The Principle of the Safe Operating Area

THE IMPORTANCE OF THE SAFE OPERATING AREA CALCULATOR

Linear-mode laser diode drivers and temperature controllers use transistors regulated in the linear mode in order to control the amount of current driven to the load.

This simple design is robust, relatively inexpensive, and allows for precision control, but also requires the transistors to dissipate power in the form of heat. Under some circumstances the internal power dissipation may be too great, and the transistor will be damaged or destroyed.

An engineering tool called the Safe Operating Area (SOA) Calculator is used to make sure the controller is operated within its designed power range. The SOA Calculator on the Wavelength Electronics website is a critical tool that will help you design your laser and temperature control system using our products.

The power supply voltage, drive current, load resistance, ambient temperature, and design properties of the controller determine how much power can be dissipated within the controller.

The on-line SOA Calculators can be found at:
Laser Diode Drivers
http://www.teamwavelength.com/support/calculator/soa/soald.php

Temperature Controllers
http://www.teamwavelength.com/support/calculator/soa/soatc.php

This Application Note explains the theory behind the SOA Calculator, why it is critical to use this valuable design tool, and provides design advice in case the calculator indicates your controller is not operating within the Safe Operating Area.

INTERNAL POWER DISSIPATION

The internal power dissipation of the controller is determined by three factors:

1) Power supply voltage
2) Drive current
3) Load impedance

Figure 1 illustrates the power dissipation model for a very simple controller system. The power dissipated within the controller and load must equal the power supplied by V_{DD}.

If V_{DD} is 5 V and I_{LD} is 1 A, the total power dissipation is

$$\mathbf{P_{VDD} = V * I = 5 * 1 = 5\ W}$$

The load, a 1 Ω resistor, dissipates

$$\mathbf{P_{LOAD} = I^2 * R = 1^2 * 1 = 1\ W}$$

The remaining four watts must therefore be dissipated within the current source. The current source must be rated for at least 4 W internal power dissipation, or else it might be damaged when internal components overheat.

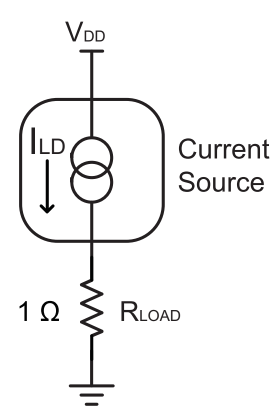

Figure 1. A Simple Linear Controller System

DETERMINING THE MAXIMUM INTERNAL POWER DISSIPATION

Every time Wavelength Electronics designs a new product, the acceptance test protocol includes a process to determine the Safe Operating Area. The SOA is first determined theoretically, and then empirically confirmed by slowly increasing the internal power dissipation until the output transistors fail.

The transistor temperature increases as the internal power dissipation increases, and eventually the high temperature causes the transistor to fail. While running the test, the temperature of the output transistor is logged. The temperature—and ultimately the internal power dissipation—at which the device fails determines the Safe Operating Area.

To demonstrate how the Safe Operating Area is determined, consider a laser driver operating with V_{DD} = 30 V and I_{LD_MAX} = 10 A. Initial conditions for the SOA test:

R_{LOAD} = 0.5 Ω
I_{LD} = 10 A
V_{DD} = 13 V
$T_{AMBIENT}$ = 25ºC

At these settings the Controller + Load power dissipation is 130 W. The load power dissipation is 50 W (I^2R), so the internal power dissipation is 80 W (= 130 W - 50 W). Once the transistor temperature stabilizes, the supply voltage is stepped up by 0.5 V. The settle-step cycle is repeated until the output stage transistors fail.

The test data in **Figure 2** shows that the transistor temperature tracks the internal power dissipation step-for-step.

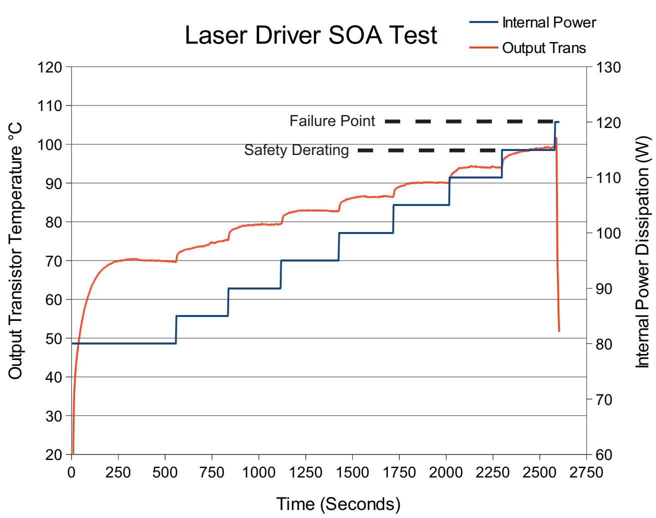

Figure 2. Safe Operating Area Test

Since the current and load resistance remain constant throughout the test, the load power dissipation remains constant at 50 W. Therefore each voltage step increases power dissipation within the controller by 5 W and pushes the output stage toward the failure point.

In this test, when V_{DD} was stepped to 17 V, the internal power dissipation reached 120 W, the transistor reached 100ºC, and failed.

When the product specification is finalized, a safety factor is built into the product specification. For example, in this case the maximum internal power dissipation might be specified at 110 W. But for the sake of discussion in this paper, all calculations will use 120 W as the maximum internal power dissipation.

BUILDING THE SOA CHART

The SOA chart is drawn with the Safe Operating Area defined by a line at 120 W. Pick any point on the curve in **Figure 3**, multiply the corresponding I_{LD} and V_{DD} values, and the result is 120 W.

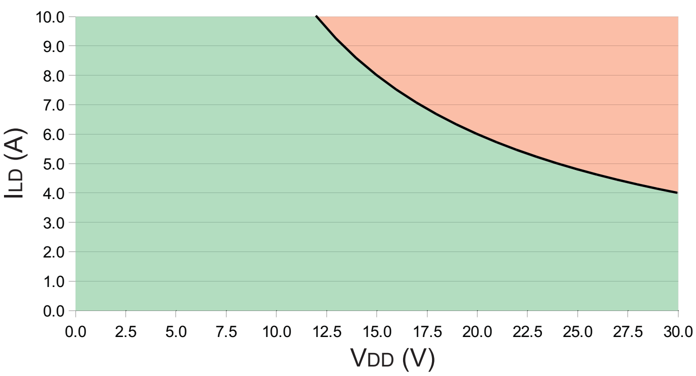

Figure 3. Room Temperature SOA Chart

Note that this SOA applies only when operating at 25ºC because that is the temperature at which the test was performed. Operating at other elevated temperatures causes the SOA line to shift. The effect of elevated temperatures is discussed later.

The SOA Calculator on our website supports all Wavelength Electronics products and takes into account ambient temperature.

USING THE SOA CHART

The SOA chart is used to visually calculate the internal power dissipation as a function of V_{DD}, I_{MAX}, and the electrical characteristics of the load.

Follow these steps to determine if the driver will be operating within the Safe Operating Area. **Figure 4** illustrates the process, using the following example data:

V_{MAX} = 3 V

I_{MAX} = 8.5 A

V_{DD} = 20 V (power supply voltage)

- Refer to the product datasheet to find the maximum voltage (V_{MAX}) and current (I_{MAX}) specifications.
- Calculate the voltage drop across the controller:

  $V_{DROP} = V_{DD} - V_{MAX}$
- Mark V_{DROP} on the X-axis, and extend a line upward.
- Mark I_{MAX} on the Y-axis, and extend a line to the right until it intersects the V_{DROP} line.
- On the X-axis, mark the value of V_{DD} .
- Extend a diagonal line from V_{DD} to the intersection of the V_{DROP} and I_{MAX} lines; this is the **Load Line**.

At the maximum rated drive current of 8.5 A, the voltage across the load is 3 V; therefore V_{DROP} is 17 V.

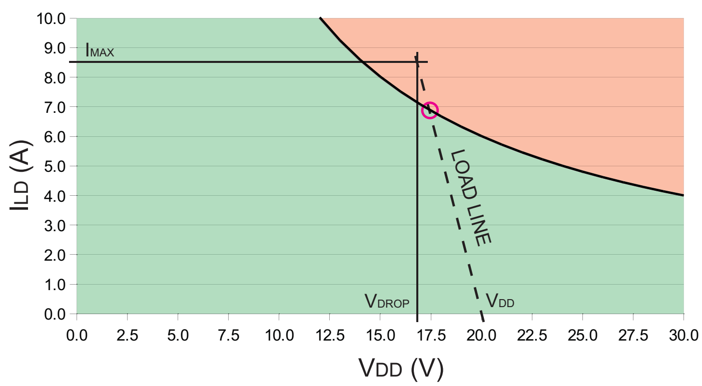

Figure 4. SOA Example Laser Driver Application

If the Load Line crosses the Safe Operating Area line at any point, the configuration is not safe. In this case the load line crosses the Safe Operating Area line, which indicates imminent failure of the output stage transistor. The driver will fail at the current where the load line crosses the SOA line, about 6.9 A.

If the SOA Calculator indicates the unit will be outside of the Safe Operating Area, the system must be changed so that less power is dissipated within the driver. Stated another way, the load line must be “moved to the left.”

MOVING THE LOAD LINE

If the SOA chart indicates imminent failure, then the system design must be modified in order to *reduce the internal power dissipation*. There are five avenues to explore.

Solution 1—Reduce V_{DD} Supply Voltage

If the system design is flexible, V_{DD} can be reduced from 20 V to 15 V (**Figure 5**). The load-line shifts left because internal power consumption is reduced.

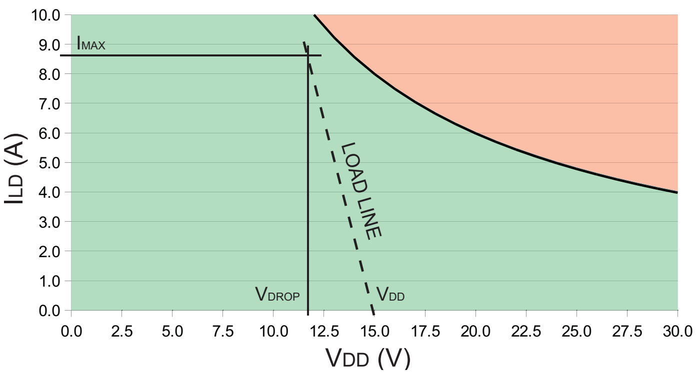

Figure 5. SOA, Reduced V_{DD}

Some Wavelength Electronics controllers and drivers can be configured to use two separate power supplies so the system can be tuned for minimum total power dissipation.

Solution 2—Increase the Load Power Dissipation

Remember that Controller + Load power dissipation remains constant, so increasing load power dissipation reduces the amount of power that must be dissipated within the controller. Refer to **Figure 6**.

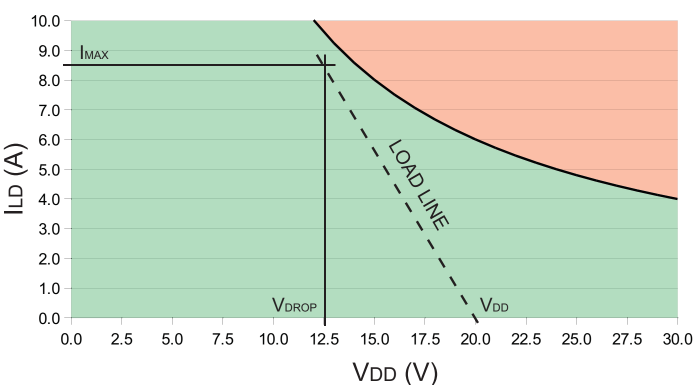

Figure 6. SOA, Increased Load Power Dissipation

Increase load power dissipation by changing the load impedance:

- A dominant impedance can be added in series with the laser diode. Use a power resistor, but keep in mind that thermal noise may increase the optical output noise.
- Specify a TEC or heater with higher resistance.

Solution 3—Reduce I_{MAX} Current Limit

The third solution is to reduce the current limit. In this example the current limit must be reduced to <6.9 A in order to guarantee safe operation at all times; the resulting SOA chart is shown in **Figure 7**.

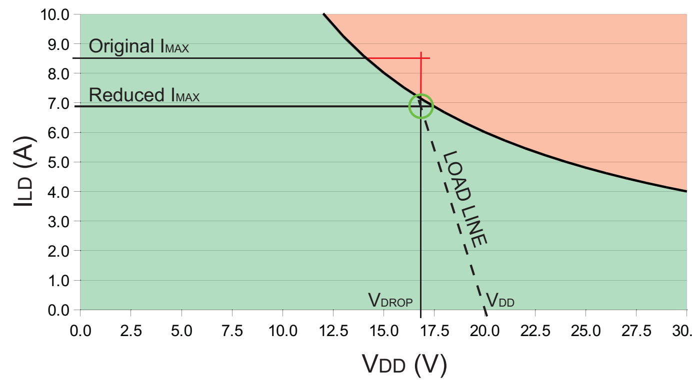

Figure 7. Reduced I_{MAX}

Reducing I_{MAX} is effective for both laser diode driver and temperature controller applications, but with potential disadvantages.

- In a laser application, reducing I_{MAX} may reduce the optical output power unacceptably.
- Reducing the current limit in a temperature control application will limit the ultimate heat pump capability of the TEC. Thoroughly test the temperature control system to ensure the load will remain within the required temperature range under all foreseeable operating conditions.

Solution 4—Improve Heat Dissipation to Ambient

In any design scenario, a thorough review of the heat dissipation scheme is beneficial.

The internal power dissipation capability of some controllers can be increased by adding a heatsink, and then further increased by forcing airflow over the heatsink. The on-line SOA Calculator allows you to experiment with the external heat dissipation options.

Solution 5—Respecify the Controller

If none of these solutions are successful, then a new controller should be specified. Find a controller with a higher internal power dissipation specification, and run the SOA calculation with your system design parameters to make sure that it will operate safely in your application.

HOW THE AMBIENT TEMPERATURE IMPACTS THE SAFE OPERATING AREA

The SOA chart in **Figure 3** is derived from data taken at $T_{AMBIENT}$ = 25ºC. In the real world, the ambient temperature fluctuates, or can be quite a bit higher than 25ºC. The system designer must know if the driver will operate robustly through a wide range of temperatures, and the SOA must be adjusted accordingly.

The ambient temperature directly impacts the maximum internal power dissipation—every 1ºC increase in ambient temperature means the transistor is 1ºC closer to the failure temperature, so the allowable temperature increase due to power dissipation *decreases* by 1ºC. The internal power consumption, therefore, must be *derated* based on ambient temperature. **Figure 8** illustrates the derating curve.

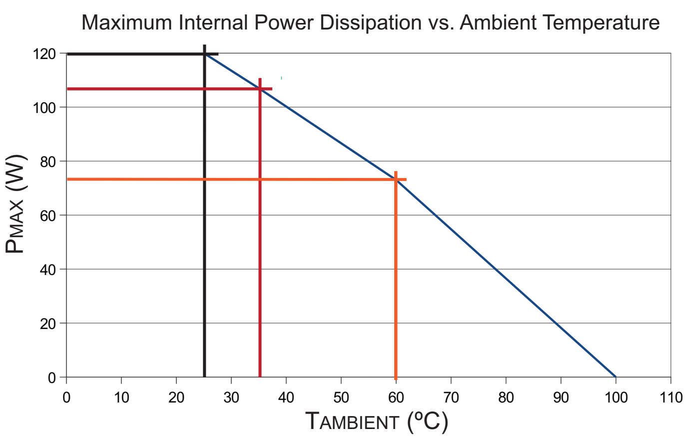

Figure 8. Derating Due to Ambient Temperature

Figure 9 shows the same effect in terms of the SOA graph. The SOA line moves "down" as ambient temperature increases, reflecting the reduced temperature overhead before the transistor reaches 100ºC and fails.

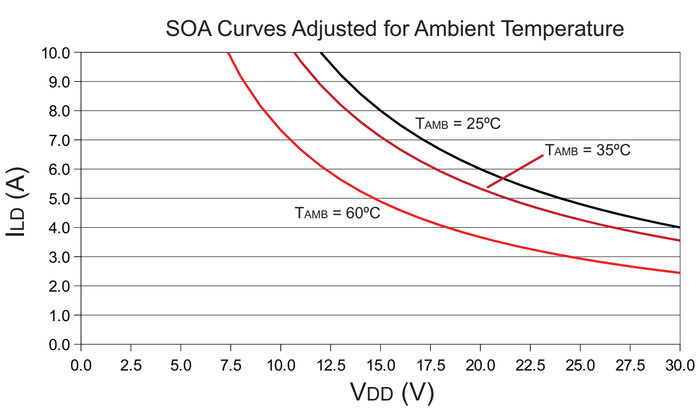

Figure 9. SOA at Elevated Ambient Temperatures

The SOA Calculator on the Wavelength website takes into account the ambient operating temperature.

SUMMING IT UP

When designing an application using a Wavelength Electronics laser diode driver or temperature controller, it is essential to verify that the device will be operating within the Safe Operating Area. Operating outside of the SOA will damage or destroy the electronics, and may also damage the load. Operating outside of the SOA voids the warranty.

SOA charts are included in the datasheets for all our products, but using the SOA Calculator on the Wavelength website guarantees the most accurate results. Critically, the on-line SOA Calculator takes into account ambient temperature while the paper SOA charts do not.

Webpage for laser diode driver SOA:
http://www.teamwavelength.com/support/calculator/soa/soald.php

Webpage for temperature controller SOA:
http://www.teamwavelength.com/support/calculator/soa/soatc.php

If, at any time, questions arise about operating a Wavelength Electronics laser diode driver or temperature controller, call our knowledgeable Sales and Technical Support engineers for free and prompt assistance.

REVISION HISTORY

REV	DATE	NOTES
A	13-Jul-12	Initial Release

KEYWORDS

internal heat dissipation, temperature fluctuation, derating, safe operating area, laser diode driver temperature control, temperature controller operating range