THE DIFFERENCES BETWEEN THRESHOLD CURRENT CALCULATION METHODS

This Application Note explains the four threshold calculation algorithms used by ILX Lightwave® and why each method will result in a slightly different threshold value.

BACKGROUND

Four different algorithms are used to calculate the laser threshold current:

1. Linear line fit
2. Two-segment line fit
3. First derivative of light vs. current
4. Second derivative of light vs. current

These four methods are recognized and described in the Telcordia Technologies standard "Introduction to Reliability of Laser Diodes and Modules" (SR-TSY-001369). Each method, even when used on the same data set, will typically generate slightly different values for the threshold current.

Some laser diode manufactures have a preferred calculation method, or their customers require a particular method is used. In other applications, such as R&D or university environments, no particular method is prescribed. In these cases, the user needs to understand the differences between the methods, and why they give different results.

Understanding the factors that affect threshold calculation allows the user to choose the right method for particular applications, and leads to more effective and efficient use of test time and resources.

DISCUSSION

The four methods of threshold calculations each act upon a different characteristic of the L/I curve, so they will be described individually with ideal examples; Figure 1 shows an ideal L/I curve which will be used through the rest of this application note to illustrate the different threshold calculation methods. For these ideal examples, arbitrary current numbers are assigned so the methods can be compared.

The most critical portion of the graph is the threshold knee region. This is the point where the laser switches from strictly spontaneous emissions to lasing emissions, and the slope efficiently increases dramatically.

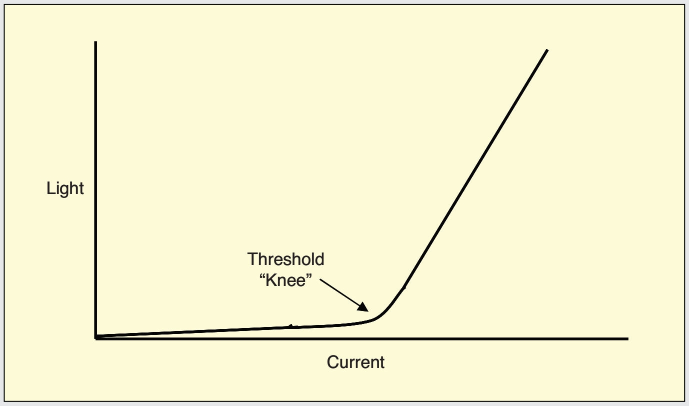

Figure 1 – Ideal L/I Curve with Derivative Curves

Linear Line-Fit Threshold Calculation

The linear fit method is the simplest, but potentially the most unreliable. This method simply extends a straight line down the lasing portion of the L/I curve until it intersects the horizontal axis. The intercept point is defined as the threshold current.

Figure 2 shows a close up of the threshold knee and the single line Linear Fit method of calculating threshold current.

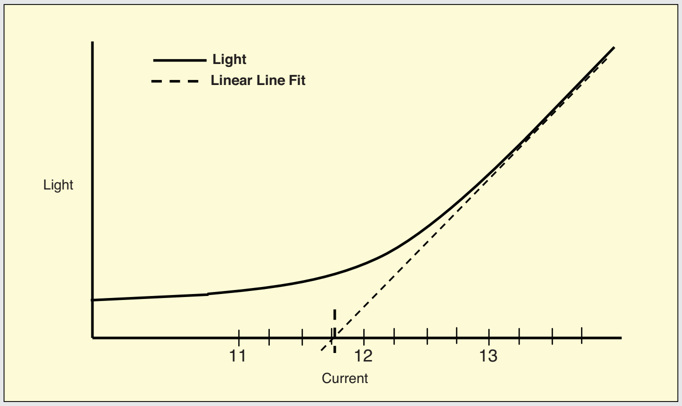

Figure 2 – Linear Line-Fit

There are several serious disadvantages to the linear line-fit method:

1. The calculated I_{th} value is highly dependent on the slope efficiency of the laser. Less efficient lasers will have a lower calculated threshold value, especially when the threshold knee is rounded instead of very sharp. The slope efficiency may shift due to internal laser module properties or even because of improper light coupling to the photodetector used to measure light output.
2. If the linear line is based on a linear regression, then the proper start and stop points of the regression must be selected. If the regression uses data too near the threshold knee then the calculated threshold value will shift to a lower value. Conversely, if the regression starts too far from the knee, the line fit may be strongly influenced by non-linearities at higher powers.
3. If the linear line is based on a two-point fit, then the selection of the first point is critical. A point too low on the threshold knee and the x-intercept is shifted to a much lower current value. Conversely, if the point is too high on the light curve then the linear line may be impacted by non-linearities at higher light output powers and the threshold value will be shifted.

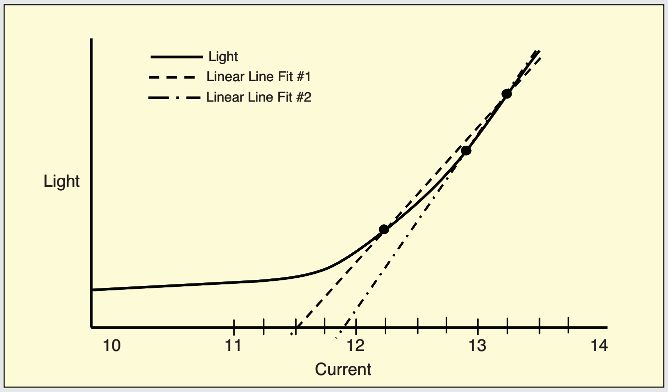

Figure 3 – First-Point Selection, Effect on Calculated I_{th} Value.

Two-Segment Line-Fit Threshold Calculation

Figure 4 shows a close-up of the threshold knee region and the two-segment line fits. A line is fitted to the pre-threshold portion of the curve; a second line is fitted to the lasing portion in the same manner as the linear fit method. The point where the two lines intersect is projected down onto the current axis and labeled at I_{th} value.

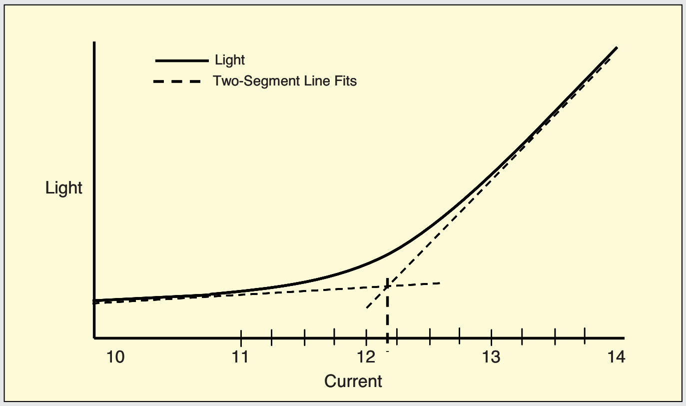

Figure 4 – Two-Segment Line Fit

First Derivative (dL/dI) Threshold Calculation

Figure 5 shows an ideal example of a first derivative threshold calculation. The threshold current is defined as the current at which the first derivative curve reaches ½ of the maximum value.

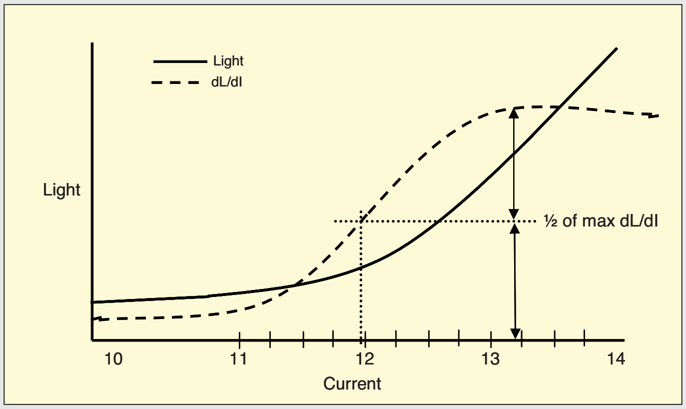

Figure 5 – Ideal First Derivative Threshold Calculation

The first derivative method is straight forward in most cases, but problems arise when the maximum of the dL/dI curve is not easily defined. Figure 6 shows an example of a dL/dI curve that continues to increase after the threshold knee, and does not have an apparent maximum.

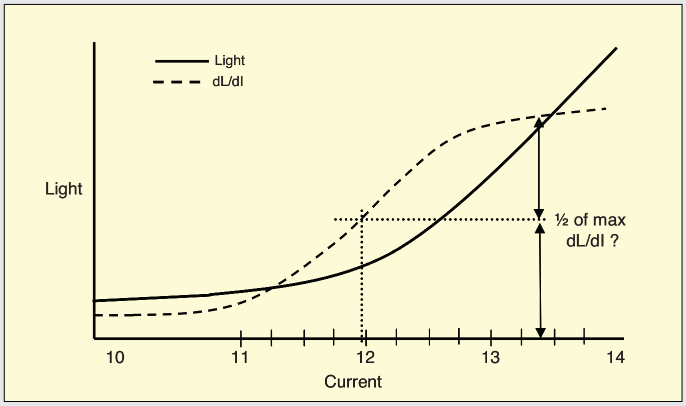

Figure 6 – Continuously Increasing dL/d

The problem of poorly defined first derivative maximum is exacerbated by measurement noise, which is a real problem encountered on any test system. Figure 7 shows the first derivative curve from a 918 nm pump laser. Notice that measurement noise at the dL/dI maximum level, as well as the lack of a clearly defined maximum point.

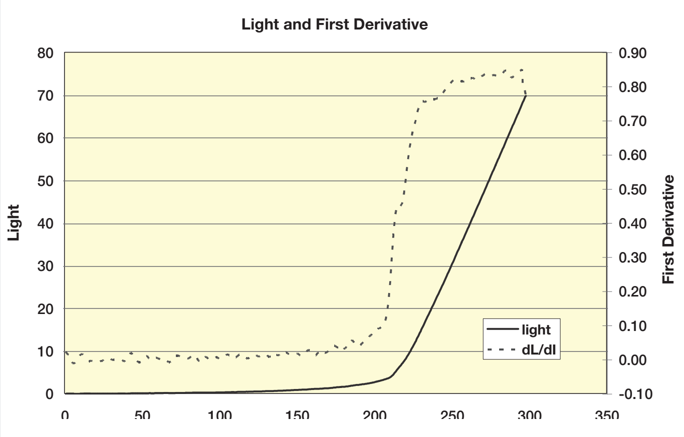

Figure 7 – Real First Derivative Curve with Noise

In this case, the threshold calculation repeatability was poor because the noise value changed slightly from sweep to sweep. When the dL/dI maximum point is not repeatable then, of course, neither is the calculated threshold current.

Second Derivative (d^2L/dI^2) Threshold Calculation

The second derivative threshold calculation method is recommended by Telcordia Technologies in the GR-3013-CORE Generic Requirements document. The method is illustrated in Figure 8.

The second derivative method locates the point of maximum rate of change of the L/I curve, which is also the inflection point of the first derivative curve. It is not necessarily the same threshold point that is calculated using the first derivative method, however.

The second derivative method is insensitive to the non-linearities before and after the threshold knee since those portions of the curve are not considered in the calculation.

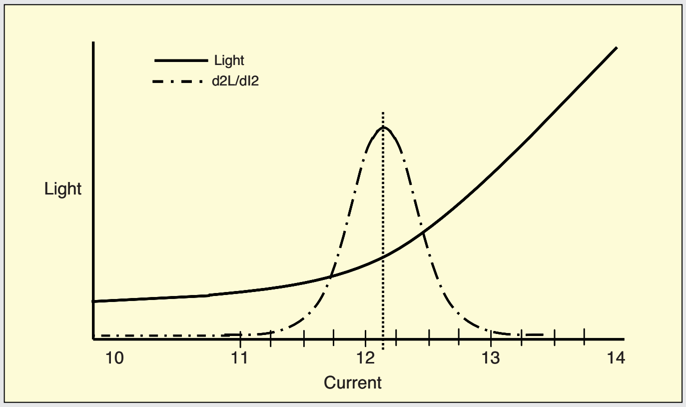

Figure 8 – Ideal Second Derivative Threshold Calculation

In testing real laser diodes, there can be a dual peak in the second derivative curve, with the second peak caused by a kink in the threshold knee (Figure 9, same laser as used to generate Figure 7). This possibility is acknowledged by the Telcordia document, and in most cases, it is easy to determine which d^2L/dI^2 peak is real, even when using an automated test program to calculate I_{th}.

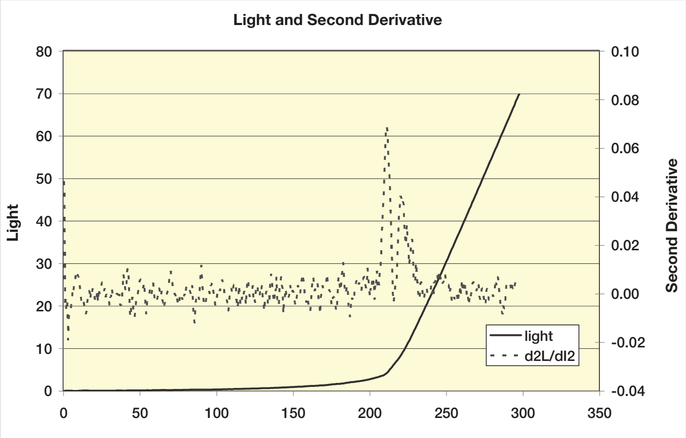

Figure 9 – Second Derivative, Double Peak

Automated Threshold Calculation

The second derivative calculation method does not guarantee reliable and repeatable threshold measurements, especially when automated test equipment is used to run the test. A number of test parameters need to be adjusted in order to reduce measurement noise, optimize test resolution, reduce test time, and balance other factors. Contact your local ILX Lightwave® representative on how to best address test configuration optimization issues, including the selection of Sentinel Laser Reliability and Burn-In Test Systems.

Conclusion

The threshold calculation method you choose for your test application will depend on a number of factors:

- Does your customer require that you use a particular method?
- Are you calculating the threshold manually or with an automated system?
- How linear are the pre- and post-threshold portions of the L/I curve?
- How repeatable does the threshold calculation have to be?

Although all four calculation methods are recognized in the Telcordia document, the derivative methods are the most reliable and least affected by anomalous laser characteristics. The second derivative method is preferred and is recommended in the Telcordia CORE document.

Real Threshold Values (in mA)

Calculation Method	**1615 nm DWDM** P_{op} **= 20 mW**	**918 nm Pump** P_{op} **= 1 W**	**1408 nm Pump** P_{op} **= 200 mW**
Linear Fit	11.89	261.68	23.90
Two-Segment Fit	12.15	262.57	24.10
First Derivative	12.00	258.09	23.41

The following publications are available for download at www.newport.com/ilxlightwave.

White Papers

- A Standard for Measuring Transient Suppression of Laser Diode Drivers
- Calibration and Traceability Ensure Measurement Accuracy
- Degree of Polarization vs. Poincaré Sphere Coverage
- Laser Diode Burn-In and Reliability Testing
- Power Supplies: Performance Factors Characterize High Power Laser Diode Drivers
- Simplifying Parametric Analysis of Laser Diodes
- Reliability Counts for Laser Diodes
- Reducing the Cost of Test in Laser Diode Manufacturing

Technical Notes

- Accuracy and Repeatability of Power Measurements Using the FPM-8220
- Automatic Wavelength Compensation of Photodiode Power Measurements Using the OMM-6810B Optical Multimeter
- Bandwidth of OMM-6810B Optical Multimeter Analog Output
- Broadband Noise Measurements for Laser Diode Current Sources
- Callendar-Van Dusen Equation and RTD Temperature Sensors
- Clamping Limit of an LDX-3525B Precision Current Source
- Connecting Your Laser to the LDP-3830
- Determining the Polarization Response of the FPM-8220
- Effects of Cabling and Inductance When Pulsing High Power Laser Diodes
- Facility Power Requirements for the LDX-36000
- Four-Wire TEC Voltage Measurement with the LDT-5900 Series
- Guide to Selecting a Bias-T Laser Diode Mount
- High Power Linearity of the OMM-6810B and OMH-6790B Detector Heads
- Large-Signal Frequency Response of the 3916338 Current Source Module
- Laser Wavelength Measuring Using a Colored Glass Filter
- LDC-3736 Laser Protection
- LDM-4982 and 4984 Quick Setup Guide
- LDP-3830 Independent Current Limit
- LDP-3830 Laser Protection
- LDP-3830 Pulse Performance
- LDT-5900C Temperature Stability
- LDT-5910C PID Control Quick Start
- LDT-5940C Voltage Measurement Techniques
- LDX-3232 Modulation Bandwidth
- LDX-36000 CQW Pulse Characteristics
- Long-Term Output Stability of an LDX-3620B Laser Diode Current Source
- Long-Term Output Stability of an LDX-3525B Precision Current Source
- LRS-9434 Temperature Set Point Accuracy
- LRS-9434 Temperature Coefficient
- LRS-9434 Threshold Current Measurement Repeatability
- LRS-9434 and LMS-9406 Transient Protection
- LRS-9550 Device Temperature Algorithm
- LRS-9550 Fixture Temperature Range
- LRS-9550 Laser Drive Current Setpoint Accuracy
- LRS-9550 Laser Eye Safety Features
- LRS-9550 Water Quality Guidelines
- Measurement of 4-Wire Voltage Sense on an LDC-3916 Controller
- Measuring the Power and Wavelength of Pulsed Sources Using the OMM-6810B Optical Multimeter
- Measuring the Wavelength of Noisy Sources Using the OMM-6810B
- Minimum Temperature Range of the LDM-4405
- Minimum Temperature Control Range of the LDM-4982M / LDM-4894T
- Nominal PID Constants for the LDT-5900 Series Controller
- Output Current Accuracy of an LDX-3525B Precision Current Source
- Paralleling Laser Diodes
- Pulse Parameters and LDP-3830 Control Modes
- Quick Start: Modulation a Laser Diode Driver
- Repeatability of Wavelength and Power Measurements Using the OMM-6810B Optical Multimeter
- Square Wave Modulation of the LDX-3500B
- Stability of the OMM-6810B Optical Multimeter and OMH-6727B InGaAs Power/Wavehead
- Temperature Control Range of the LDM-4409
- Temperature Measurement Using a Linearized Thermistor Network
- Temperature Stability Using the LDT-5948 / LDT-5980
- Thermal Resistance of the LDM-4409
- Thermistor Constant Conversions: Beta to Steinhart-Hart
- Triboelectric Effects in High Precision Temperature Measurements
- Tuning the LDP-3840B for Optimum Pulse Response
- Typical Long-Term Temperature Stability of a LDT-5525 TEC
- Typical Output Drift / Noise of an LDX-3412
- Typical Temperature Stability of the LDT-5500B
- Using Status Event Registers for Event Monitoring
- Using the Dual Modulation Inputs of the LDX-3620B
- Using the LDM-4984 with the LDP-3840B
- Using Three-Wire RTDs with the LDT-5900 Series Temperature Controllers
- Voltage Drop Across High Current Laser Interconnect Cable
- Voltage Drop Across High Current TEC Interconnect Cable
- Voltage Limit Protection of an LDC-3916 Laser Diode Controller

Application Notes

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- App Note 2: Selecting and Using Thermistors for Temperature Control
- App Note 3: Protecting Your Laser Diode
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