



## Luminary Micro Inc.

### ***RMA FAILURE ANALYSIS REPORT***

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<b>Customer:</b>	Individual FRC Teams	<b>RMA #:</b>	Multiple
<b>Product #:</b>	MDL-BDC (Jaguar)	<b>Report Date:</b>	4/13/09
<b>Return Qty:</b>	136	<b>Author:</b>	Scott Emley

## 1 Executive Summary

In June 2008, FIRST selected Luminary Micro to design and supply the next generation speed controller, MDL-BDC (Jaguar) module, for the upcoming FRC2009 official Kit of Parts (KoP). Since production units began shipping to FIRST in October 2008, and as of April 7, 2009, Luminary Micro has sold over 9,000 MDL-BDC units directly to FIRST and through Luminary Micro's distribution channels.

The MDL-BDC (Jaguar) module is designed for accurate and smooth speed control in industrial environments; designed to meet FIRST's specifications for the current competition year and also including features that FIRST can unveil in future competition years. To date, Luminary Micro has received 187 reports of MDL-BDC failures from FRC teams, all of which Luminary Micro has promptly replaced so that teams can continue their respective build and competition seasons with minimal interruption. Of those 187 MDL-BDC units that Luminary Micro replaced, Luminary Micro has received 136 returned units from FRC teams for failure analysis which showed the following results:

- 131 of the 136 returned units are legitimate failures.
- The total validated failure rate for MDL-BDC is 1.4% of all units sold.

While there were several types of failure reports, the most common failure reported was a loss of control in the forward direction (representing over 40% of all specific reported issues). Failure analysis of all units concluded that over 70% of units returned for examination exhibited a failure of the U6 and/or U7 gate driver, sometimes in addition to other components. One probable cause of the gate driver(s) failure can be attributed to a variety of factors, including inadvertent misuse (for example, temporarily mis-wiring the MDL-BDC Jaguar unit or accidental swarf causing a short) and potential ESD vulnerability of the MDL-BDC design. Luminary Micro makes several recommendations to users on how to mitigate risk of U6 and/or U7 gate driver failures, as well as other failures analyzed in this report. Finally, Luminary Micro has identified potential design improvements for future revisions of the MDL-BDC Jaguar design.

For more information on the MDL-BDC Jaguar, see the Luminary Micro web site:

<http://www.luminarymicro.com/jaguar> and  
<http://www.luminarymicro.com/products/mdl-bdc.html>.



## 2 Customer Failure Reports

This section describes the failure reports received from individual FRC teams and groups them into similar categories. Since the launch of the MDL-BDC (Jaguar), Luminary Micro has sold 9,083 units and has replaced 187 units. Of the 187 units that Luminary Micro has replaced, Luminary Micro has retrieved 136 units back from FRC teams for failure analysis. Of the 136 units received back, Luminary Micro has deemed 131 units have legitimately failed for various plausible reasons, including misuse. Therefore, the analyzed legitimate failure rate of MDL-BDC Jaguars is approximately 1.4% (131 / 9,083) of all Jaguars sold.

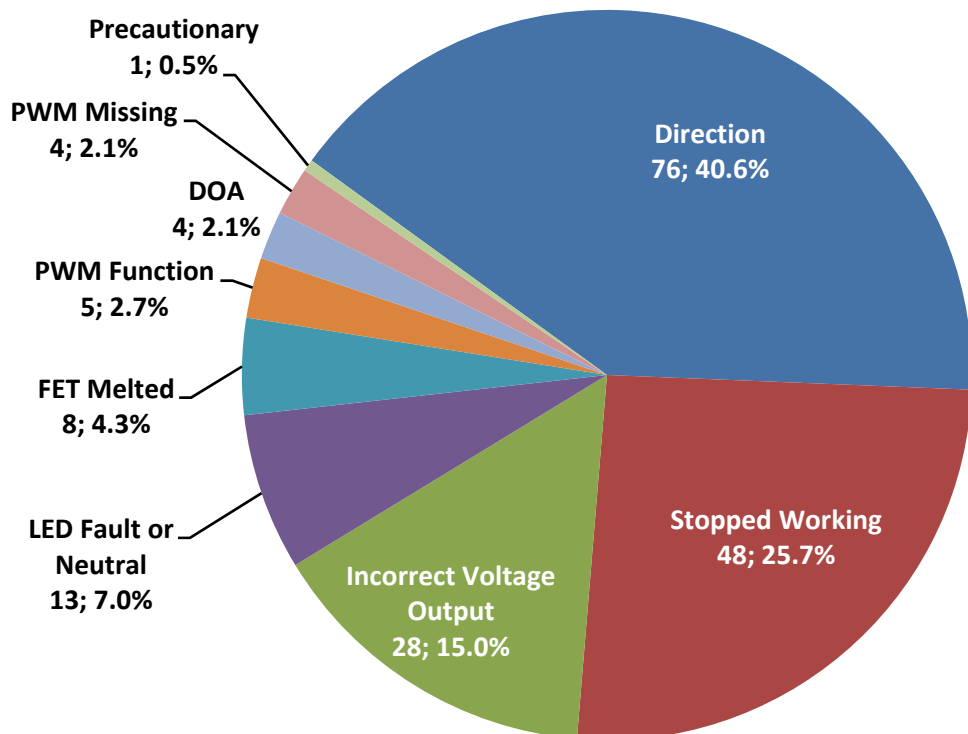
### 2.1 Summary of Failure Reports

- **Direction:** The report is that the Jaguar module only works in one direction (usually the reverse direction) although there are some instances of Jaguar modules only working in the forward direction. Reports indicate that the failures mostly occur “unexpectedly” after some minutes or hours of “working just fine”. In some case, a slight burning smell was also reported.
- **Stopped Working:** Most instances reporting a MDL-BDC that “stops working” are similar to the “Direction” issue, except that the MDL-BDC does not work in either direction. In some cases, this issue also included “smoke” or “burning”.
- **Incorrect Voltage Output:** Report of an unexpected voltage output at the motor terminals.
- **LED Fault or Neutral:** LED indicates a fault condition at power-up – or LED would not light up at all.
- **FET Melted:** A catastrophic failure report included significant smoke, a burning smell, and slight-to-significant warping of the plastic ring inside of the MDL-BDC main enclosure. One or more of the MDL-BDC’s MOSFETs are usually visibly destroyed.
- **PWM Function:** Reports indicate a problem with the PWM function, such as the MDL-BDC driving a motor without a PWM command signal.
- **DOA:** The MDL-BDC does not power up.
- **PWM Missing:** Reports that the PWM “servo” connector is not populated on the MDL-BDC, indicating a manufacturing process flaw.
- **Precautionary:** Failure report did not describe a legitimate issue, but indicated that the MDL-BDC was “acting up” and wanted to replace the Jaguar module to prevent any possible issues.



# MDL-BDC RMA FA REPORT

## 2.2 Summary of Failure Reports



Reported Failure	Count	Percent of Total
Direction	76	40.6%
Stopped Working	48	25.7%
Incorrect Voltage Output	28	15.0%
LED Fault or Neutral	13	7.0%
FET Melted	8	4.3%
PWM Function	5	2.7%
DOA	4	2.1%
PWM Missing	4	2.1%
Precautionary	1	0.5%



## 3 Failure Analysis Summary

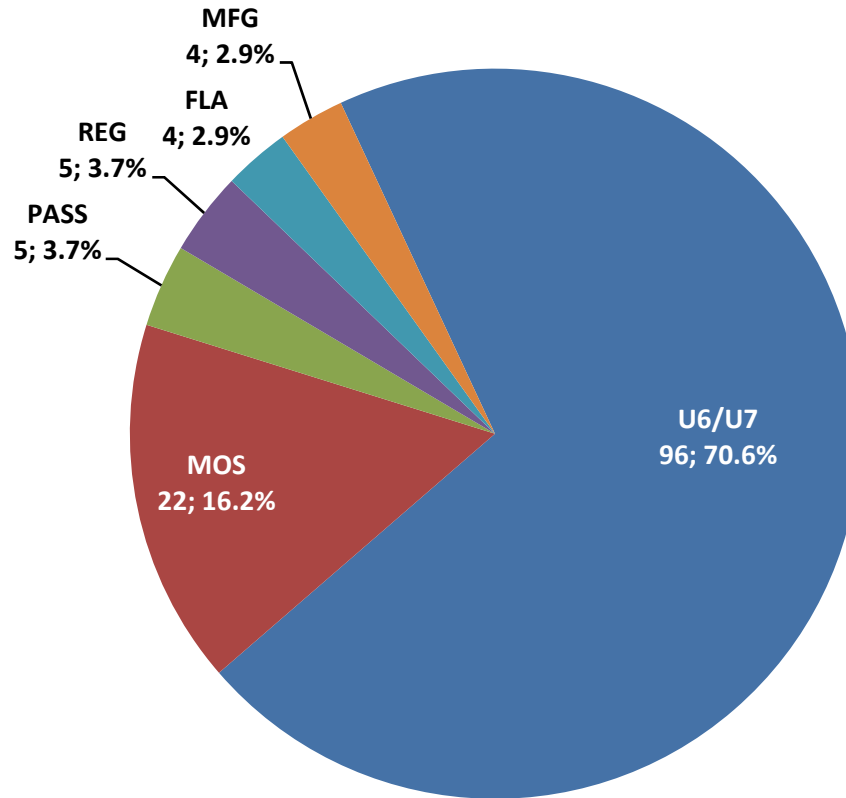
This section summarizes the failure analysis completed on each of the 136 units returned to Luminary Micro by placing failures into related categories and correlating back to the original failure reports received.

### 3.1 Failure Analysis Categories

- **U6/U7:** Gate Driver U6 and/or U7 is malfunctioning or is destroyed.
- **MOS:** Excessive heat is evident in one or more MOSFETs.
- **REG:** 5 V Regulator (U4) is malfunctioning or is destroyed.
- **PASS: Returned** MDL-BDC unit passes all functionality and quality tests.
- **FLA:** Flash memory is incorrectly programmed on MDL-BDC, indicating a program test escape.
- **MFG:** MDL-BDC is missing PWM “servo” connector, indicating a manufacturing test escape.



## 3.2 Summary of Failure Analyses



Failure Analysis Category	Count	Percent of Total
U6/U7	96	70.6%
MOS	22	16.2%
PASS	5	3.7%
REG	5	3.7%
FLA	4	2.9%
MFG	4	2.9%



## 3.3 Simple Correlation of Failure Analyses to Reported Customer Issues (Count)

<b>Direction</b>	<b>52</b>
MOS	3
U6/U7	49
<b>DOA</b>	<b>3</b>
FLA	1
PASS	1
REG	1
<b>FET melted</b>	<b>7</b>
MOS	3
U6/U7	4
<b>Incorrect Voltage Output</b>	<b>26</b>
FLA	1
MOS	7
U6/U7	18
<b>PWM Missing</b>	<b>4</b>
MFG	4

<b>LED Fault or Neutral</b>	<b>8</b>
FLA	1
MOS	2
REG	1
U6/U7	4
<b>PWM Function</b>	<b>2</b>
PASS	1
U6/U7	1
<b>Stopped Working</b>	<b>34</b>
FLA	1
MOS	7
PASS	3
REG	3
U6/U7	20



## 4 Failure Mechanisms and Preventive Actions

This section describes the possible failure mechanisms for the various MDL-BDC failure categories.

### 4.1 Detailed Description of Proposed Failure Mechanisms

- **ESD (ESD):** The MDL-BDC module was designed with ESD protection on all I/O lines. However, Luminary Micro has determined there is vulnerability on the motor output terminals. All terminals should pass an 8 kV air-discharge test. In our testing, the negative (with respect to the 0 V terminal) may fail at lower levels. Typically, the gate driver is the root cause of failure under these conditions. Preventive measures include the use of ESD-safe packaging and handling stations as well as taking precautions to ensure that any moving equipment does not accumulate static. Future designs will include additional ESD protection on the power and motor terminals.
- **Gate Driver (GDR):** A latch-up event in the gate driver (U6 or U7) results in simultaneous conduction through high-side and low-side MOSFETs. The low-side MOSFET often fails first in a low-impedance state. The user typically observes either continuous excessive current draw or high-current draw whenever the unit tries to run a motor. Circuit design modifications are needed to correct this failure mode.
- **Reversed Power During Testing (RPP):** Luminary Micro conducted an additional power-on test prior to shipment. In a few cases, the power connections to the unit under test were reversed. The unit appears to operate normally until the motor run takes place, at which time damage to the gate drivers (U6 and/or U7) become apparent. Corrective action has been taken to ensure that test equipment cannot damage the unit under test.
- **Contract Manufacturer Test Escape (ESC):** Some MDL-BDC units were shipped from the manufacture that had not properly completed the automated Factory Acceptance Test. These units had blank or partially programmed microcontroller memories. The units will function correctly if they are re-run through the tester. Corrective action has been taken to ensure completion of the FAT before any modules are shipped from the manufacturer.
- **Voltage regulator Failure (REG):** Failures of the 3.3 V or 5.0 V linear regulator could be due to one of two conditions. The most likely root cause is excessive current draw from the power rail at the interface connector. The regulator is specified to shut down internally under these conditions; however, our testing has shown that this regulator feature does not work correctly. The second possible root cause is input over-voltage. The regulators have a maximum input voltage of 15 V, which is reflected in the absolute maximum rating of the Jaguar module. Bench tests have shown that the regulators function beyond 15 V with no degradation or failures at less than 17 V. Although there is no measured data showing DC supply voltages greater than 15 V, there is speculation that the supply could exceed this under certain regenerative conditions. Efforts to replicate this failure on the bench using a motor in full-regeneration were



unsuccessful. Despite lack of correlation with bench testing, this is the only reasonable explanation for certain regulator failures, and because of the range of installations, not every condition can be reasonably replicated. Luminary Micro will use a regulator with an increased voltage range and functional over-current protection in future revisions of this design.

- **Metal Debris (MET):** Even small amounts of metal debris (or swarf) inside the MDL-BDC module will cause catastrophic failure – either immediately or over time as the debris shifts. Metal debris is clearly evident in several failed units returned from the field. Two possible sources of the debris have been identified. The first source is external debris that results from machining operations in the vicinity of the MDL-BDC module control or machined parts that have not been cleaned properly before installation. Entry points include the fan intake, terminal areas, and exhaust vents. The second source of debris is the captive terminal screws. If the screws are completely removed or if the thread is crossed, small strands or flakes of metal are dislodged from the body of the terminal. Using spade terminals so that the screws do not need to be removed is the best way to prevent this. Future designs will consider barrier options to reduce the risks presented by debris. Until then, teams should use caution when machining metal parts where it is possible for swarf to fall into the MDL-BDC module.
- **Misuse (MIS):** Most misuse involves incorrect power wiring – either reversed input polarity or transposing motor and power sources. Either configuration results in catastrophic failure. If the motor and power sources are transposed, the unit will power up normally because the power MOSFETs act as a full-bridge rectifier. Failure will occur either immediately when any motor run command is issued or eventually over prolonged use.
- **Via Failure (VIA):** In order to meet Removal of Hazardous Substances (RoHS) requirements, the MDL-BDC was assembled using lead-free solder. Lead-free solder does not flow as well as leaded solder, occasionally resulting in through-holes in the PCB with minimal solder flow during wave soldering. Due to the way lead-free solder flows, visual inspection is not capable of determining whether all MOSFET vias are fully “plugged” with solder. On some MOSFETs, the plating inside the via may only be marginally sufficient to carry full-load current. Under these conditions the via will fail, resulting in an open circuit. Some open circuits will cause side-effect failures. Luminary Micro will make design improvements to address this issue in future revisions of the MDL-BDC design.

In addition to the failure categories detailed in this RMA report, Luminary Micro has also identified a possible thermal runaway in the MDL-BDC’s low-side body diode of the power MOSFETs. Due to the size of the MOSFET, the forced-air cooling, and integrated over-temperature protection, this condition has not been shown to cause catastrophic failure under normal operating conditions. Luminary Micro has not been able to link thermal runaway to any MDL-BDC units returned for failure analysis.





# MDL-BDC RMA FA REPORT

## 4.2 Summary of Simple Failure Mechanism Correlation and Preventive Actions

Failure	Failure Mechanism(s)	Symptoms	Visual	Preventive Action
<b>U6/U7</b> MDL-BDC Gate Driver U6 and/or U7 is damaged or destroyed	<ul style="list-style-type: none"> <li>• ESD</li> <li>• RPP</li> <li>• MET</li> <li>• MIS</li> <li>• VIA</li> </ul>	<ul style="list-style-type: none"> <li>• MDL-BDC likely powers up</li> <li>• Only drives in one direction (usually reverse)</li> <li>• Driving in a direction sometimes causes a fault</li> </ul>	<ul style="list-style-type: none"> <li>• Potentially no visual indication</li> <li>• Analysis shows U6 will have hard short from Pin 1 (boot) to GND</li> <li>• The following might be damaged in addition to U6: U7, R15, D7, MOSFETs, potential via fuse</li> </ul>	<ul style="list-style-type: none"> <li>• Take ESD precaution when handling robot (for example, ground yourself before handling your robot, avoid sliding robot on ground/regolith, etc.)</li> <li>• Avoid positioning modules for direct impact or ESD vulnerability during competition</li> <li>• Mitigate risk for swarf (for example, do not use ring terminals; take extreme precaution when creating metal debris)</li> <li>• Avoid excessive voltage to the Jaguar voltage terminals</li> </ul>
<b>FLA</b> MDL-BDC Flash is mis-programmed	<ul style="list-style-type: none"> <li>• ESC</li> </ul>	<ul style="list-style-type: none"> <li>• No LED response at power up</li> <li>• No motor control functionality evident after power up</li> </ul>	<ul style="list-style-type: none"> <li>• No LED</li> <li>• Power rails okay</li> </ul>	<ul style="list-style-type: none"> <li>• Return affected modules to Luminary Micro for replacement</li> </ul>
<b>MFG</b> MDL-BDC is missing a PWM servo connector	<ul style="list-style-type: none"> <li>• ESC</li> </ul>	<ul style="list-style-type: none"> <li>• PWM cable cannot connect to MDL-BDC's PWM (servo) connection</li> </ul>	<ul style="list-style-type: none"> <li>• Female connector inside "SERVO" interface is missing/not populated.</li> </ul>	<ul style="list-style-type: none"> <li>• Return affected modules to Luminary Micro for replacement</li> </ul>
<b>MOS</b> Excessive heat in MDL-BDC MOSFET(s)	<ul style="list-style-type: none"> <li>• GDR</li> <li>• MET</li> <li>• MIS</li> </ul>	<ul style="list-style-type: none"> <li>• Excessive current draw by MDL-BDC</li> </ul>	<ul style="list-style-type: none"> <li>• Single low-side MOSFET melt-down with damage to plastic ring</li> <li>• Possible blown or fractured PCB traces</li> </ul>	<ul style="list-style-type: none"> <li>• Mitigate risk for swarf (for example, avoid using ring terminals; take extreme precaution when creating metal debris)</li> <li>• Avoid positioning module for direct impact vulnerability during competition</li> </ul>
<b>REG</b> MDL-BDC 5 V regulator is damaged or destroyed	<ul style="list-style-type: none"> <li>• REG</li> </ul>	<ul style="list-style-type: none"> <li>• No LED response at power up</li> <li>• No motor control functionality evident after power up.</li> </ul>	<ul style="list-style-type: none"> <li>• No LED</li> <li>• Power rails not okay</li> </ul>	<ul style="list-style-type: none"> <li>• Do not draw excess current from +3 V or +5 V pins</li> <li>• Ensure that regeneration does not exceed ratings</li> </ul>



## 5 Failure Analysis Conclusion

Luminary Micro appreciates the FIRST community's response to the company's call-to-action to promptly return MDL-BDC units that have experienced a perceived failure. Luminary Micro concludes that, while specific vulnerabilities have been identified in the MDL-BDC module design, users can significantly reduce risk of failure by taking certain precautions in handling the MDL-BDC module and the devices to which the MDL-BDC module is attached.

### Conclusion:

- 131 of the 136 returned units are legitimate failures.
- The total validated failure rate for MDL-BDC is 1.4% of all units sold.
- The most common issue reported was a loss of control in the forward direction (representing over 40% of all specific failure reports).
- Failure analysis of all units concluded that over 70% of units returned for examination exhibited a failure of the U6 and/or U7 gate driver, sometimes in addition to other components.
- The probable cause of the gate driver(s) failure can be attributed to a variety of factors, including inadvertent misuse (such as temporarily mis-wiring the MDL-BDC Jaguar unit or accidental swarf causing a short) and potential ESD vulnerability of the MDL-BDC design.

Luminary Micro makes several recommendations to users on how to mitigate risk of U6 and/or U7 gate driver failures, such as (1) Taking ESD precaution when handling your robot (e.g. ground yourself before handling your robot, avoid purposely sliding your robot on the ground/regolith, etc.), (2) Positioning MDL-BDC units such that they are not vulnerable for direct impact or ESD during competition, (3) Mitigating risk for swarf (e.g. avoid using ring terminals; take extreme precaution when creating metal debris), and (4) Avoiding excessive voltage to the Jaguar voltage terminals.

Luminary Micro is dedicated to providing excellent customer service for the FIRST competition and the individual FRC teams. As a FIRST Platinum Supplier and committed to FIRST's concept of Gracious Professionalism, we will continue to innovate and support FIRST and the FIRST community with respect to the MDL-BDC module – and any other Luminary Micro product that may be used in the competition.

For questions regarding this report, please contact our technical support team at [support@luminarymicro.com](mailto:support@luminarymicro.com).



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