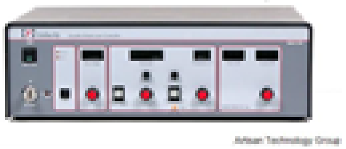
New Focus 6300
High-Power Velocity Tunable Diode Laser Controller

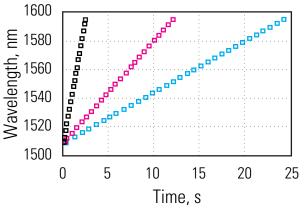


TLB-6300 Tunable Lasers

- *New wavelength ranges from 630 to 2 µm*
- *Cavity design eliminates mode-hops*
- *Smooth, linear, mode-hop-free tuning*

New—2 µm!

U.S. Patent #5,319,668



These curves demonstrate the monotonic and continuous tuning of a Model 6328 laser. They were taken using ⬛ maximum, 🟪 20% of maximum, and 🟦 10% of maximum tuning-speed settings.

Applications

- Testing and qualifying telecommunications components
- Spectroscopy of volatile gases in the atmosphere
- Seeding of optical parametric oscillators (OPOs) to provide narrow bandwidth
- Swept-frequency metrology
- FM locking and non-linear optical generation (see page 16)
- Measuring polarization-mode dispersion
- Spectroscopy and environmental sensing of methane, CO, CO$_2$, water vapor and hydrocarbons

The TLB-6300 (Velocity™ laser) series is our most versatile line of external-cavity tunable diode lasers. Designed for your most demanding applications, these lasers offer continuous tuning over wide wavelength ranges, fast linear sweeps, excellent tuning resolution, and narrow, stable linewidths.

Our laser-cavity design and proprietary manufacturing procedure ensure fast mode-hop-free tuning over the entire wavelength range and superior wavelength repeatability and precision with a greater than 40-dB side-mode suppression ratio. Our precision-engineered mechanical drive-train has a fine-frequency piezo control that allows you to set the laser's wavelength with a resolution of 0.02 pm. And unlike lasers driven by stepper motors, the TLB-6300's tuning is truly continuous and monotonic. (See page 24.) With a choice of wavelengths from 630 to 2 µm, these lasers are ideal for telecommunications, spectroscopy, metrology, and environmental-sensing applications.

Features:

High-Speed Current Modulation

Modulate the laser amplitude with a 3-dB bandwidth of 1 MHz through the controller's current-modulation input. Applying a signal directly to the laser diode via a connector on the laser head allows you to modulate the amplitude at rates of at least 100 MHz.

Easy Wavelength Modulation

Convenient wavelength modulation for spectroscopy or stabilization experiments is provided by a PZT actuator on the tuning element. Modulating the PZT through the modulation input on the back panel of the controller allows you to directly modulate the laser wavelength with a small-signal 3-dB bandwidth of 2 kHz. Full 30-GHz frequency modulation can be performed at rates up to 200 Hz.

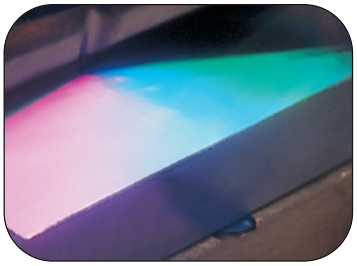
Automated Wavelength Scans

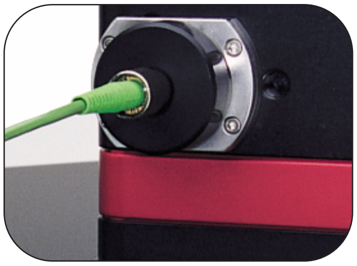
Easily perform wavelength scans over the entire tuning range of the laser. Just set the start and stop wavelengths and scanning speed (up to 20 nm/s for some models) and press the scan button.

Complete Computer Control and LabVIEW™ Programs

Anything you can adjust from the front panel can be controlled through RS-232 or GPIB (IEEE-488) interfaces. In remote mode, you still have access to the frequency-modulation input, allowing you to dither the frequency as you perform automated wavelength scans.

The general-purpose detector input on the back panel allows you to implement digital-control algorithms. This allows you to feed in signals from sources as diverse as photodetectors and frequency discriminators, and is particularly useful for stable-power wavelength scans, background correction in applied-spectroscopy experiments, and wavelength stabilization.





Laser Power: *Turns on the current to the diode.*

Piezo-Voltage Display: *Shows the percentage of the voltage applied to the piezoelectric transducer for fine-frequency control of the laser.*

Wavelength and Scan Speed Display: *Indicates operating wavelength, scan speed, and start and stop wavelengths. Accuracy: 0.1 nm.*

All front-panel functions can be controlled remotely through back-panel inputs.

Fine Frequency Control: *Sets the voltage to the piezoelectric transducer that controls the fine-frequency tuning of the laser.*

Multipurpose Paddles: *Used in conjunction with the setpoint knobs, this activates and deactivates stable-power mode, and sets wavelength, scan speed, start and stop wavelengths, diode temperature, baudrate and GPIB addressing.*

Current Controls: *Sets the diode current and monitors the actual laser output power. (Output power is measured by diverting a small fraction of the output power to a monitor photodiode.)* ***Display resolution:*** *0.1 mW and 0.4 mA.*

Frequency Modulation Input: *Allows you to control the voltage applied to the piezo. It is equivalent to the fine frequency adjust on the front panel.*

Current Modulation Input: *Lets you modulate the amplitude of the laser. It has a 1-MHz bandwidth. The SMA input on the laser head has a >100-MHz bandwidth.*

Remote Interfaces: *Let you use either an IEEE-488 or an RS-232 computer interface.*

Wavelength Output: *Results in a 0–10-V linear output that is proportional to the actual wavelength of the laser.*

Wavelength Input: *Lets you control the laser wavelength (equivalent to the coarse adjust on the front panel).* ***Resolution:*** *0.01 nm.*

Detector Input: *Gives you a general-purpose analog input for control applications.*

Higher power and custom wavelengths are available. Please contact our sales department for information on the latest products at sales@newfocus.com.

Mode-Hop-Free Tuning Range	**632.5–637 nm**	**668–678 nm**	**765–781 nm**	**838–853 nm**	**960–995 nm**	**1055–1075 nm**	**1220–1250 nm**
Minimum Power	2 mW	2 mW	5 mW	5 mW	5.5 mW	4 mW	5 mW
Typical Maximum Power	5 mW	4 mW	12 mW	7 mW	8 mW	6 mW	7 mW
Maximum Coarse-Tuning Speed	6 nm/s	6 nm/s	8 nm/s	8 nm/s	12 nm/s	12 nm/s	20 nm/s
Coarse-Tuning Resolution	0.02 nm	0.02 nm	0.02 nm	0.02 nm	0.02 nm	0.02 nm	0.02 nm
Typical Wavelength Repeatability	0.1 nm	0.1 nm	0.1 nm	0.1 nm	0.1 nm	0.1 nm	0.1 nm
Fine-Frequency Tuning Range	70 GHz (0.09 nm)	70 GHz (0.1 nm)	75 GHz (0.15 nm)	60 GHz (0.14 nm)	50 GHz (0.16 nm)	50 GHz (0.16 nm)	45 GHz (0.3 nm)
Fine-Frequency Modulation Bandwidth	2 kHz	2 kHz	2 kHz	2 kHz	2 kHz	2 kHz	2 kHz
Current-Modulation BW	100 MHz	100 MHz	100 MHz	100 MHz	100 MHz	100 MHz	100 MHz
Linewidth	<300 kHz	<300 kHz	<300 kHz	<300 kHz	<300 kHz	<300 kHz	<300 kHz
Model #	**TLB-6304**	**TLB-6308**	**TLB-6312**	**TLB-6316**	**TLB-6320**	**TLB-6321**	**TLB-6323**
Base System Price*	$19,500	$18,500	$20,000	$21,000	$27,000	$25,000	$25,000
Additional Laser Head*	Add -D to Model # and $11,000	Add -D to Model # and $10,000	Add -D to Model # and $11,500	Add -D to Model # and $12,500	Add -D to Model # and $18,500	Add -D to Model # and $16,500	Add -D to Model # and $16,500
Fiber Pigtail with FC/APC Connector*†	Add -P to Model # and $4,500	Add -P to Model # and $4,500	Add -P to Model # and $4,500	Add -P to Model # and $4,500	Add -P to Model # and $4,500	Add -P to Model # and $3,500	Add -P to Model # and $3,500

Mode-Hop-Free Tuning Range	**1270–1330 nm**	**1470–1545 nm**	**1415–1480 nm**	**1520–1570 nm**	**1550–1630 nm**	**1650–1680 nm**	**1940–1970 nm**	**1970–2000 nm**
Minimum Power	5 mW	4 mW	3 mW	20 mW	4 mW	3 mW	2 mW	2 mW
Typical Maximum Power	7 mW	10 mW	8 mW	20 mW	4 mW	5 mW	3 mW	3 mW
Maximum Coarse-Tuning Speed	15 nm/s	20 nm/s	20 nm/s	20 nm/s	25 nm/s	20 nm/s	20 nm/s	25 nm/s
Coarse-Tuning Resolution	0.02 nm	0.02 nm	0.02 nm	0.02 nm	0.02 nm	0.02 nm	0.02 nm	0.02 nm
Typical Wavelength Repeatability	0.1 nm	0.1 nm	0.1 nm	0.1 nm	0.1 nm	0.1 nm	0.1 nm	0.1 nm
Fine-Frequency Tuning Range	50 GHz (0.29 nm)	30 GHz (0.23 nm)	30 GHz (0.24 nm)	30 GHz (0.24 nm)	30 GHz (0.24 nm)	30 GHz (0.24 nm)	20 GHz (0.30 nm)	20 GHz (0.30 nm)
Fine-Frequency Modulation Bandwidth	2 kHz	2 kHz	2 kHz	2 kHz	2 kHz	2 kHz	2 kHz	2 kHz
Current-Modulation BW	100 MHz	100 MHz	100 MHz	100 MHz	100 MHz	100 MHz	100 MHz	100 MHz
Linewidth	<300 kHz	<300 kHz	<300 kHz	<300 kHz	<300 kHz	<300 kHz	<300 kHz	<300 kHz
Model #	**TLB-6324**	**TLB-6326**	**TLB-6327**	**TLB-6328**	**TLB-6330**	**TLB-6331**	**TLB-6334**	**TLB-6335**
Base System Price*	$24,000	$24,000	$25,000	$25,000	$25,000	$25,000	Call for Pricing	Call for Pricing
Additional Laser Head*	Add -D to Model # and $15,500	Add -D to Model # and $15,500	Add -D to Model # and $16,500	Add -D to Model # and $16,500	Add -D to Model # and $16,500	Add -D to Model # and $16,500	Add -D to Model # (call for price)	Add -D to Model # (call for price)
Fiber Pigtail with FC/APC Connector*†	Add -P to Model # and $3,500	Add -P to Model # and $3,500	Add -P to Model # and $3,500	Add -P to Model # and $3,500	Add -P to Model # and $3,500	Add -P to Model # and $3,500	Add -P to Model # (call for price)	Add -P to Model # (call for price)

See page 14 for tuning curves.
For special orders or items not contained in this table, please e-mail us at sales@newfocus.com.

† *Typical coupling efficiency is >30% for Model 6304, >40% for Models 6308, 6312, 6316, 6320, 6331, 6334, 6335, and >50% for all other models. Fiber used is polarization-maintaining (PM) PANDA fiber.*

Related Products: Photodetectors (pages 60–99) ■ Modulators (pages 116–119) ■ Power Meters (pages 56–59)

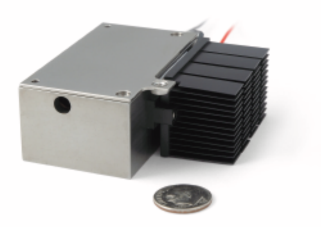
Definitions of Characteristics (page 11)

**For international prices add 10%.*

Tunable Laser Selection Guide

Whether you need a stand-alone benchtop unit or custom OEM module, turn to the world's leading supplier of tunable lasers for test and measurement—New Focus™. We offer a wide variety of lasers covering tuning ranges from 400 nm to 2 µm, including swept-wavelength sources, narrowly tunable sources, and new cPCI/PXI module sources. Their highly coherent, tunable output is ideal for applications ranging from telecommunications to atomic and molecular spectroscopy, interferometry, and metrology.

The TLM-8700 laser modules use a new technology to achieve 1-nm/s to >1,000-nm/s tuning speeds.



Our new TLB-7000-XP lasers deliver >50 mW at 780 and 850 nm.

Tunable Lasers Currently Available

Benchtop Lasers	Wavelengths Covered	Mode-Hop-Free Tuning Range
TLB-6000	400–420 nm, 630–2000 nm	Up to 80 GHz
TLB-6300	400–420 nm, 630–2000 nm	Up to 80 nm
TLB-6500*	1425–1620 nm, 1260–1340 nm, 960–995 nm	Up to 100 nm
TLB-7000	632.5–640 nm, 835–853 nm	150 GHz
TLB-7000-XP	767–781 nm, 840–853 nm	15 GHz

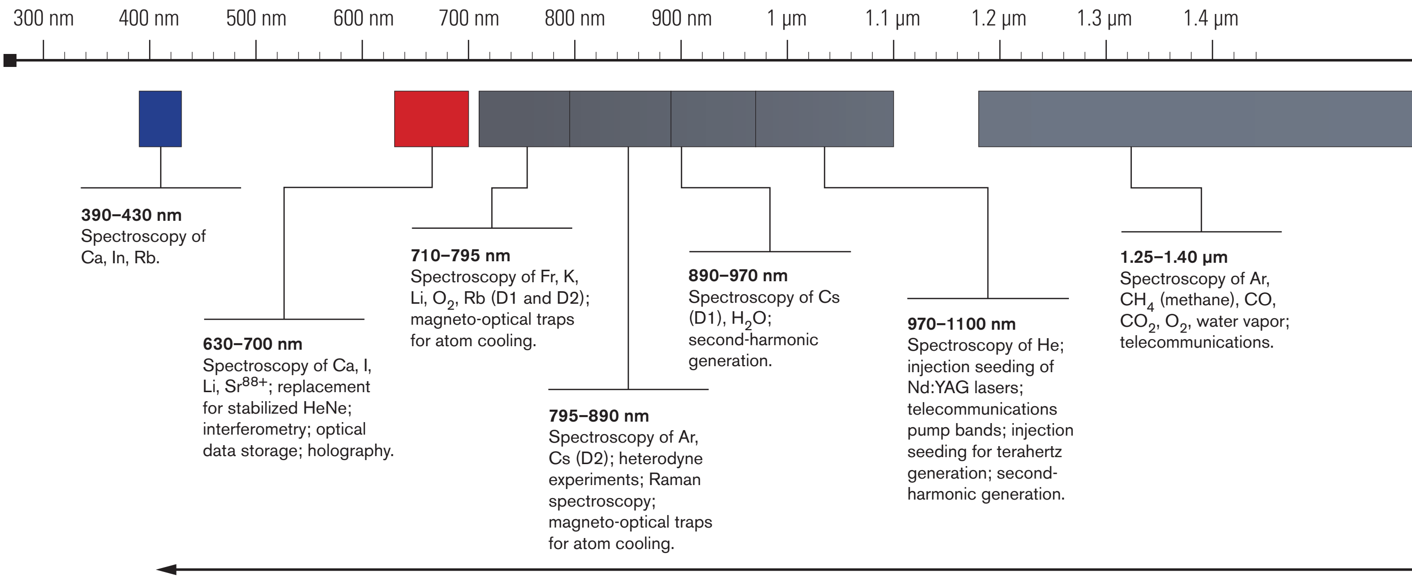
Module Lasers	Wavelengths Covered	Mode-Hop-Free Tuning Range
TLM-8700*	1460–1630 nm	>110 nm

**Custom wavelengths are also available. Call for pricing and lead times.*

Available on our Web Site

For current off-the-shelf laser solutions, visit www.newfocus.com.

Diagram of Laser Applications and Their Wavelength Regions



390–430 nm
Spectroscopy of Ca, In, Rb.

630–700 nm
Spectroscopy of Ca, I, Li, Sr^{88+}; replacement for stabilized HeNe; interferometry; optical data storage; holography.

710–795 nm
Spectroscopy of Fr, K, Li, O_2, Rb (D1 and D2); magneto-optical traps for atom cooling.

795–890 nm
Spectroscopy of Ar, Cs (D2); heterodyne experiments; Raman spectroscopy; magneto-optical traps for atom cooling.

890–970 nm
Spectroscopy of Cs (D1), H_2O; second-harmonic generation.

970–1100 nm
Spectroscopy of He; injection seeding of Nd:YAG lasers; telecommunications pump bands; injection seeding for terahertz generation; second-harmonic generation.

1.25–1.40 µm
Spectroscopy of Ar, CH_4 (methane), CO, CO_2, O_2, water vapor; telecommunications.

Wavelengths from 405 nm–2.0 µm are currently available from New Focus.

The TLB-7000 StableWave™ laser series builds upon the popular TLB-6000 (Vortex™ laser) series offering improved performance at 633 nm and 852 nm with increased ruggedness—ideal for atomic-clock, cooling, metrology, and phase-shifting-interferometry applications.

The new TLB-7000-XP laser offers a 5 to 10 times improvement in output powers at 780 and 850 nm. With greater than 50 mW of output power, these lasers are ideal for atomic cooling and clock experiments where you need more power.

The swept-wavelength TLB-6500 laser family offers coverage across all key telecom bands, low ASE, and an easy-to-use icon-based interface for telecom-component characterization and fiber-sensing applications.

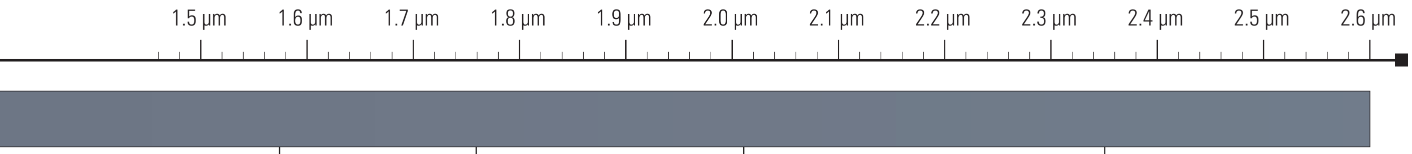
The TLB-6300 (Velocity™ laser) series is ideal for FM locking, measuring polarization-mode dispersion, and nonlinear optics. The 980-nm model is useful for characterizing EDFA pump components. New this year are lasers that cover the wavelength ranges from 1.6 to 2.0 µm for environmental sensing. For other wavelengths, please contact us.

The TLB-6000 (Vortex™ laser) series consists of reasonably priced, built-to-order lasers with tuning ranges up to 80 GHz—wide enough for most absorption spectra and metrology applications.

The TLB-390X laser is ideal for DWDM telecom test-and-measurement applications requiring 20 mW of output power across the C band.

The new TLM-8700 cPCI/PXI tunable laser modules deliver ultrafast tuning of 1,000 nm/s over more than 165 nm of tuning in the C-band. They are easily integrated into the PXI platform with our other modules (swept-wavelength meter and power sensor).

And, if you don't see what you need, let our award-winning, interdisciplinary engineering team work with you to design lasers specifically for your application. With our ISO 9001:2000-compliant quality systems, we will manufacture to your specs, on time, and with engineered cost savings. We even have lasers in development for use in space-deployed atomic clocks.



1.48–1.67 µm
Spectroscopy of acetylene, CH_4 (methane), CO, CO_2, Kr, NH_2, water vapor, hydrocarbons; telecommunications; fiber-Bragg gratings that measure temperature, pressure, and strain.

1.70–1.82 µm
Spectroscopy of CH_4 (methane), He, NO, water vapor.

1.94–2.08 µm
Spectroscopy of CO_2, NH_2, water vapor.

2.10–2.60 µm
Spectroscopy of CO, N_2O, CH_4 (methane), NH_2, water vapor.

For wavelengths above 2.0 µm please call for availability.

New Focus™ Tunable Lasers

What's Inside Our Tunable Lasers

The laser cavities in our external-cavity diode laser (ECDL) systems and laser modules are the result of many years of experience in designing and manufacturing tunable lasers. Their demonstrated quality and reliability have helped make New Focus the leading supplier of tunable lasers for test and measurement.

All New Focus lasers start out as commercially available semiconductor-diode lasers. These diodes typically operate with several longitudinal modes lasing simultaneously, leading to low coherence and large linewidths. To ensure high coherence, we anti-reflection (AR) coat the diodes so they act only as gain elements. The diode can then be placed in an external cavity that contains wavelength-selective optics so that only a single mode lases at any given time.

Robust, Proprietary AR Coating for Broad Wavelength Tunability

True single-mode tuning requires that the optical feedback is dominated by the external optics, not by reflections from the diode facet. We use a proprietary AR-coating process to reduce residual diode reflectivities to below 0.001—which guarantees true single-mode operation. This process allows us to use nearly any available single-mode diode laser and achieve low reflectivity over a broad wavelength range. In addition, since the lifetime of an ECDL is commonly limited by that of the AR coating, our proprietary process ensures that our coatings last.

Precision Mechanics Result in a Laser with Truly Continuous, Mode-Hop-Free Tuning

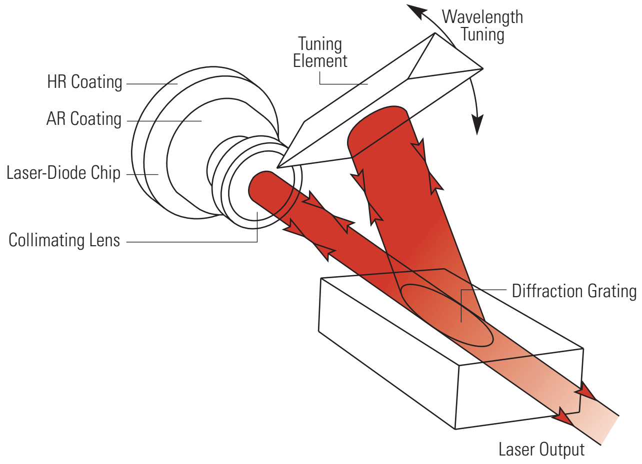
Once the diode is coated, we place it in an external laser cavity that is a modified Littman-Metcalf configuration. In this cavity, a grazing-incidence diffraction grating and a tuning element provide all the necessary dispersion for single-mode operation. In addition, our cavity design allows mode-hop-free tuning. The wavelength in our modified Littman-Metcalf laser is changed by rotating the tuning element, which changes the diffracted wavelength fed back into the cavity. To prevent mode hopping, the cavity length must be kept at a constant number of wavelengths as the laser tunes. This requires positioning the pivot point around which the tuning element rotates with sub-micron accuracy, enabling us to produce lasers with no mode hops.

Tight Environmental Control for Narrow Linewidth

Once single-mode operation is established by the optics in the external cavity, the linewidth of the laser can be affected by acoustic coupling and cavity-temperature variations, each of which can change the cavity length, and electrical-noise coupling, which causes changes in the index of refraction of the diode and in the piezo length (also affecting the cavity length). Every aspect of our laser design aims to minimize these effects. For example, our laser controllers feature current sources with less than 100-nA$_{rms}$ current noise in a 1-MHz bandwidth.

Laser Cavity Designs for 24/7 Reliability

Adding our extensive experience in manufacturing lasers and opto-mechanics to the proprietary AR coating and unique cavity design results in a robust and rugged laser that can withstand rough handling and a variety of environmental conditions. These lasers surpass international shipping standards for shock and vibration and can operate in environments with up to 80% relative humidity from 15–35 °C. This means that they can survive the long-term, 24/7 use (and abuse) found on many manufacturing floors.



A modified Littman-Metcalf configuration.

New Focus™ Tunable Lasers

Absolute Wavelength Accuracy

The maximum difference between the measured wavelength and the displayed wavelength of the laser system.

Amplified Spontaneous Emission (ASE)

The ratio of the optical power at the center of the laser linewidth to the optical power at a given distance, as measured using an optical spectrum analyzer with a set resolution bandwidth. (See "Why is the Noise Spectrum Important?" on page 12.)

Coarse-Tuning Resolution

The smallest wavelength change you can make with the coarse-tuning DC motor on the TLB-6300 laser.

Current-Modulation Bandwidth

The highest rate at which the laser diode's current can be changed. This is the 3-dB frequency of the direct-modulation input located at the laser head.

Fine-Frequency Modulation Bandwidth

The highest rate at which the fine-tuning PZT in the laser cavity can modulate the laser frequency. The specified bandwidth is for a 3-dB drop from a low-frequency baseline under small-signal modulation.

Fine-Frequency Tuning Range

The frequency range over which the laser can be piezoelectrically tuned. (If λ is the wavelength of the laser and c is the speed of light, the tuning range expressed in frequency, $\Delta\nu$, and wavelength, $\Delta\lambda$, is related by $\Delta\nu = c \cdot \Delta\lambda/\lambda^2$. Keep in mind that 30 GHz is equivalent to 1 cm^{-1}.)

Integrated Dynamic Range

The ratio of the signal to the source emission, integrated over all wavelengths. This is measured by observing the spectrum of two cascaded fiber-Bragg gratings with a total rejection ratio of >100 dB and a 0.8-nm window, and is a realistic expectation of the dynamic range of your measurement. (See "Why is the Noise Spectrum Important?" on page 12.)

Linewidth

The laser's short-term frequency stability. It is measured using a heterodyne beatnote that is recorded over a 50-ms interval. The linewidth varies as a function of integration time. For a graph of the measured frequency stability versus integration time, please see the discussion on page 14.

Maximum Coarse-Tuning Speed

The highest guaranteed speed at which the TLB-6300 laser can tune using the coarse-tuning DC motor. The actual maximum coarse-tuning speed for individual systems may vary, but will always be at least this fast.

Minimum Power

The lowest power that the laser will output across its specified tuning range when the current is set to its recommended operating value. Due to changes in diode gain and cavity loss with wavelength, the laser's output power is not constant as it tunes. (See tuning curves on page 14.)

Output Power

The typical power that the laser will output across the entire tuning range.

Power Repeatability

The typical difference in power between scans for a given wavelength.

Power Stability

The maximum deviation in power as the laser sits at a specific wavelength over a 1-hour period.

Side-Mode Suppression Ratio

The ratio of the carrier to the nearest side mode.

Tuning Range

The span of wavelengths over which the laser is guaranteed to operate. For the TLB-6300 series, the laser may be able to tune outside this range, but this may introduce mode hops.

Tuning Speed

The speed over which the laser can sweep over the entire tuning range.

Typical Maximum Power

The maximum output power you can expect over the laser's tuning range. Due to changes in diode gain and cavity loss with wavelength, the laser's output power is not constant as it tunes.

Wavelength Repeatability

The largest measured deviation that may occur when the laser returns to a given set wavelength. This is a measure of how well the laser returns to a set wavelength over many attempts and when approached from different directions.

Wavelength Resolution

The smallest step the laser can tune.

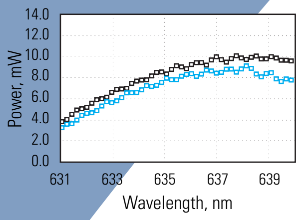
Wavelength Stability

The maximum amount of drift the laser will exhibit over a specified period of time and temperature variation.

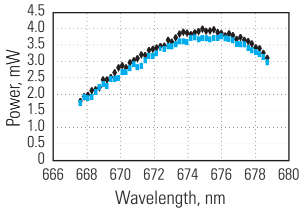
TLB-6300 (Velocity™ Laser) and TLB-6000 (Vortex™ Laser) Performance Data

Tuning Curves

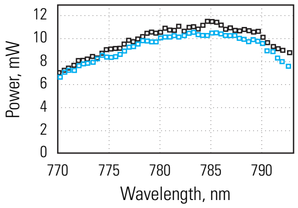
These graphs show sample tuning curves for some of our TLB-6300 lasers. The two curves represent the maximum and minimum power over a tuning resolution of about 0.1 nm. This modulation is due to residual reflectivity at the diode output facet. Since the TLB-6300 diodes and laser cavities are similar to those used in the TLB-6000 lasers, you may also use these curves to approximate the power output at any wavelength for the narrow-tuning TLB-6000 lasers.



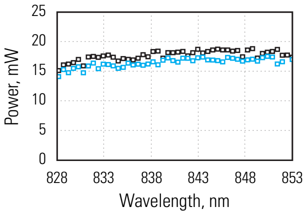
Model 6304



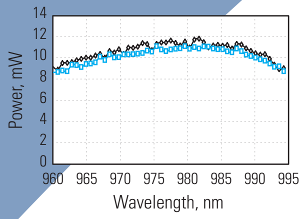
Model 6308



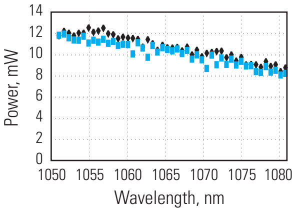
Model 6312



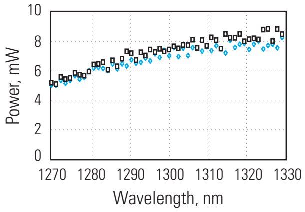
Model 6316



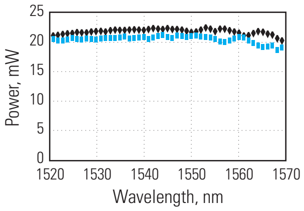
Model 6320



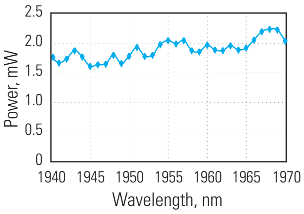
Model 6321



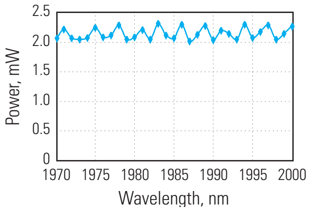
Model 6324



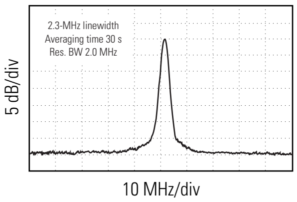
Model 6328



Model 6334

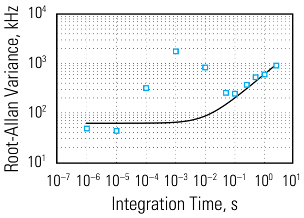


Model 6335



Laser Linewidth

This beatnote linewidth between two external-cavity diode lasers was measured over a 30-s interval. The linewidth was determined using a heterodyne technique. The individual laser linewidth over a 50-ms interval was less than 300 kHz.



Linewidth as a Function of Integration Time

The Root-Allan variance, like heterodyne linewidth, is a measure of the frequency stability of an oscillator. It can be interpreted as the laser linewidth over a given time interval and gives you a very accurate description of long-term laser frequency variations.* The measured Allan variance for two of our lasers shows that the linewidth is narrowest (~50 kHz) at short integration times and increases with integration time. The short-time fluctuations are mainly due to electrical fluctuations. The long-time fluctuations are mainly due to slow temperature changes, and the middle-time spikes are the result of acoustically excited mechanical resonances in the laser cavity. The curve fit is based on a model that includes flicker and random-walk frequency noise. The linewidth at longer time intervals can be estimated by extrapolating the line.

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* F.L. Walls, and D.W. Allan, "Measurements of Frequency Stability," *Proc. IEEE 74*, No. 1 (1986) pp. 162–168.

TLB-6300 and TLB-6000 Lasers

What is the output-beam polarization?

The output beams are linearly polarized in a vertical plane, with a polarization ratio of 100:1 free space.

Does the laser mode hop? How can I tell if it does?

With the precise pivot-point location of the tuning element, our lasers do not mode hop over the specified tuning range. However, if the laser does mode hop, the frequency change would be 3 GHz—equal to the external-cavity free-spectral range. (In contrast, for a poorly coated diode laser, it can be as much as 100 GHz.) To determine if the laser has mode hopped, you will need a wavelength meter. The meter will indicate a phase-error signal and a discontinuous change in frequency of about 0.1 cm^{-1}.

We individually test every laser we build and ship them with printouts of their tuning curves, so you'll know exactly what to expect from your laser. (Please contact us if you would like to see sample tuning curves in your wavelength range.)

How is the tuning achieved?

For the TLB-6300, we separate wavelength tuning of our lasers into coarse and fine tuning. Coarse tuning is accomplished by using a DC motor to turn a precision screw. An angle sensor incorporated in the laser cavity feeds back to the microprocessor to scan to the desired wavelength. On the end of the coarse tuning screw is a piezoelectric actuator (PZT). This actuator provides independent fine control of the laser wavelength and can also be used to modulate the laser frequency while it is being slowly scanned. For the narrow tuning of the TLB-6000 lasers no DC motor is required, so we use the PZT to control the wavelength.

How precisely can I set the wavelength?

For the TLB-6300, the coarse-tuning mechanism allows you to set the wavelength with a resolution of 0.02 nm. The fine-frequency resolution is 10 MHz (about 2×10^{-5} nm) with a range several times larger than the coarse-tuning resolution. For the TLB-6000, the tuning resolution is wavelength dependent, but is always finer than 1/100 of the tuning range.

What's the frequency stability?

The frequency drift of the laser is less than 0.02 nm over an entire day, and less than 5 MHz over a 5-second interval. The 50-ms linewidth is 300 kHz or less. Stabilizing the frequency of the laser is easy with an error feedback signal to the frequency-modulation input on the back panel. Using this technique, wavelength drift can be dramatically reduced.

Can I stabilize the frequency of the laser?

The laser can easily be locked either to an atomic line or to an external cavity using wavelength-modulation techniques to produce a feedback signal. Dither the laser frequency through the frequency-modulation input. The error signal generated can then be fed back to the laser through the drive current.

What is the minimum observable frequency shift over >5-second intervals?

The minimum frequency shift that is observable over the frequency jitter of the laser is 1 MHz.

Can I eliminate coherence effects due to the narrow linewidth?

If you're working with unterminated fibers, you may be concerned about possible coherence effects due to the narrow linewidth. For most measurements, a simple way to make the linewidth appear much broader is to apply a signal to the piezo in order to frequency modulate the laser.

Can I modulate the laser amplitude? Will the wavelength be affected?

You can modulate the laser current by applying analog voltages to the current-modulation input at a rate of up to 1 MHz with a modulation amplitude of up to 2-mA peak. You can also modulate the laser's amplitude with a bandwidth of 100 MHz and an amplitude of up to 10-mA peak through the SMA connector on the laser head. Small changes in the index of refraction of the laser-gain medium as a function of laser current lead to changes in the laser wavelength when the current is modulated. The wavelength-modulation coefficient depends strongly on each laser diode's characteristics, but is typically 50 MHz/mA and at most 1 GHz/mA.

What is the wavelength-modulation bandwidth?

While you can modulate the wavelength by scanning the drive motor (TLB-6300 only) or by changing the laser-drive current, the most straightforward way to modulate the laser wavelength is by changing the voltage to the PZT actuator on the tuning element. The small-signal bandwidth of the fine-frequency input is 2 kHz in the TLB-6300 lasers and 3.5 kHz in the TLB-6000 lasers.

How stable is the output amplitude? Can I amplitude-stabilize the laser?

The amplitude stability of our TLB-6300 and TLB-6000 lasers over 10 seconds is better than 0.25% at any given wavelength. To prevent optical feedback from affecting the laser's performance, we recommend using an optical isolator with our free-space lasers. For fiber-coupled lasers, the fiber pigtails have built-in isolators.

Are the laser heads interchangeable?

Yes. The same controller will work with any laser head in its family. However, wavelength calibration for each laser head is guaranteed only when it is used with its original controller. Laser heads will not work with controllers from other families. (When ordering additional laser heads for a TLB-6300 system, initial calibration of the head to the controller may be required.)

How many laser heads can I operate at one time?

Each controller can operate one laser head at a time. To operate two lasers simultaneously, you need two controllers.

What if I need to get a specific wavelength or higher power?

We routinely build systems to order. Contact us for more information.

What's the fiber used in the TLB-6300 optional fiber pigtail?

Included with this option are all the necessary coupling optics and a fiber isolator which provides at least 30-dB isolation over the laser's entire tuning range. This package bolts to the front of the laser head and alignment screws are provided to peak up the output power. The fiber is a polarization maintaining (PM) PANDA fiber. All pigtails have FC/APC connectors standard. The coupling loss from the laser to the fiber pigtail is >3 dB. The PM fiber is aligned with the polarized axis to within two degrees of the output polarization of the laser. This results in an 18-dB to 20-dB polarization ratio (approximately 100:1). For this option, add "-P" to the model number.

Tunable Lasers—Applications to Spark Your Imagination

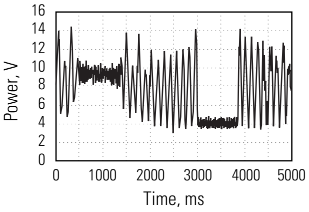
TLB-7000-XP, TLB-7000, TLB-6300, and TLB-6000

These pages highlight a few of the wide variety of applications that have used our tunable lasers. If you are interested in learning more about these applications, we will happily fax you the references.

We're always interested in hearing how you are using (or plan to use) our lasers, so please contact us if you have an application you'd like to share.

Mode-Hop-Free Tuning and Narrow Linewidths for Swept-Frequency Measurements

Interferometry is widely used to make precision length and displacement measurements ranging from less than a nanometer to tens of meters. Researchers used our 630-nm TLB-6300 laser to perform these types of precision measurements. The graph below shows a wavelength scan of a short-path-length interferometer (a couple of centimeters). The interferometer fringes are smooth and evenly spaced, demonstrating that the laser is operating single mode and mode-hop free over the entire tuning range. The phase-continuous (mode-hop-free) tuning over a wide tuning range allows high-resolution measurements over large distances.[1]



Swept-wavelength measurement of an unbalanced interferometer. The scanning range was 5 nm with a path-length difference of a few millimeters.

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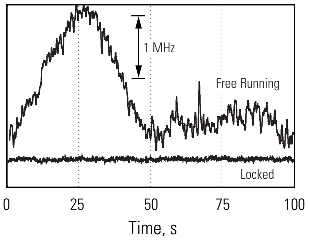
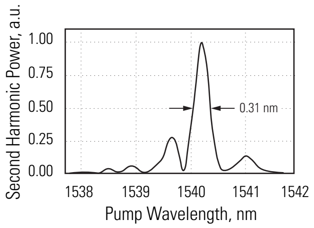
[1] G.P. Barwood, P. Gill, and W.R.C. Rowley, *Meas. Sci. Technol.* 4 (1993) pp. 988–994. "Laser diodes for length determination using swept-frequency interferometry."

FM Locking and Nonlinear Generation

Researchers have used one of our lasers locked to the atomic lines of rubidium and potassium to create frequency standards at 1550 nm. In their setup, the output of the external-cavity diode laser at 1550 nm was frequency doubled in a periodically poled $LiNbO_3$ waveguide, then injected into a cell containing either rubidium or potassium gas. By dithering the laser frequency, wavelength-modulation spectroscopic techniques were used to create an error signal that was then fed back to the laser to stabilize the laser's output frequency. Such techniques are important in developing frequency standards for dense wavelength-division-multiplexed (DWDM) optical-communication and fiber-optic sensing systems.



This graph compares the frequency noise of a New Focus™ laser without any feedback control to the same laser when actively stabilized to a sub-Doppler absorption line of rubidium.[2]



This phase-matching curve was generated in a periodically poled $LiNbO_3$ waveguide doubler using a New Focus laser at 1540 nm.[3]

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[2] V. Mahal, A. Arie, M.A. Arbore, and M.M. Fejer, *Opt. Lett.* 21 (1996) pp. 1217–1219. "Quasi-phase-matched frequency doubling in a waveguide of a 1560-nm diode laser and locking to the rubidium D_2 absorption lines."

[3] A. Bruner, A. Arie, M.A. Arbore, and M.M. Fejer, *Appl. Opt.* 37 (1998) pp. 1049–1052. "Frequency stabilization of a diode laser at 1540 nm by locking to sub-Doppler lines of potassium at 770 nm."

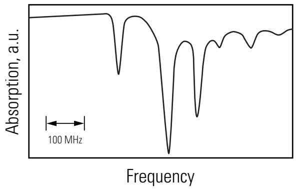
Absolute Frequency Measurements

Absolute frequency measurements can be a challenge, but they can be aided significantly by commercially available tunable diode lasers. A team at JILA/NIST has used nonlinear optics to compare the UV sum frequency generated from the doubled Nd:YAG output plus 778-nm Ti:Sapphire light with the UV frequency obtained by doubling a stabilized, tunable 632-nm diode laser. Effectively this experiment measures the 532-nm frequency of an iodine reference transition in terms of known standards at 633 nm and 778 nm. The international team included French, Russian, Japanese, Australian, and Chinese scientists, in addition to University of Colorado students and postdocs. Pictured are: Scott Diddams (JILA/NIST), Bruce Tiemann (CU), and Lei Hong (from NIST's sister organization, NRLM, in Tsukuba, Japan).

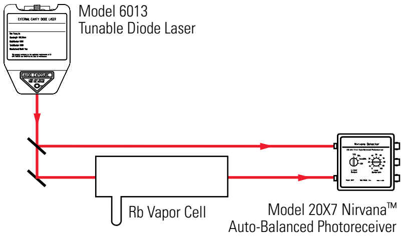
FM Spectroscopy with our TLB-6000 Tunable Diode Laser

The TLB-6000 laser is ideal for frequency-modulation (FM) spectroscopy—a powerful laser-spectroscopic technique that can achieve a high signal-to-noise ratio with a relatively simple experiment. A typical setup is shown at right. In the simplest FM spectroscopy experiment, a laser beam is transmitted through a gas cell containing an atomic or molecular vapor. The wavelength of this continuous-wave laser is modulated at a particular frequency through direct frequency modulation. As the wavelength is scanned across the atomic transition, the frequency modulation is converted into amplitude modulation through the optical absorption of the beam. In the case of the TLB-6000, this is easily achieved with the frequency-modulation input that has a bandwidth of 3.5 kHz. A Doppler-free saturated absorption spectrum, taken using a TLB-6000 laser, is shown in the graph below.

NOTE: For more information, see page 282 for "Application Note 7: FM Spectroscopy with Tunable Diode Lasers."



This graph shows Doppler-free absorption lines of rubidium obtained with a TLB-6000 laser and a Nirvana auto-balanced photoreceiver.



In the FM-spectroscopy setup above, a second laser beam that does not pass through the vapor cell is used to eliminate laser-intensity fluctuations. A dual-balanced photodetector, such as the Model 20X7 Nirvana™ photoreceiver (page 76), is used to make a differential measurement.

Phase-Shifting Interferometry for Determining Optical Surface Quality

Determining the surface quality of an optic—the deviation from the intended shape whether flat, spherical, etc—is critical to optics manufacturing. Traditional methods consist of an interferometer, for example a Twyman-Green interferometer (pictured below) that compares the test optic to a reference. Differences in optical path length between the two arms of the interferometer lead to bright and dark fringes in the photodetector—typically a CCD array. Points lying on the same fringe center are at an equal optical path-length difference while points on adjacent centers represent a difference of a half wavelength. Introducing a small tilt between the reference and test optic results in an interferogram where any deviation from an evenly spaced straight fringe implies an aberration from the test optic, as shown below.

While analyzing interferograms is an extremely powerful technique, there are a few disadvantages. Finding the location of the fringe centers, which ultimately limits the accuracy of the technique, is a difficult task, and any intensity variations across the interferogram or sensitivity variations in the photodetector introduce spurious errors. Another drawback is that data is obtained only along the fringe centers not on the regularly spaced grid that many analysis routines demand. Lastly, since a few widely spaced fringes can be measured more accurately than many closely spaced ones, there is a tradeoff between resolution and the number of data points.

Phase-shifting interferometry overcomes these limitations. First, phase-shifting interferometry does not rely on finding the fringe centers. Second, measurements can be taken at every element in the photodetector array directly yielding optical path-length differences on a regularly spaced grid. The concept behind phase-shifting interferometry is to apply a time-varying phase shift between the reference and test wavefronts. This can be achieved, for example, by mounting the reference optic on a linear transducer, such as a piezoelectric transducer. If the relative phase-shift, α, is linear in time, the intensity on every point in the photodetector array, I, will change sinusoidally with time

$$I(x, y, t) = B(x, y) + A(x, y)\cos[\phi(x, y) + \alpha(t)]$$

where the bias level, B, and modulation amplitude, A, are unknown and the optical phase difference between the test and reference optic, ϕ, is the quantity to be measured. ϕ is related to the height errors of the test optic, h, by

$$\phi = 4\pi h/\lambda$$

where λ is the laser wavelength. Since there are three unknowns, measurement of at least three interferograms at known phase differences is needed to determine ϕ. For example, by taking data at $\alpha = 0$, $\pi/2$, π, and $3\pi/2$, one can compute the phase difference at every point by the simple formula

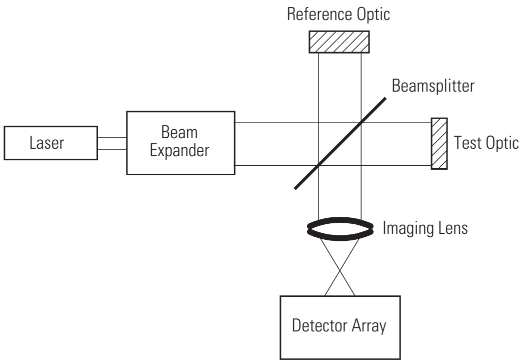
$$\phi(x, y) = \tan^{-1}[(I_4(x, y) - I_2(x, y))/(I_1(x, y) - I_3(x, y))],$$

where $I_1 \ldots I_4$ are the intensities measured at every photodetector element at times corresponding to the phase shifts $\alpha = 0 \ldots 3\pi/2$. Since the calculation is performed at every point, variations in intensity and photodetector sensitivity are not issues.

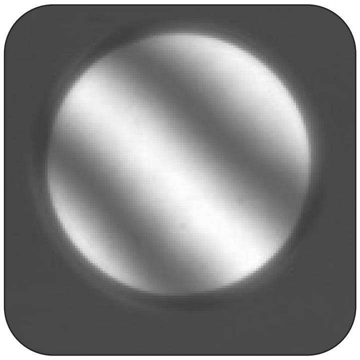
While most phase-shifting interferometers use HeNe lasers as the source, using an external-cavity tunable diode laser such as the TLB-7000 provides significant advantages. First, the laser wavelength can be chosen to exactly match the operating wavelength of the optics, of particular value when the optics are coated and may not be reflective at 633 nm. Second, the time-varying phase shift can be achieved by unbalancing the two arms and varying the laser wavelength, eliminating the need for a linear actuator to translate the reference optic. When using a tunable laser, the phase shift is given by

$$\alpha = 2\pi \ \mathit{OPD}\, \Delta\lambda/\lambda^2,$$

where OPD is the optical path-length difference between the two arms of the interferometer, λ is the laser's center wavelength, and $\Delta\lambda$ is the time-varying wavelength change. Therefore using a tunable diode laser such as the TLB-7000 enables measurements, and increases the speed of the measurement.



Typical configuration of a Twyman-Green interferometer.



Bright and dark fringes of an interferogram.