Arctic Spyder III G1 - 1W Blue Hand Held Laser
Power Input Circuit Analysis and Failure Discussion.

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The WickedLasers Arctic Spyder III G1 - 1W Blue Hand Held Laser is a truly revolutionary product. It is quite clever in both concept and construction. However, there have been reports of numerous early failures of some of these units. Here we will analyze part of the Laser Diode Driver circuit of these lasers, and identify some of the issues that may be leading to early failures. Note that the Arctic G2 is an upgraded version of the G1 laser. It is possible that currently shipping G2 models may have already addressed some or all of the issues discussed here.

Motivation for this article stems from the fact that the author would rather not ship a failed laser to China for repair or replacement. WickedLasers has not been willing to provide schematics or replacement parts. (WickedLasers has provided warranty replacement lasers to customers who return defective units.) The analysis below is done as both an exercise in reverse engineering, as well to help those that are unwilling or unable return their Arctic laser for repair.

Note: The analysis that follows only details the power input circuitry, or approximately half of the laser driver board. In short, the remaining circuity seems to be a fairly straight forward laser diode driver based on an LM358 Dual OP AM, driving a 2SD882 NPN Transistor (via a intermediate driver transistor), which in turn, drives the actual laser diode. A reference is provided by an SC431L shunt regulator diode. Actual analysis of the laser drive circuit may be addressed in a future article if such is warranted by demand or future failure.

There is an excellent article at:
http://www.repairfaq.org/sam/laserdps.htm
on Laser Diode driver circuits.

Dissembling the Arctic Laser is not recommended or detailed here. Due to the way that it is constructed, once disassembled, the Arctic Spyder III laser cannot be re-assembled as originally designed. The circuitry of the Spyder III laser relies on Surface Mount Technology (SMT). Replacement of electronic components in this device requires specialized soldering equipment and techniques. In addition to the inherent danger of a laser of this power, inadvertent movement of the laser beam is more likely if the laser is operated while it is disassembled. This would result in increased likelihood of direct, reflected, or diffuse laser energy causing injury including permanent blindness.

The basic electrical components of the G1 Lasers include the Laser Diode, the driver board, a battery meter board, the battery, and a tail switch. The tail switch assembly consists of the actual switch as well as several contacts that constitute a simple lock-out system. Postings on various forums have suggested that some of the same failure symptoms discussed in this article can also be caused by poor contact in the tail switch assembly.

The battery negative terminal (spring) is directly soldered to the power driver board inside the main tube of the G1. The wire that forms the spring provides the only physical support for the board. The other end is suspend inside the tube. Positive voltage from the battery passes through the tail switch and then through the case to the separate battery meter board. Contact between a solder "blob" on the bottom of the meter board and the tube is maintained by a spring. A wire carries the positive voltage from the meter board to the driver board. Another wire connects from the negative pad on the power board to the meter board to provide reference for battery measurement.

If you are concerned that the case is connected to the positive (+) battery terminal, consider that "ground" on a hand-held device is relative. If it makes you feel better, assume that the case is at 0 volts reference, and the laser driver circuitry actually runs on minus (-)3.7 Volts. Either way of looking at it is just as valid.

It appears that after the driver board was designed, it was realized that the circuit was susceptible to damage from the user inserting the battery the wrong way. The Arctic has no physical means of preventing the battery from being installed the wrong way. Furthermore, the design of the 18650 Li-Ion battery used in this device would make any practical means of preventing incorrect battery installation impossible. For these reasons, a SMT P-Channel MOSFET (Metal Oxide Semiconductor Field Effect Transistor) was tacked across the main input (+) and (-) pads on the driver board, with it's drain suspended off the board. The positive lead (from the battery meter board) was directly hand-soldered to the drain of this SMD (Surface Mount Device) component.

There is an informative article here:
http://focus.ti.com/general/docs/lit/getliterature.tsp?baseLiteratureNumber=SLVA139&fileType=pdf
Explaining the use of a MOSFET to provide reverse battery protection.

The part number of this protection P-Ch MOSFET is not known at the present time, but it is very likely to be the Vishay Si2323 described in the referenced article or an equivalent part.

There are several problems with this "fix". First, the tiny SMD MOSFET must carry the full battery current when the device is operation. It is likely that it does not have sufficient margins for this application. A larger, higher "on" current device should have been used. Secondly, mounting it in this fashion is not acceptable. SMT, when done properly, results in extremely durable products, with even common consumer devices sometimes meeting or exceeding aerospace industry specifications for shock and vibration. This is based on the surface mount components being properly attached to the circuit board, and the fact that they have very little mass. In this case, the designers have defeated both of these conditions -- First by tacking only 2 of the 3 pads to the board, and then by requiring the device to support not only itself, but also the relatively large mass and moment of the interconnecting wire. Lastly, SMT devices are soldered using automated techniques where the soldering temperature and duration are carefully controlled; however, connecting a wire to a component lead in this fashion must be done by hand, were the lead maximum temperature, and the duration of heat application cannot be accurately controlled. The MOSFET and the wire were covered in a glue substance to hold them in place, but the substance is flexible, and the exact quantity and arrangement of the substance is also not possible to control from one particular device to the other. These factors may ultimately lead to failure by either physical movement or simply by the component being used past or too near it's ratings. Physical movement causes breakage or degradation of the connection, which either leads directly to failure, or leads to increased contact resistance. Any contact resistance here, where the full battery current is present, will lead to heating. Heating leads to additional stress on the possibly under-rated component, and to softening, or decomposition of the glue substance, which in turn allows more movement, and thus a vicious cycle.

The failures described above can result in several symptoms that match reported customer comments. Should the MOSFET or it's connections fail open, or to a high resistance state, the symptoms can be no, or a very dim beam. It should be noted that the drive circuit, and the laser diode itself, are very efficient. Producing 1 Watt of laser power from a single, small battery requires high efficiency. Any remaining leakage or path through the failed MOSFET will result in some light from the laser. Similarly, the MOSFET can fail “Slagged” or simply reduced to a lump of semi-conductor with some resistance. It may end up acting as a voltage divider, allowing some flow of current to ground, and some flow into the drive circuit. This results in a functioning laser, but one with a fraction of the expected output power, and may also result in very fast draining of the battery.

If the protection MOSFET should fail in such a manner, (i.e. there is a relatively low, and uncontrolled resistance path from Drain to Source) it also no longer provides reverse polarity protection. Should the user subsequently reverse the battery further damage will result.

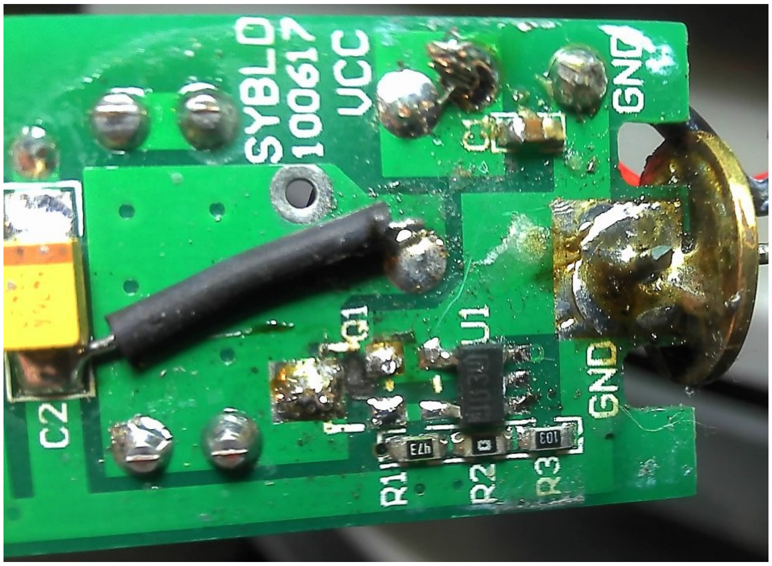
It also may be possible for the MOSFET to fail conductive Drain to Source, while the gate remains open, but with the device no longer able to function as a MOSFET. In this case, the laser will operate very nearly normally but there will be no wrong way battery protection. Again, a future error in battery installation will result in a more obvious failure.

If the above conditions should exist, and reverse polarity gets to the remaining circuitry, the next thing that will fail is the other MOSFET, Q1. From a DC perspective, Q1 is directly connected across the battery terminals. In a reverse polarity condition, the body diode inside Q1 will conduct, and thus be subject to the full battery current. Destruction of Q1 is a certainty.

Some users have purchased 18650 batteries with internal protection circuitry. While such batteries do improve safety (particularly during charging), they will not help in the above cases. The protection circuitry in such batteries is designed to provide short circuit, over charging, and over discharging protection for the battery (not the device). In a case where the laser's wrong-way protection MOSFET is missing or damaged, even a battery with a protection circuit will provide more than sufficient current to instantly destroy Q1 and possibly Integrated Circuit U1 if the battery is installed backwards and the laser is operated.

Based on these possible failures it is recommended that Arctic Spyder III owners/users be exceedingly cautious when inserting the battery even if the unit appears to be functioning correctly.

Integrated Circuit U1, the MOSFET (Q1) and several passive components form a “Boost” circuit. The purpose of this is to provide a higher voltage to the actual laser drive circuit than the single 18650 battery provides. In order to do proper current regulation, the laser drive circuit needs approximately 8 to 10 volts input. The circuit also provides an initial level of transient smoothing.



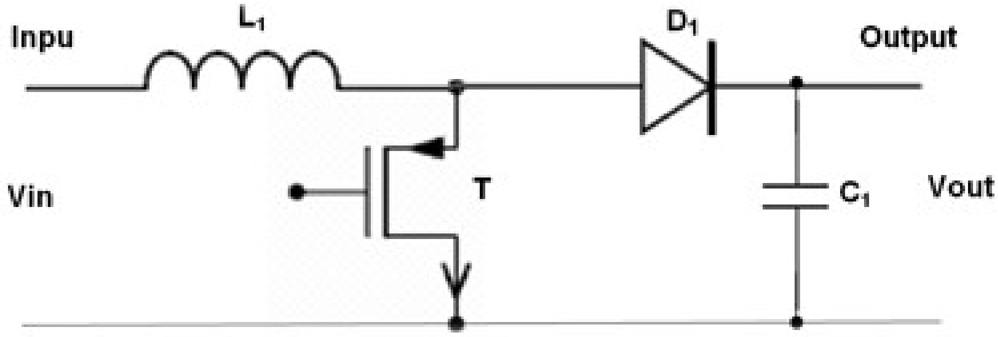
A view of the bottom of the board showing U1 and some of the associated circuitry.
Both the protection P-MOSFET and N-MOSFET Q1 have been removed in this picture.
The insulated jumper provides additional GND path current handling,
and is shown un-tacked from pin 4 of U1 to facilitate replacement
of Q1.

The boost circuit, by way of L1, forms a high frequency pulse, whose peeks are higher than that of the battery voltage. These pulses are rectified by the 2 large diodes on top of the board so that a 220 μF capacitor (C3) is charged to a voltage appropriate for the actual laser drive circuit. Electrolytic capacitors like C3 have a relatively large internal inductance. The capacitor on the bottom of the board, and a smaller chip capacitor are used to help overcome the inductance of C3. This is needed because the boost circuit operates at a relatively high frequency.

Resistor R1, Jumper R2, and Resistor R3, located on the bottom of the board, next to U1, form a voltage divider that provides a feedback reference voltage to U1. This feedback voltage is used by U1 to properly regulate the boosted voltage.

Similar circuits are commonly used to provide drive for LED back-lights in cell phones and other battery powered devices.

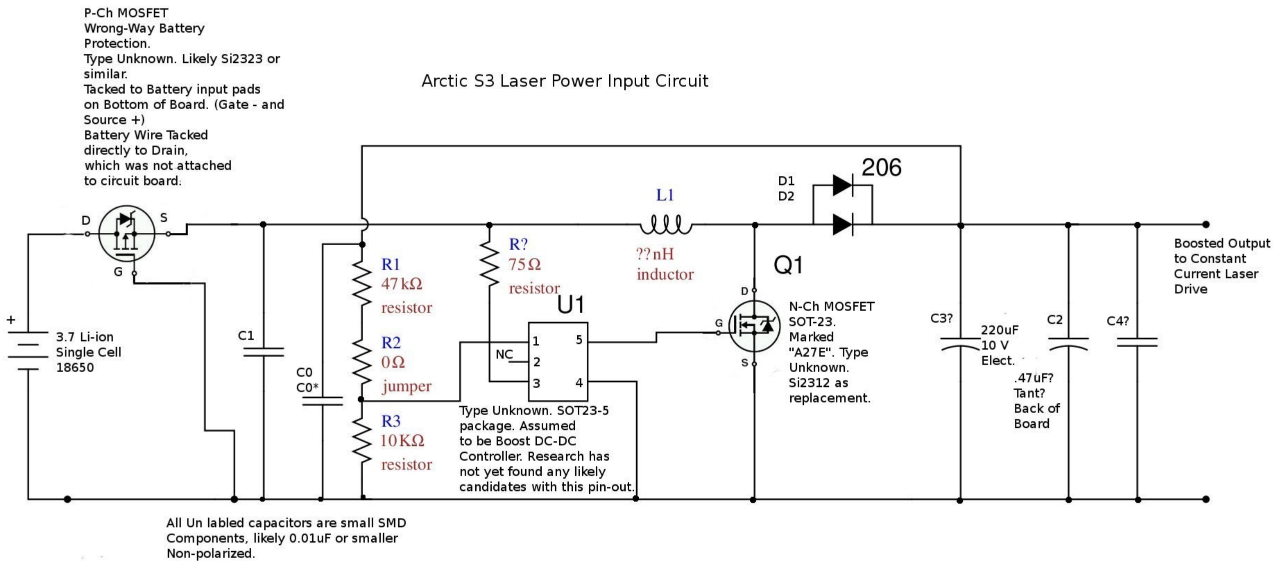
An electrical model of a DC-DC boost circuit is shown below. This is a simplification of exactly what is being done with the G1's input circuitry.



Simplified DC-DC Boost circuit
Credit: WOLFGANG FRANK
Infineon Technologies AG Milpitas, CA
http://www.infineon.com

In the Arctic laser, Integrated Circuit U1 provides switching control of MOSFET Q1. U1 is some sort of Boost controller chip. It is in an SOT-23-5 package, and directly drives Q1, an external N-ch MOSFET. Many varieties of such chips are available; however most devices in this package have internal driver MOSFET's, and are for slightly lower power applications. The circuitry of the Arctic G1 seems to occupy a rare middle ground between LED drivers and higher power devices utilizing one or more large, external Power MOSFETs. Research to date has not identified any boost controllers that fit the package and pin-out of U1.

Analysis of data sheets and experimentation has shown that the Vishay Si2312 N-MOSFET (the same device shown used as return lead wrong-way battery protection in the above referenced article) will function to replace Q1 in an Arctic S3 laser. This device has one of the highest current and power handling capabilities of any SOT-23 device. Even still, it is very likely that this component is being used uncomfortably close to it's maximum ratings in the Arctic Spyder III blue laser.



Reverse Engineered Power Input Circuitry of the
Arctic Spyder III Laser.

The power input circuitry of the Arctic Spyder III is efficient, very small, and utilizes state of the art components and design practice; however, we can see that the way at least some G1's are constructed, and the fact that very small surface mount components are being used in a relatively high power application may be causing some of the reported failures, and that likely failure modes of the Arctic's power input circuitry are consistent with customer reports.