02, drawing [6]. This signal has an integrated power supply [9], 2 side lights [8], and the main signal head. The second signal to be analyzed is model 1607-508-04, drawing [7]. This model differs only in that it makes use of an internal rectifier, instead of the integrated power supply.

To determine the component reliability of each of the two LED signals, the circuit design of each LED signal subsystem must first be analyzed to determine the points of failure that have the most impact on reliability. To complete this task, each subsystem schematic was reviewed and a primary point of failure defined for each of the subsystems mentioned in the failure scenarios of Section 2.2.3. The subsystems considered in this analysis and their primary points of failure are determined to be as follows:

- LED cluster – The main signal head of both configurations, as determined from drawing [5], is made up of thirteen clusters of twelve LEDs, with each of the LED clusters in parallel and fed by a resistor. Each LED cluster is configured as three sets of four LEDs; each set of four is in series with the others, while each set consists of four LEDs in parallel. In order for the LED cluster to fail, it is assumed that either the cluster resistor must fail, or all four LEDs in one of the three sets must fail, disabling the remainder of the cluster.
- Rectifier – The rectifier, found on drawing [5], is an integrated component used only with the 1607-508-04 signal design. The rectifier is made up of four diodes within its component package. It is assumed that when any one of the four diodes within the rectifier fails, the signal head will be disabled.
- Power Supply – The power supply, used only with the 1607-508-02 signal, is made up of several components connected in parallel and series as determined from drawing [3]. It is assumed that if any of the power supply components fail, the power supply will cease to function, disabling the signal head.
- Side Light – The side light used in both configurations, as determined from drawing [4], consists of six LEDs, the same as those LEDs found on the main signal head. The LEDs are configured as three pairs of diodes, each pair in series with the others. The LEDs in each pair are parallel with one another. In order for the side light to fail, both of the LEDs in one or more pairs must fail, or the single resistor that feeds voltage into both side lights must fail.

2.2.5 Results of the Component Reliability Analysis

Based on the configuration of the various subsystems, described above, and the component failure rates from Table 2, the subsystem failure rates are shown below in Table 2. For a detailed description of the subsystem failure rate calculations, see Table A-2, Appendix A.

Table 2. Subsystem Failure Rates

Subsystem Description	Failure Rate (failures/hour)
Side Light	5.92×10^{-16}
Power Supply (1607-508-02 only)	1.04×10^{-6}
LED Cluster (including feed resistor)	2.07×10^{-8}

Based on these subsystem failure rates and the failure rates of the three failure scenarios defined in Section 2.2.3, the overall system failure rates are shown below in Table 3 and Table 4. For a detailed description of the overall failure rate calculations for both LED signal configurations, see Table A-2, Appendix A.

Table 3. Scenario and Overall Failure Rate for 1607-508-02

Description	Failure Rate (failures/hour)
Scenario 1 (Power Supply)	1.04×10^{-6}
Scenario 2	2.54×10^{-21}
Scenario 3	2.07×10^{-8}
Overall System (1607-508-02)	1.06×10^{-6}

Table 4. Scenario and Overall Failure Rate for 1607-508-04

Description	Failure Rate (failures/hour)
Scenario 1 (At least one rectifier fails)	6.57×10^{-7}
Scenario 2	2.54×10^{-21}
Scenario 3	2.07×10^{-8}
Overall System (1607-508-04)	6.77×10^{-7}

3. FIELD RELIABILITY ANALYSIS

In this section, a description of the statistical reliability calculation for the 1607-400 LED signal is given. This calculation is based on time of service and failure data from sources in the field. Since the MIL-HDBK-217 [2] calculation for failure rate is typically very conservative, and the design of the 1607-400 LED signal is similar to the two new configurations, analysis of the 1607-400 LED signal should give some insight into the expected field behavior of the 1607-508-02 and 1607-508-04 signals.

3.1 ANALYSIS METHOD

For the Field Reliability calculation, field data regarding dates and quantities of shipped units and units returned due to failure are analyzed to find the empirical failure rate of the system. The shipping data is analyzed and used to determine the total number of hours of service provided by the system under analysis. The number of failures observed in the field are totaled and then fed into the statistical analysis. Finally, the shipping data and failure data are used as parameters into a Chi-Square distribution to determine the failure rate experienced in the field. The failure data is used as the number of degrees of freedom in the Chi-Square distribution. The data provided is tabulated in Table 5.

Table 5. Field Reliability Data

Data Item	Model #	2001	2002	2003	2004	2005	2006	Total
Shipment – Units	1607-400	5,050	5,264	6,472	4,072	3,674	2,800	27,332
	4607-400		276	819	8	2		1,105
Total Units		5,050	5,540	7,291	4,080	3,676	2,800	28,437
Returns	both			2	16	4		22

3.2 ASSUMPTIONS MADE DURING ANALYSIS

In order to more accurately represent the actual conditions in the field, a few assumptions were made to support the field reliability calculation, as follows:

- Since the shipment data is given by year, shipments were uniformly distributed over the twelve months in each year, with the 2006 shipments spread over January through July.
- Two separate sets of signal data were provided; based on feedback received, those data sets were lumped together.
- A six month delay was imposed between the ship date and start of service time. This represents unpacking, inspecting for damage, and getting the units installed in the field.
- The number of failures was increased by 50% to account for underreporting.

3.3 RESULTS OF FIELD RELIABILITY CALCULATION

The shipping data, after analysis, yielded 531 million hours of service from units in the field since 2001. The 22 failures, after the 50% correction factor was used, yielded 68 degrees of freedom for the Chi-Square distribution. Based on these inputs, the statistical analysis yields a field failure rate of 0.078 failures per million hours, which equates to a field MTBF of 12.7 million hours. See Appendix B, Tables B-1 and B-2, for details.

Due to the fact that the 1607-508 series signals are designed similar to the 1607-400 series signal but with greater reliability in mind (with series-parallel combinations of LEDs, etc), it is reasonable to expect that the actual failure behavior in the field with the new signal will be similar to that of the 1607-400 series signal, analyzed in this section. However, due to such factors as differing operating profiles and/or installation environments, this expectation cannot be certain.

4. ESTIMATION OF SYSTEM RELIABILITY AND CONCLUSIONS

Based on the calculations in Section 2, the 1607-508-02 signal was determined to have a failure rate of 1.06×10^{-6} failures/hour and the 1607-508-04 signal was determined to have a failure rate of 6.77×10^{-7} failures/hour. These failure rates yield the MTBF values listed in Table 6 below.

**Table 6. Final MTBF for the
1607-508-02 & 1607-508-04 Signals**

Signal Type	MTBF (hours)
1607-508-02	946,022
1607-508-04	1,476,363

Based on the field reliability calculation summarized in Section 3.3, the 1607-400 signals are an order of magnitude more reliable than what the MIL-HDBK-217 analysis shows for the 1607-508 series signals. This is to be expected, as the MIL-HDBK-217 analysis tends to be more conservative than field reliability data, even when accounting for design details as was done in Section 2. The expectation would be the same for field reliability of the new signals, perhaps showing even superior performance.

Note that once the new signals have been in the field for some time (at least long enough to accumulate significant service time and perhaps some failures), it would be beneficial to analyze the field data for the 1607-508 series signals to achieve a more accurate estimate of the field failure rate.

APPENDIX A – MIL-HDBK-217 CALCULATIONS

In this appendix, the component and subsystem failure rates used to determine component reliability are illustrated in Table A-1 as well as Table A-2.

The following table illustrates the components used in the two LED signal models and their associated failure rates. In each row, the part number and its final failure rate are listed, along with all the parameters selected for the calculation from the handbook.

Table A-1. Detailed Component Failure Rates

RESISTORS AND CAPACITORS										
Part Number	Type	Section	Final Failure Rate	Base Failure rate	πR	πQ	πE	Notes		
B0207C61K0F5T	Resistor	9.1	2.07E-08	4.60E-10	1	15	3			
B0207C15K00F5T	Resistor	9.1	2.07E-08	4.60E-10	1	15	3			
R25G 000T	Resistor	9.1	2.07E-08	4.60E-10	1	15	3			
5073NW39R00J	Resistor	9.1	2.07E-08	4.60E-10	1	15	3			
Part Number	Type	Section	Final Failure Rate	Base Failure rate	πCV	πQ	πSR	πE	Notes	
199D685X9035D1V1	Capacitor	10.12	1.16E-07	1.40E-08	1.258639	10	0.33	2	6.8	microFarads
199D106X9035D2B1	Capacitor	10.12	1.22E-07	1.40E-08	1.318257	10	0.33	2	10	microFarads
DIODES										
Part Number	Type	Section	Final Failure Rate	Base Failure rate	πT	πS	πC	πQ	πE	Notes
KBL01	Rectifier (4 diodes)	6.1	3.28E-07	3.00E-09	3	0.19	1	8	6	Plastic body
GBU8B	Rectifier (4 diodes)	6.1	3.28E-07	3.00E-09	3	0.19	1	8	6	Plastic body
CG 75L	Surge Protector (Zener Diode)	6.1	3.76E-08	2.00E-09	3	0.19	1	5.5	6	
LED										
Part Number	Type	Section	Final Failure Rate	Base Failure rate	πT	πQ	πE			
LC503 AHR2-30Q-A	LED	6.11	9.94E-09	2.30E-10	2.7	8	2			
INTEGRATED CIRCUITS										
Part Number	Type	Section	Final Failure Rate	Base Failure rate	πT	πA	πR	πS	πQ	πE
SPX29302AU5-L	Voltage Regulator (16 Transistors)	6.3	3.91E-07	7.40E-10	2.1	0.7	3.240993496	0.21	5.5	6

The following table illustrates the subsystem calculations, an intermediate step for determining the system failure rate. In addition, this table illustrates the final MTBF calculations based on the results found for each subsystem.

Table A-2. Detailed MBTF Calculations

SUBSYSTEM CALCULATIONS					
Subsystem	Component	Comp Failure Rate			
Power Supply	B0207C61K0F5T	2.07E-08			
	B0207C15K00F5T	2.07E-08			
	199D685X9035D1V1	1.16E-07			
	199D106X9035D2B1	1.22E-07			
	KBL01	3.28E-07			
	SPX29302AU5-L	3.91E-07			
	CG 75L	3.76E-08			
Power Supply Failure Rate (series):		1.04E-06	failures/hour		
Side Light	LC503 AHR2-30Q-A	9.94E-09			
	Side Light Failure Rate: (one of three pairs must fail)		5.92E-16	failures/hour	

Table A-2. Detailed MBTF Calculations (Continued)

FINAL CALCULATIONS					
Model#	Subsystem	Failure Rate	No. of Units	Failure modes	Notes
1607-508-02	LC503 AHR2-30Q-A	9.94E-09	156		
	Side Light	5.92E-16	2	1	Power supply failure
	Power Supply	1.04E-06	1	2	Three LED Clusters fail
	R25G 000T	2.07E-08	14	3	One Side Light Failure or R1 fails
	LED Cluster (12 LED + Resistor)	2.07E-08	13		
	Failure rate of failure mode 1	1.04E-06			
	Failure rate of failure mode 2	5.25E-28			
	Failure rate of failure mode 3	2.07E-08			
	Total Failure Rate	1.06E-06			
	MTBF	946,022	hours		
Model#	Subsystem	Failure Rate	No. of Units	Failure modes	Notes
1607-508-04	LC503 AHR2-30Q-A	9.94E-09	156		
	Side Light	5.92E-16	2	1	Rectifier failure
	GBU8B	3.28E-07	2	2	Three LED Clusters fail
	5073NW39R00J	2.07E-08	14	3	One Side Light Failure or R1 fails
	LED Cluster (12 LED + Resistor)	2.07E-08	13		
	Failure rate of failure mode 1	6.57E-07			
	Failure rate of failure mode 2	5.25E-28			
	Failure rate of failure mode 3	2.0700E-08			
	Total Failure Rate	6.77E-07			
	MTBF	1,476,363	hours		

APPENDIX B – FIELD RELIABILITY CALCULATIONS

Table B-1. Field Service Time

Batch	No. of Signals	Net Signals (removing 10% for spares)	Ship Date	Service Start Date	Calc Date	Service Time (days)	Service Time (hours)	Batch Service Time (hours)
2001	5,050	4545	7/15/2001	1/15/2002	8/1/2006	1603	38,472	174,855,240
2002	5,540	4986	7/15/2002	1/15/2003	8/1/2006	1252	30,048	149,819,328
2003	7,291	6561	7/15/2003	1/15/2004	8/1/2006	901	21,624	141,875,064
2004	4,080	3672	7/15/2004	1/15/2005	8/1/2006	549	13,176	48,382,272
2005	3,676	3308	7/15/2005	1/15/2006	8/1/2006	198	4,752	15,719,616
Jan 2006	400	360	1/15/2006	7/15/2006	8/1/2006	17	408	146,880
Feb 2006	400	360	2/15/2006	after 8/1/2006	8/1/2006	0	0	-
Mar 2006	400	360	3/15/2006	after 8/1/2006	8/1/2006	0	0	-
Apr 2006	400	360	4/15/2006	after 8/1/2006	8/1/2006	0	0	-
May 2006	400	360	5/15/2006	after 8/1/2006	8/1/2006	0	0	-
Jun 2006	400	360	6/15/2006	after 8/1/2006	8/1/2006	0	0	-
Jul 2006	400	360	7/15/2006	after 8/1/2006	8/1/2006	0	0	-
							Total Accumulated Service Time:	530,798,400 hours

Table B-2. Field Reliability

Wayside Device	Units in Service	Total Service Time (TST), hours	Total Observed Failures, f	Deg Freedom, $n=2*(f+1)$	Chi-Square (Alpha,n)	Failure Rate, fails/hour = $CS / (2*TST)$	MTBF, hours = $1 / FR$
1607-400 Signal	28,437	530,798,400	33	68	83.3079	7.8474E-08	12,743,050