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An Overview of Laser Diode Characteristics

APPLICATION NOTE

ILX Lightwave

Laser Diode Instrumentation & Test Systems

Measuring Diode Laser Characteristics

Diode Lasers Approach Ubiquity, But They Still Can Be Frustrating To Work With

By Tyll Hertsens

Diode lasers have been called “wonderful little devices.” They are small and efficient. They can be directly modulated and tuned. These devices affect us daily with better clarity in our telephone system, higher fidelity in the music we play at home, and a host of other, less obvious ways.

But diode lasers can be frustrating to work with. The same family of characteristics that permit wide areas of application also make diode lasers difficult to control.

An Overview

Laser diode characterization can be broken down into five categories, as shown in Table 1.

TABLE 1 - FIVE CATEGORIES OF DIODE LASER MEASUREMENT	
Electrical	Measurement of light output, voltage drop, and photodiode monitor current. Derivative analysis of this data may also be performed.
Spatial	Output light intensity profile in the far and near field and pointing angle of the radiation pattern.
Spectral	Spectral data acquired to calculate spectral width and center wavelength, and to observe mode structure.
Optical	Measurement of astigmatism and other wavefront errors.
Dynamic	Measurement of noise, intermodulation distortion, rise time, fall time, chirping and so on.

This article presents a general look at the electrical, spatial, and spectral characteristics of diode lasers. The “optical” category of Table 1 generally falls into the realm of interferometry, while the “dynamic” category of Table 1 represents an involved and highly interactive attempt at real-time equivalent-circuit modeling, mostly *during* device modulation. The last two categories of Table 1 represent topics of other articles, for other authors.

Electrical Characteristics

The L/I Curve. The most common of the diode laser characteristics is the L/I curve (Figure 1). It plots the drive current applied to the laser against the output light intensity. This curve is used to determine the laser’s operating point (drive current at the rated optical power) and threshold current (current at which lasing begins).

As can be seen in Figure 1, the threshold of the laser is strongly affected by the laser’s temperature. Typically, laser threshold will increase exponentially with temperature as I_{th} µ $\exp(T/T_o)$, where T is the laser temperature in degrees Kelvin and T_o is the “characteristic temperature” of the laser (typically 60 to 150 K).

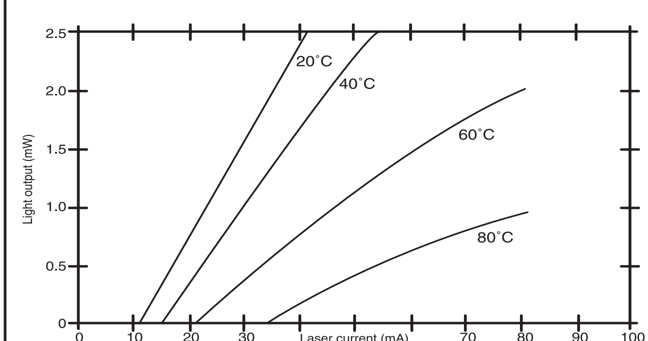

Figure 1. The continuous wave L/I curve.

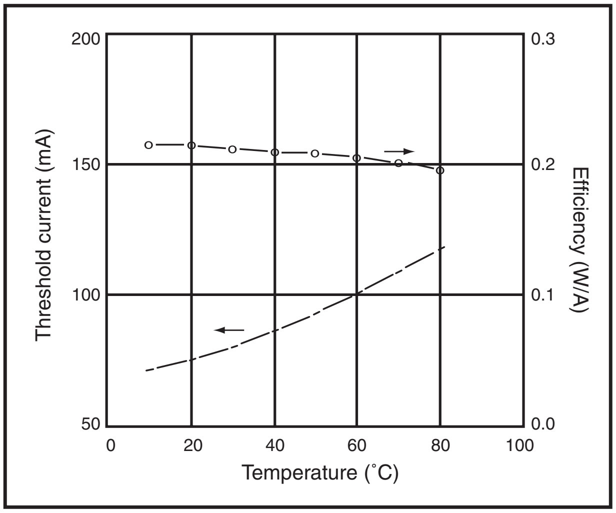

Figure 2. Threshold current rises and efficiency falls as the temperature increases.

The efficiency of a diode laser is also derived from the L/I curve. It is most commonly expressed as slope efficiency and measured in units of mW/mA. Although not as apparent as threshold shift, laser efficiency also falls off with increasing temperature (Figure 2). Laser efficiencies are typically about 0.3 mW/mA at 25°C, and drop about 0.01 mW/mA for every 10°C increase in temperature.

Pulsed L/I Curve. The L/I characteristics may also be acquired in a low-duty-cycle pulsed mode. The increase in threshold and decrease in slope efficiency observed in the continuous wave data, as compared to the pulsed data (Figure 3), stems from the rise in junction temperature. This rise, due to the thermal resistance of the device, is typically 40 to 80°C/W. Typically, pulse widths used in this type of measurement are 100 to 500 nanoseconds, with a duty cycle of less than one percent.

Unusually large differences between the continuous wave and pulsed L/I curves may suggest poor die attachment or a leaky junction, and are often an indicator of poor laser quality.

Tracking Ratio. Many diode laser packages include a back-facet monitor photodiode that detects the intensity of the light exiting the rear facet of the laser cavity. Normally, the signal current from this photodiode is used as a feedback source for the laser drive circuits, for output power stabilization of the diode laser.

The monitor photodiode is most commonly characterized by comparing its output current against the light output from the diode laser. Since the monitor photodiode current is directly proportional to the output light, the tracking ratio is a single number and is measured in mA/mW.

An unusual application of this measurement occurs when characterizing diode lasers coupled directly to optical fibers. In this case, tracking ratio is a comparison of light output from the fiber with the monitor photodiode current. Tracking ratio changes with temperature and drive current, indicating changes in coupling efficiency between the laser's output facet and the input end of the fiber. Such fluctuations of tracking ratio can be

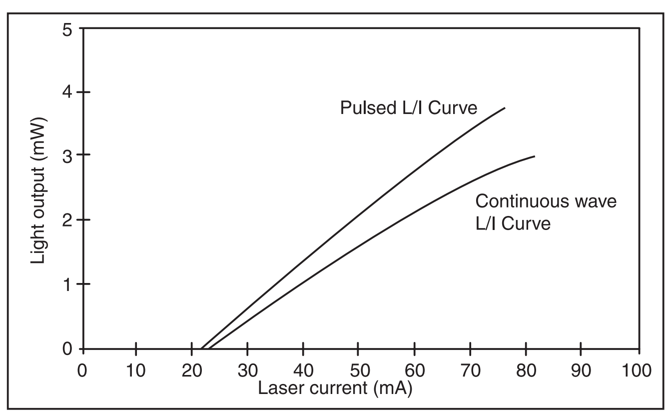

Figure 3. The pulsed L/I curve.

used to detect mechanical instabilities in the fiber mounting or changes in the near-field emission pattern of the laser.

The V/I Curve. The voltage drop across the laser is often acquired during electrical characterization. This characteristic is similar to the analogous characteristic of any other type of semiconductor diode and is largely invariant with temperature, as depicted in Figure 4. (Note: Diode laser manufacturers usually place the forward voltage on the X axis, in compliance with conventional practice in the electronics industry for other types of diodes. Companies manufacturing instrumentation to characterize diode lasers often present the curve in the manner of Figure 4, with the forward current on the X axis. Thus, other performance curves – as will be described in later sections – may be overlaid onto the V/I curve. Conventional electronics people would call this an I/V curve, rather than accept our nomenclature of a V/I curve). The typical voltage drop across a diode laser at operating power is 1.5 volts. V/I data are most commonly used in derivative characterization techniques.

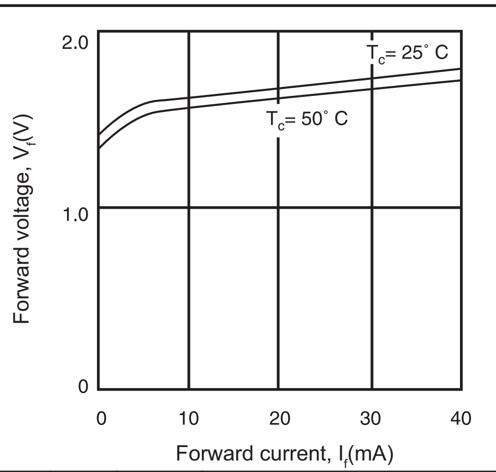

Figure 4. The V/I curve.

A note of caution. It is extremely damaging to apply a large reverse bias to a diode laser. Manufacturers of diode lasers may look at the reverse bias breakdown characteristics of the laser to control some of the device geometries. Even in that limited instance, manufacturers are careful not to exceed about 10 µA of reverse current.

There is no one right way to calculate threshold current. There are, however, four commonly accepted methods, as described in Table 2 and graphically depicted in Figure 5. Any of the four methods outlined in Table 2 may be successfully used, but the second derivative method seems to be most widely favored. The two-segment fit, 1st derivative,

TABLE 2 - FOUR METHODS OF CALCULATING THRESHOLD CURRENT	
Linear Fit	The point at which a straight-line fit to the linear portion of the L/I curve above the threshold intercepts the X-axis corresponding to the zero optical power (Figure 5a).
Two-Segment Fit	The point at which a straight-line fit to the linear portion of the L/I curve above the threshold intercepts the straight-line fit to the linear portion of the L/I curve below it (Figure 5b).
First Derivative	The point at one-half the maximum of the rising edge of the dL/dI curve (Figure 5c).
Second Derivative	The point at which the d^2L/dI^2 curve is maximum (Figure 5d).

and 2nd derivative methods are based on Telcordia GR-468-CORE and GR-3010-CORE. The linear fit is not recognized by Telcordia.

Derivative Characterizations

There are four frequently used derivative curves calculated from L/V/I data. The most commonly used derivative is the dL/dI curve.

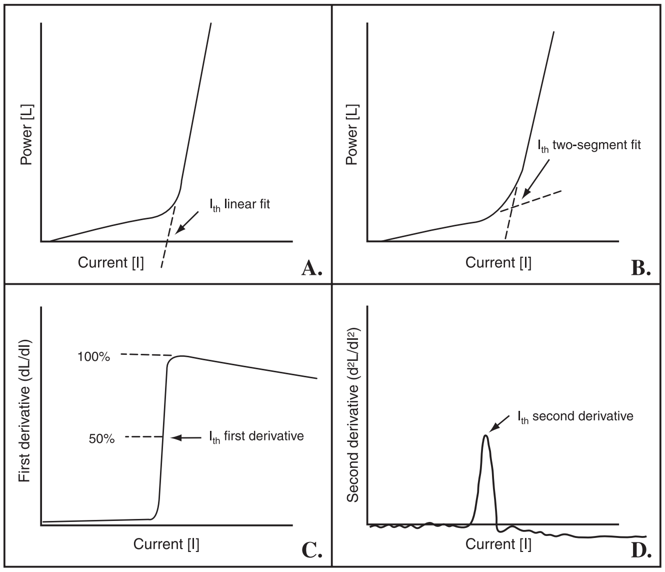

Figure 5. Several ways to find the threshold current: A) the linear fit, B) the two-segment fit, C) the first-derivative technique, and D) the second-derivative technique.

The dL/dI curve of Figure 6 plots the instantaneous slope efficiency against drive current. It is extremely sensitive to nonlinearities and is used to identify “kinks” in the L/I data. Once you become accustomed to viewing the relationship between the dL/dI curve and the L/I curve, you will not want to see diode laser data without it.

The second derivative of L/I data is the d^2/dI^2 curve. It is almost exclusively used in the calculation of diode laser threshold, as noted in Figure 5d.

The two remaining derivatives, the dV/dI and the IdV/ dI curves (Figure 7), are most often used for process control feedback in the diode laser manufacturing process. The dV/dI curve, usually called the dynamic resistance curve, is expressed in ohms and is the effective resistance to a change in current at a given current. As shown in Figure 7, typically there is a shift in this curve at lasing threshold separating LED operation from laser operation.

The IdV/dI curve is expressed in volts and is so far removed from the original data that it is difficult to understand intuitively. However, the IdV/dI curve is an extremely powerful tool for the diode laser manufacturer. Analysis of IdV/dI data allows equivalent circuit models to be created, for the specific diode laser under test. These models will show series and parallel, linear and nonlinear, resistive circuit elements. From this data, junction ideality factor, contact resistance, leakage currents, and threshold can be calculated. Device manufacturers use these derived data to control such process aspects as junction width, epitaxial growth, stoichiometry and a number of other process variables.

Remember, laser threshold can be determined using the IdV/dI curve. This may prove extremely convenient in production applications where a bare laser die must be characterized before mounting and packaging. This method of characterization permits threshold calculation without the time-

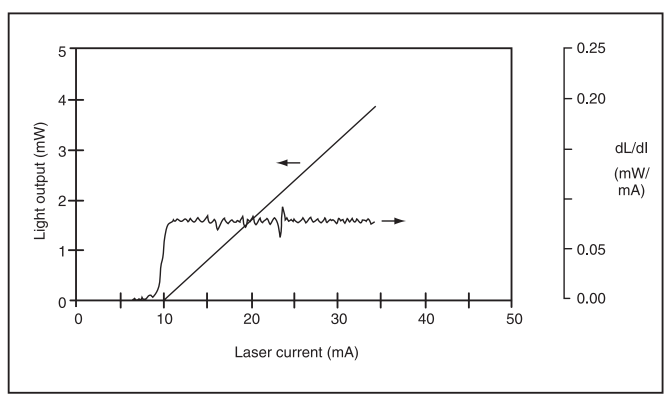

Figure 6. The first derivative of the L/I curve identifies subtle “kinks” in the L/I curve of a real device.

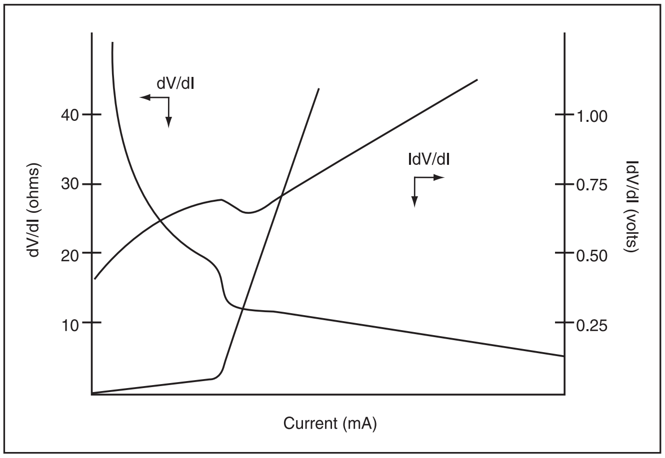

Figure 7. The dV/dI and IdV/dI curves are often used by diode laser manufacturers to control the manufacturing process.

consuming (and expensive) inconvenience of having to position the die in front of a detector!

Spatial Characteristics

The Far-Field Pattern. Unfortunately, diode lasers do not emit a collimated beam. The average laser emits a cone of light, typically elliptical in cross section. The divergence angles of this cone are measured by the full width-half maximum light power in the axes perpendicular to and parallel to the laser's active region. Typical values are 30° and 12°, respectively.

This ellipticity occurs because the emission aperture of the laser is a narrow slit, the long axis of which lies in the plane parallel to the junction. Diffraction effects are therefore stronger in one direction than in the other leading to larger angles in the plane perpendicular to the juncation and smaller angles in the plane parallel to the junction.

Excellent progress has been made in altering device structures to create diode lasers that emit round beams. These advances have been accomplished by adjusting the refractive index of the semiconductor material along the length of the laser cavity, producing various so-called index-guided structures.

The light intensity distribution profile of the laser output is roughly Gaussian in the perpendicular plane; in the parallel plane this is not nearly so often the case (Figure 8). Light within the laser cavity is easily confined to a single transverse mode in the perpendicular plane by the refractive indices in the layers of the device structure.

Confining the light to a single mode in the parallel plane is much more difficult. In simplified terms this is accomplished through carrier concentration and a number of index-guiding methods. At best, these methods hold off oscillations of higher-order transverse modes parallel to the junction until the laser is above its rated optical output power. At worst,

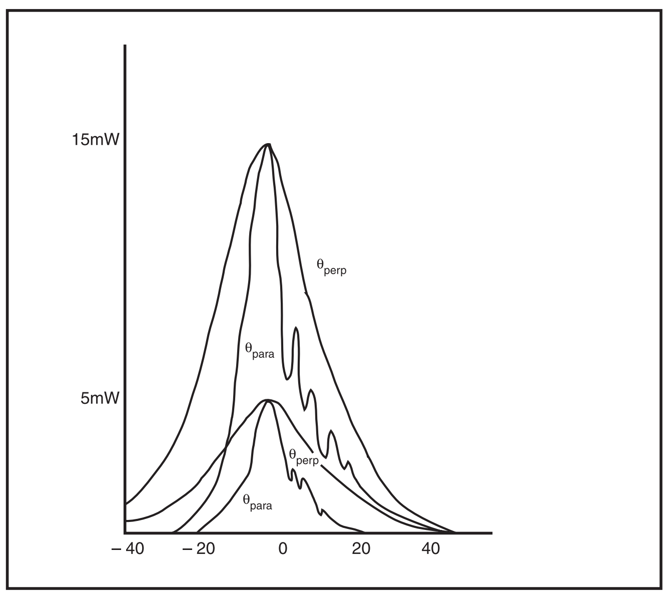

Figure 8. Far-field characteristics of a real-world diode laser.

the far-field pattern in this plane is a ragged mess.

One other far-field characteristic is worthy of note: the pointing angle. This is the axis of maximum radiated intensity, referenced to the mechanical centerline of the laser package. Every diode laser package has a reference surface. This reference surface is usually the front surface of the flange to which the can is welded. (The flange also typically has indexing notch that references the parallel and perpendicular axes). Pointing-angle errors an average about 1°, but may be occasionally as large as 4°.

The conventional method for acquiring far-field data is to sweep a small-area detector through arcs parallel and perpendicular to the laser. In practice, this can be accomplished three ways. The first is to literally swing the detector through the two arcs using a complex set of gimbals. The second is to leave the detector stationary and swing the laser. The third combines the two methods, giving the detector and the laser each one degree of freedom in which to move. None of these methods are particularly easy to implement.

The Near-Field Pattern. Gathering near-field data consists essentially of imaging the light output at the output facet of the diode laser. This can be done in a microscope with an attachment for a film holder or a television

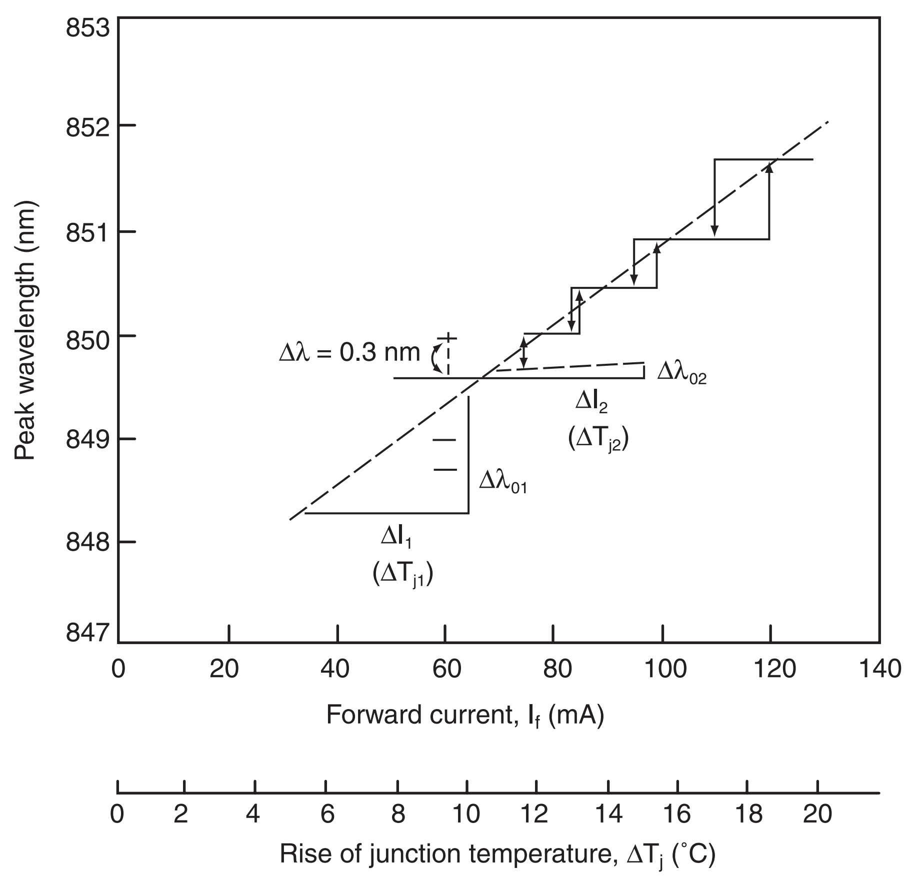

Figure 9. Spectral shift with changes in forward current in single longitudinal mode for an 850-nm diode laser.

camera. DO NOT LOOK AT THE LASER THROUGH THE MICROSCOPE WITH THE LASER TURNED ON!

Transverse mode changes and beam ellipticity observed in the far field are related to phenomena which can be observed by imaging the near field. In the case of multistripe lasers, however, near-field imaging will also permit relative intensity measurements of each individual laser element. Near-field imaging also shows multi-mode output in the plane parallel to the junction by non-uniformities in the radiation pattern.

Spectral Characteristics

Spectral Width. There are two basic types of spectral mode structures for diode lasers: singlemode and multimode. In the spectral context, these are longitudinal modes. Generally, 1300-nm and 1550-nm devices are multimode devices, with a spectral linewidth of about 3 nm FWHM. The exception to this is the distributed feedback laser (DFB), where a linewidth of less than 0.1 nm is typical.

Among the shorter wavelength lasers, both single- and multimode devices are available. At present, visible-wavelength lasers are multimode devices, but the technology is very new and certain to change rapidly.

Tunability. The two parameters that cause the laser's center wavelength to shift are junction temperature and drive current. Changes in temperature affect the bandgap of the semiconductor junction and therefore the peak wavelength of the cavity gain profile. Typical values for temperature tuning coefficients are 0.25 nm/°C in 780-nm devices and 0.4 nm/°C in 1300-nm and 1550-nm devices. In the case of telecom DFB lasers, the wavelength may vary 0.1 nm/°C.

The allowed longitudinal modes may be shifted by varying the effective cavity length of the laser with drive current (Figure 9). This effect occurs because current density in the laser junction and the instantaneous junction temperature change the refractive index of the junction material and therefore the effective cavity length. The thermal factor provides the larger effect, except at high modulation frequencies. These effects also have the fortunate property of tending to confine the transverse laser modes (as noted in the "Far Field" section earlier). The typical longitudinal mode tuning coefficient is 1 pm/mA in 830-nm lasers.

Mode Hopping. In single longitudinal mode lasers, these tuning effects cause what is commonly referred to as "mode hopping." Not only does the position of these mode hops vary from device to device, but a temperature-dependent hysteresis also occurs. Mode hopping can be very difficult to deal with.

A note of caution. The ability to make even moderately accurate generalities about diode lasers begins to break down when discussing their spectral characteristics. Many of the previously described effects tend to compound and degrade the performance of the device. In general, when operating a laser, it is important to provide a low-noise drive current and a stable and controllable temperature.

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

White Papers

- A Standard for Measuring Transient Suppression of Laser Diode Drivers
- Degree of Polarization vs. Poincaré Sphere Coverage
- Improving Splice Loss Measurement Repeatability

Technical Notes

- Attenuation Accuracy in the 7900 Fiber Optic Test System
- 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
- Clamping Limit of a LDX-3525 Precision Current Source
- Control Capability of the LDC-3916371 Fine Temperature Resolution Module
- Current Draw of the LDC-3926 16-Channel High Power Laser Diode Controller
- Determining the Polarization Dependent Response of the FPM-8210 Power Meter
- Four-Wire TEC Voltage Measurement with the LDT-5900 Series Temperature Controllers
- Guide to Selecting a Bias-T Laser Diode Mount
- High Power Linearity of the OMM-6810B and OMH-6780/6790/6795B Detector Heads
- Large-Signal Frequency Response of the 3916338 Current Source Module
- Laser Wavelength Measuring Using a Colored Glass Filter
- Long-Term Output Drift of a LDX-3620 Ultra Low-Noise Laser Diode Current Source
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- Long-Term Stability of an MPS-8033/55 ASE Source
- LRS-9424 Heat Sink Temperature Stability When Chamber Door Opens
- Measurement of 4-Wire Voltage Sense on an LDC-3916 Laser Diode Controller
- Measuring the Power and Wavelength of Pulsed Sources Using the OMM-6810B Optical Mutlimeter
- Measuring the Sensitivity of the OMH-6709B Optical Measurement Head
- Measuring the Wavelength of Noisy Sources Using the OMM-6810B Optical Multimeter
- Output Current Accuracy of a LDX-3525 Precision Current Source
- Pin Assignment for CC-305 and CC-505 Cables
- Power and Wavelength Stability of the 79800 DFB Source Module
- Power and Wavelength Stability of the MPS-8000 Series Fiber Optic Sources
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- Stability of the OMM-6810B Optical Multimeter and OMH-6727B InGaAs Power/Wavehead
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- 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
- Wavelength Accuracy of the 79800 DFB Source Module

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