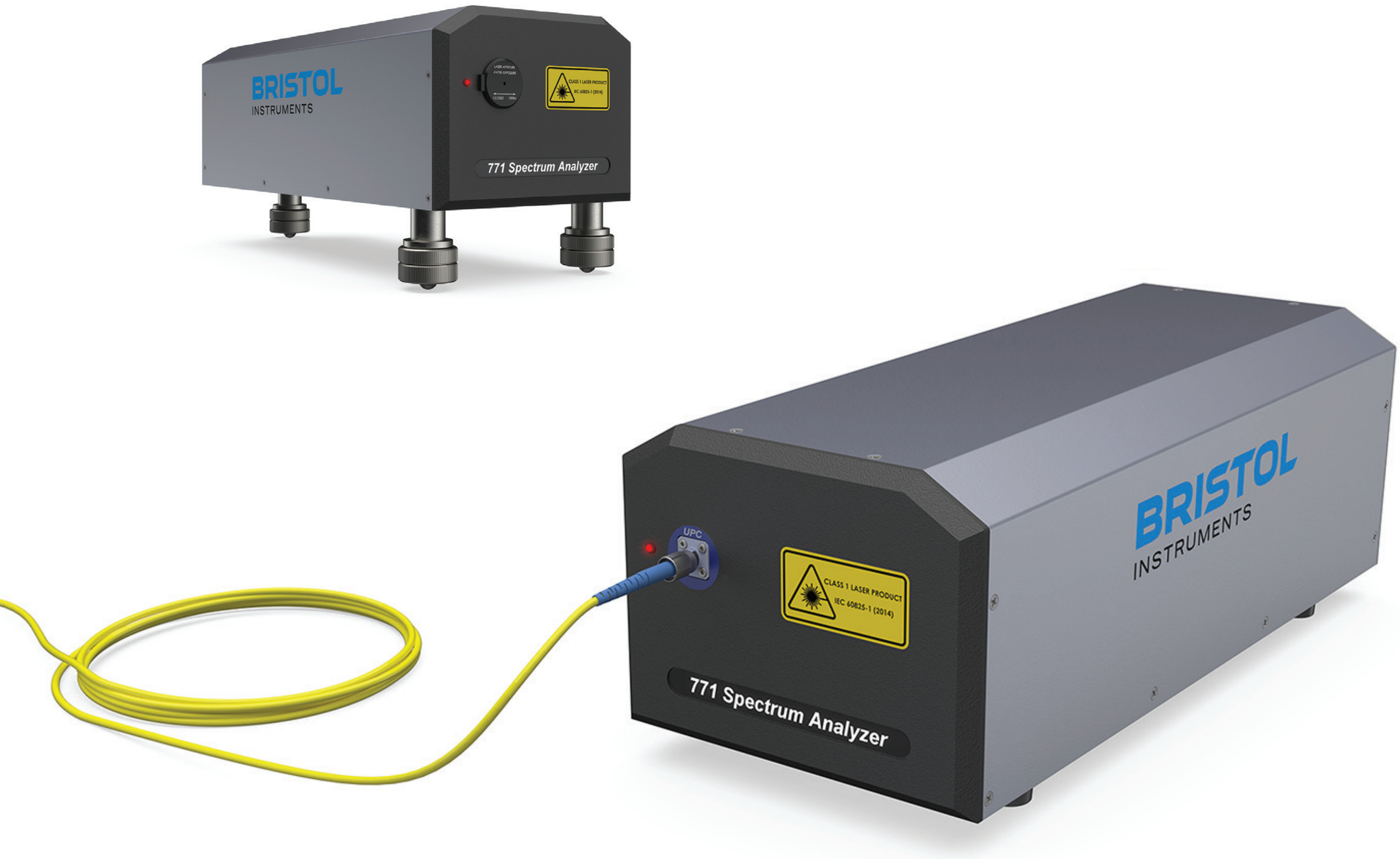

771 Series

LASER SPECTRUM ANALYZER

Combines **proven Michelson interferometer technology with fast Fourier transform analysis** resulting in a unique instrument that operates as both a high-resolution spectrum analyzer and a high-accuracy wavelength meter.

BRISTOL
INSTRUMENTS

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The 771 Series Laser Spectrum Analyzer combines proven Michelson interferometer technology with fast Fourier transform analysis resulting in a unique instrument that operates as both a high-resolution spectrum analyzer and a high-accuracy wavelength meter. With spectral resolution up to 2 GHz, wavelength accuracy as high as ± 0.2 parts per million (± 0.0002 nm at 1000 nm), and an optical rejection ratio of more than 40 dB, the model 771 provides the most detailed spectral characterization of lasers that operate from 375 nm to 12 μm.

LASER SPECTRAL ANALYSIS

The 771 Laser Spectrum Analyzer, when used as a high-resolution spectrum analyzer, measures and displays the spectral features of CW and high-repetition rate pulsed lasers. The spectrum can be reported as relative intensity vs. wavelength (nm), wavenumber (cm^{-1}), or frequency (GHz). Relative intensity is displayed using a linear or log (dB) scale.

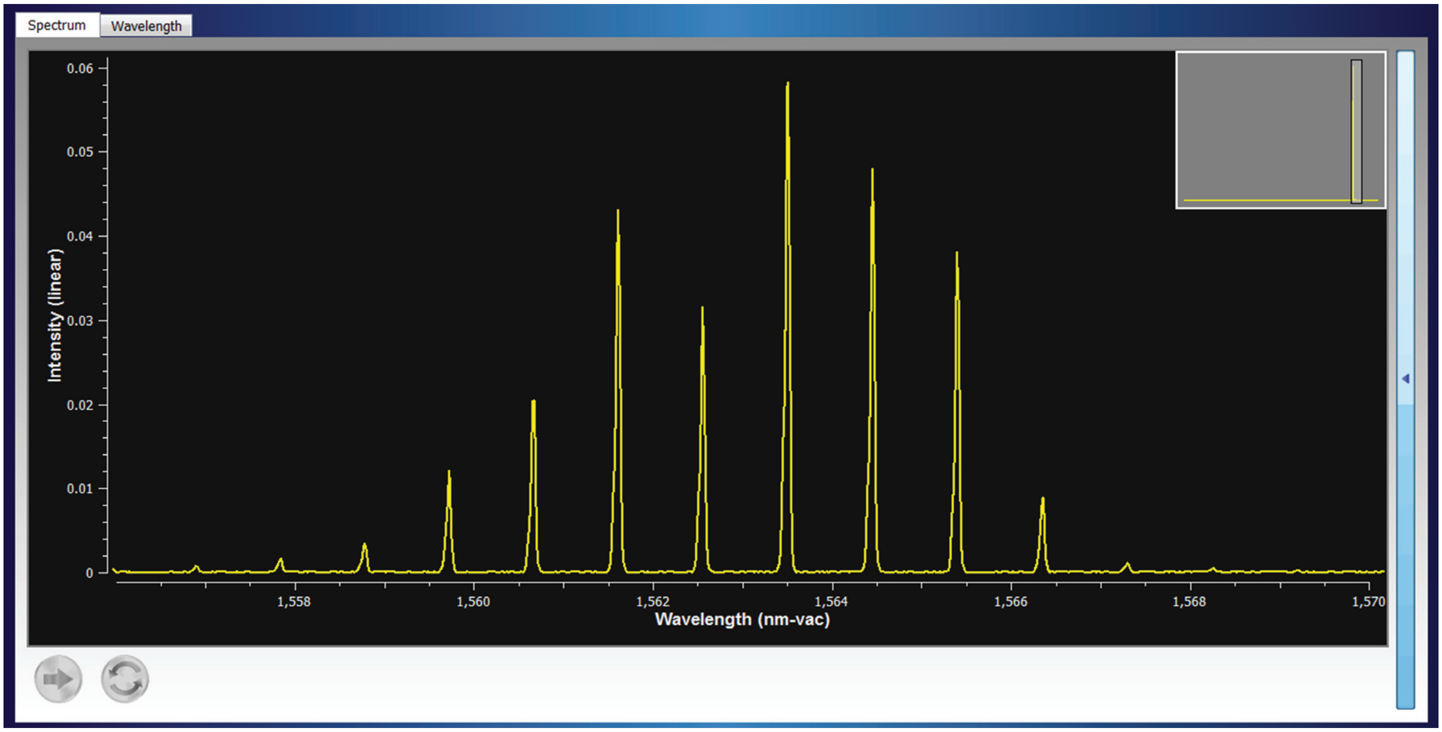

***Figure 1.** Sample NuView™ software display of a Fabry-Perot laser spectrum with thumbnail overlay in upper right corner.*

Convenient zoom and scroll functions are available to optimize the displayed spectrum. In order to keep track of any changes, a thumbnail overlay shows a representation of the entire measured spectrum with an indication of the portion that is currently being displayed. The 771 system can generate either a discrete spectrum, measure spectra continuously, or average a chosen number of spectra over time. For quantitative analysis, detailed information can be calculated automatically and reported in a data table.

Wavelength Accuracy

The spectrum's wavelength axis is calibrated to the specified accuracy of the instrument. The model 771A has a wavelength accuracy of ± 0.2 parts per million for the most precise measurements. For less demanding applications, the model 771B is available with an accuracy of ± 0.75 parts per million. For wavelengths greater than 5 µm, the system's accuracy is ± 1 part per million.

To ensure the most meaningful experimental results, the wavelength accuracy specifications are guaranteed by continuous calibration with a built-in HeNe laser. This is an ideal reference source because its wavelength is known and fixed by fundamental atomic structure. To achieve the highest accuracy, the 771A system uses a single-frequency HeNe laser that is stabilized using a precise balanced longitudinal mode technique. A standard HeNe laser is used as the wavelength reference in the model 771B.

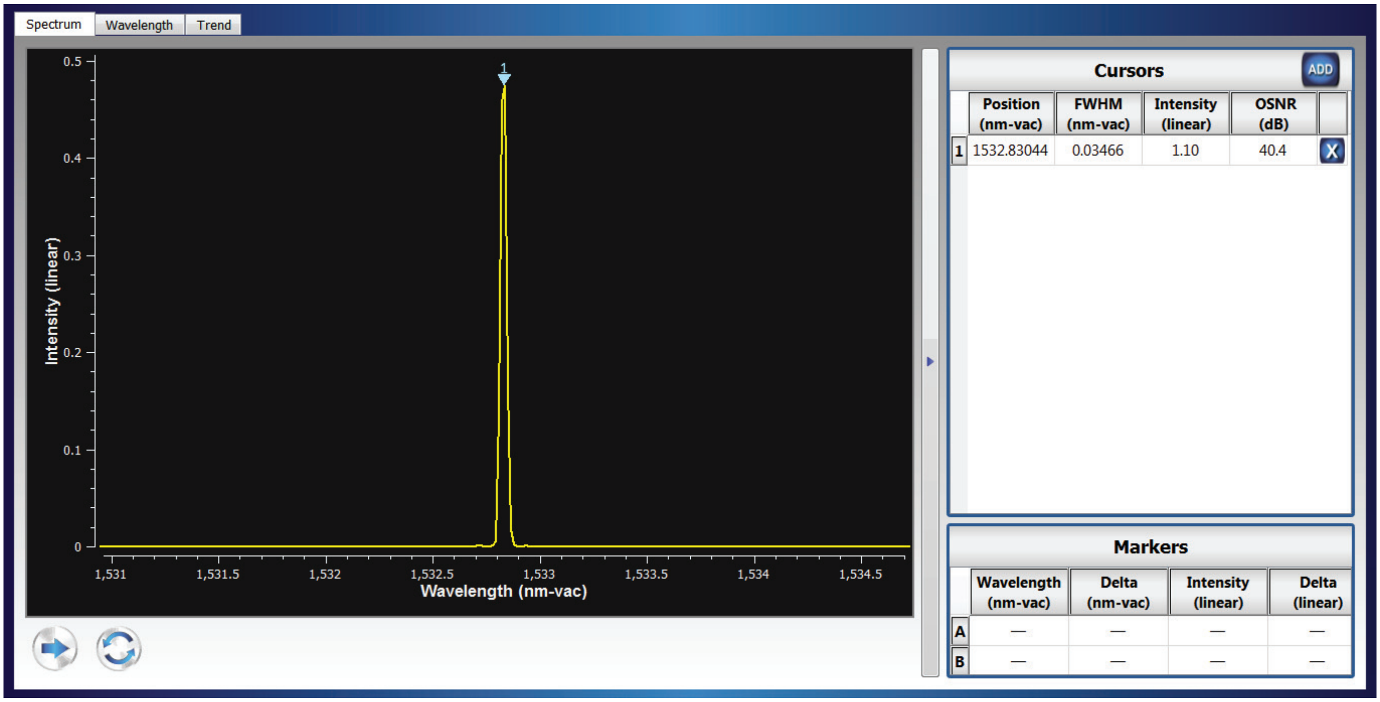

***Figure 2.** Spectrum generated by a 771A-NIR Laser Spectrum Analyzer of a laser diode locked to the P13 absorption of acetylene. The measured wavelength of the spectral peak is 1532.83044 nm. According to NIST Special Publication 260-133, the wavelength of the P13 acetylene transition is 1532.83045 nm. The difference between the measured and actual wavelengths is 0.00001 nm, which is well within the 771 system's accuracy limit of ± 0.2 parts per million (± 0.0003 nm).*

Spectral Resolution

Spectral resolution is defined as the measured full width at half maximum intensity (FWHM) of an infinitely narrow optical signal. The 771 Laser Spectrum Analyzer provides a spectral resolution of 4 GHz (8 GHz with the IR version) combined with an optical rejection ratio of greater than 40 dB.

This performance is the result of an FFT analysis using the Approximate Blackman window function. Other window functions can be used to achieve a spectral resolution as high as 2 GHz (4 GHz with the IR version). However, this will result in a lower optical rejection ratio and may result in reduced wavelength measurement accuracy.

The effect of using different window functions for the FFT analysis is demonstrated in the two spectra of the same narrow band laser shown below.

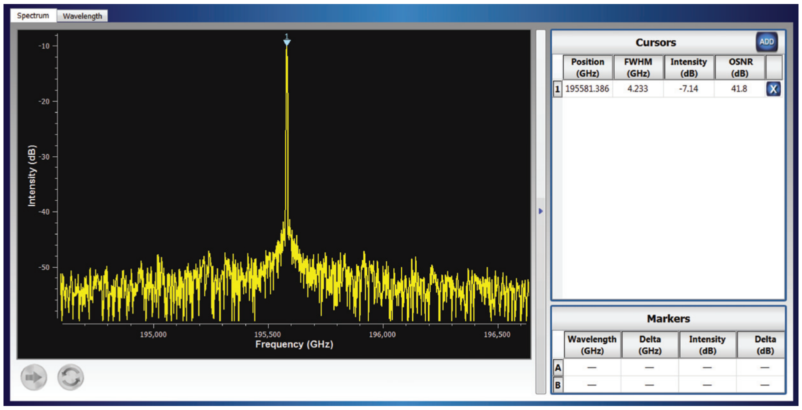

***Figure 3.** APPROXIMATE BLACKMAN FOURIER TRANSFORM WINDOW FUNCTION*

The generated spectrum shows measured bandwidth is 4.223 GHz and the optical signal-to-noise ratio (OSNR) is greater than 40 dB at 1 nm away from the peak.

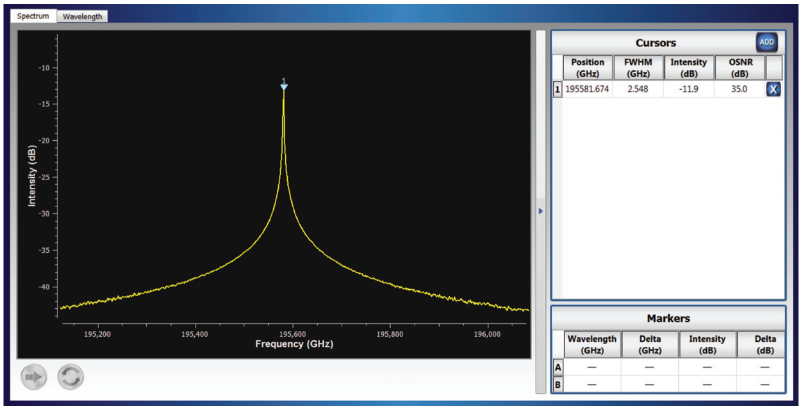

***Figure 4.** RECTANGLE FOURIER TRANSFORM WINDOW FUNCTION*

The generated spectrum shows higher spectral resolution is achieved as evidenced by the measured bandwidth of 2.548 GHz. However, the noise floor drops gradually near the peak thereby reducing the OSNR measurement.

In addition, our Spectral Resolution specification can also be stated in terms of the Minimum Resolvable Separation between two peaks of interest which is equal to 2x the FWHM resolution measurement.
For example: an 8 GHz Spectral Resolution will corresond to a 16 GHz Minimun Resolveable Separation.

Optical Rejection Ratio

The Optical Rejection Ratio (ORR) of a laser spectrum analyzer defines its ability to measure a low intensity signal near a higher intensity peak. It is the ratio between the measured noise level at a given distance from the peak and the intensity of the peak.

The ORR of the 771 Laser Spectrum Analyzer is greater than 40 dB (30 dB with the MIR version), which is the highest available for a Fourier transform-based laser spectrum analyzer. ORR is important because a laser spectrum analyzer with a higher ratio is able to provide a more detailed spectral response.

This performance advantage is demonstrated with the spectrum below showing an optical signal that includes two distinct lasers. The two lasers have wavelengths that are 1 nm apart and intensities that differ by about 30 dB. Because the 771 Laser Spectrum Analyzer has an ORR of 40 dB, the less intense laser signal is easily observed. An instrument with an ORR of only 30 dB would have a higher noise level that would obscure the second laser signal.

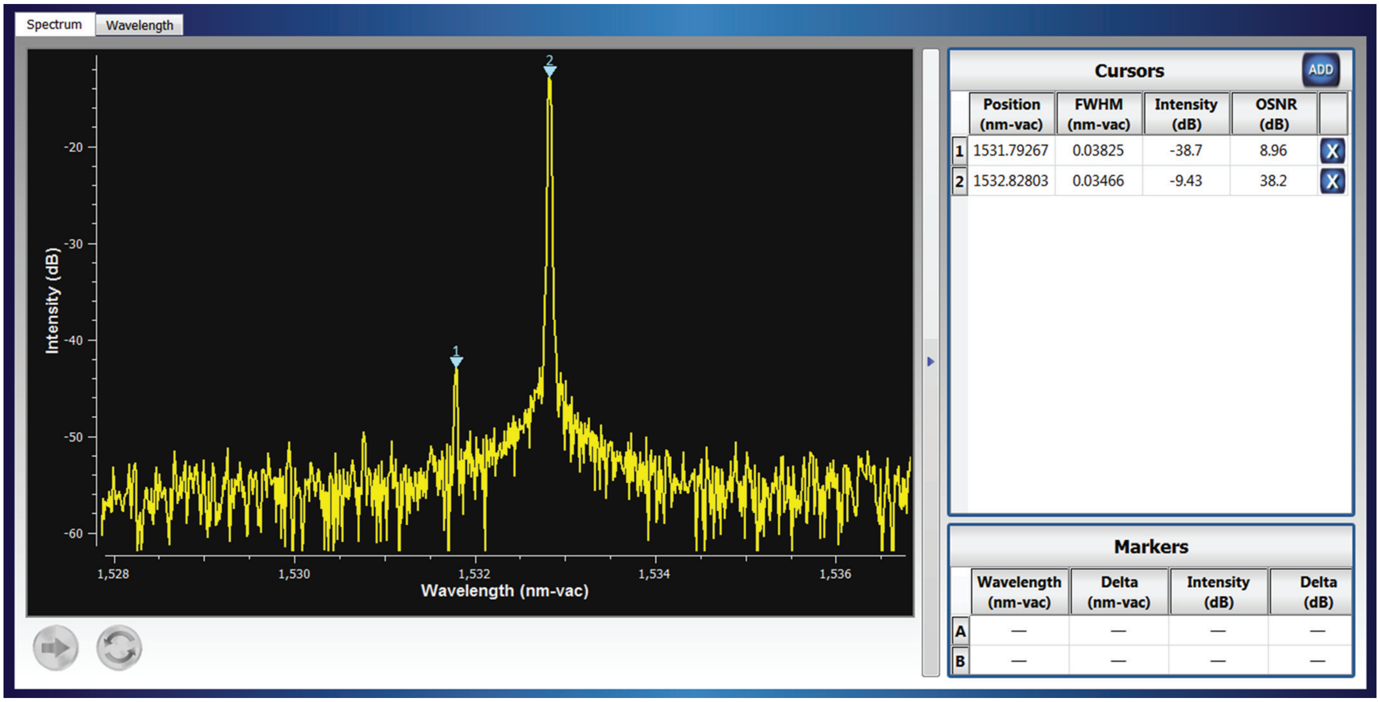

***Figure 5.** Spectral display of two lasers spaced 1 nm apart, highlighting the excellent signal-to-noise performance of the 771 Laser Spectrum Analyzer.*

The fundamental limit of the 771 Laser Spectrum Analyzer's ORR is the electronic noise floor of the measurement. Because the specification of 40 dB is based on a single measurement. ORR can be improved by using averaging to lower the noise floor.

The 771 system features a special co-addition algorithm that calculates a spectrum from an average of as many as 100 measured interferograms. This has the effect of lowering the noise floor, and therefore increasing the ORR by a factor equal to the square root of the number of averaged interferograms. For example, a 5 times improvement in the ORR (~7 dB) can be achieved by averaging 25 scans, or a 10 times improvement (10 dB) will result from an average of 100 scans.

The following spectra show the value of the co-addition averaging feature. The optical signal used to generate these spectra includes two distinct lasers with wavelengths that are about 10 nm apart. Their intensities differ by just over 40 dB.

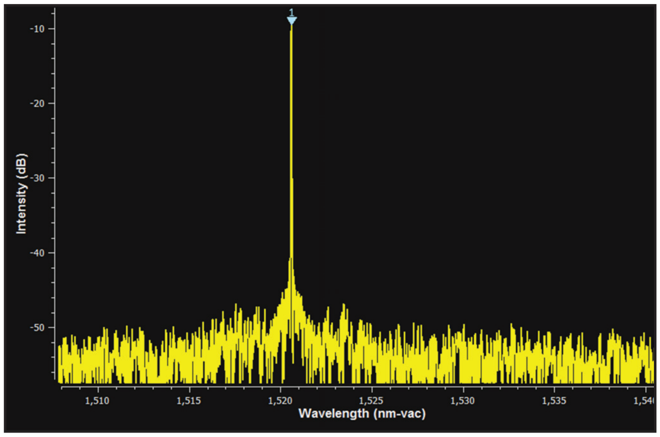

Figure 6. ***Sample spectrum with no averaging: Only the first more powerful laser can be observed.***

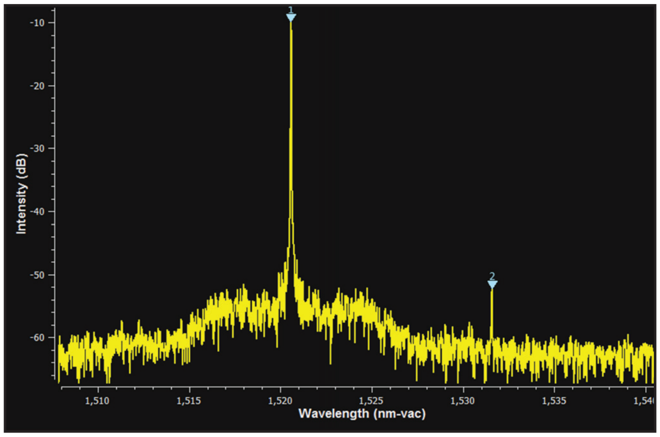

Figure 7. ***By averaging 100 interferograms, an improved ORR of about 50 dB is achieved to reveal the second laser. In addition, this spectrum also shows that the more intense laser peak actually sits on a 10 nm wide "pedestal" about 45 dB below the peak.***

The ORR of the 771 Laser Spectrum Analyzer is also dependent on the intensity of the laser under test. The ORR rises as the input power increases from the minimum detectable power, and then levels off as the electronic noise floor begins to rise with the input signal.

Broadband Laser Mode

The Broadband Laser Mode is available to better measure the spectral features of broadband optical signals. The spectrum of a broadband superluminescent LED (SLED) using the Broadband Laser Mode is shown below. Even with a bandwidth of 100 nm, the noise floor is about 30 dB below the spectrum's peak intensity.

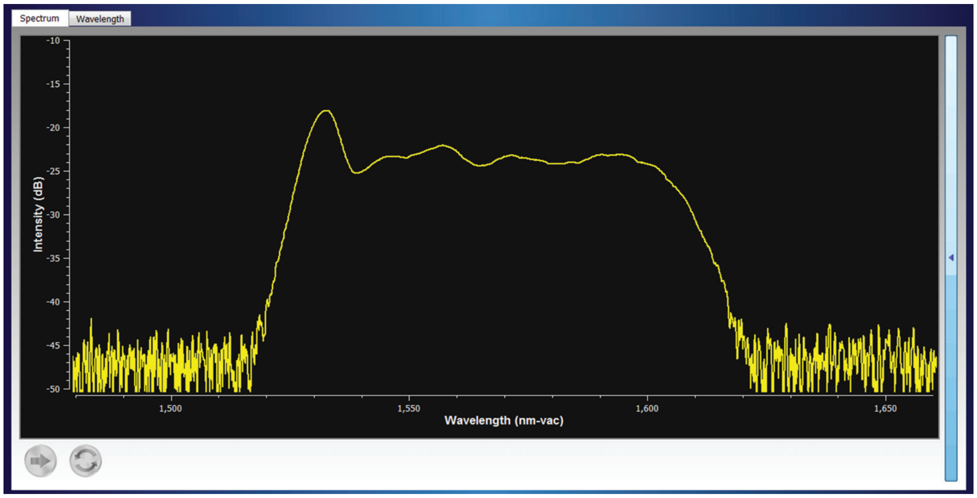

***Figure 8.* Spectrum of a broadband superluminescent LED (SLED) when the model 771 is in broadband laser mode. Note the noise floor is approximately 30 dB below the spectrum's peak intensity.**

When the Broadband Laser Mode is not used, the spectrum of the same broadband superluminescent LED has a noise floor that is only about 25 dB below the spectrum's peak intensity.

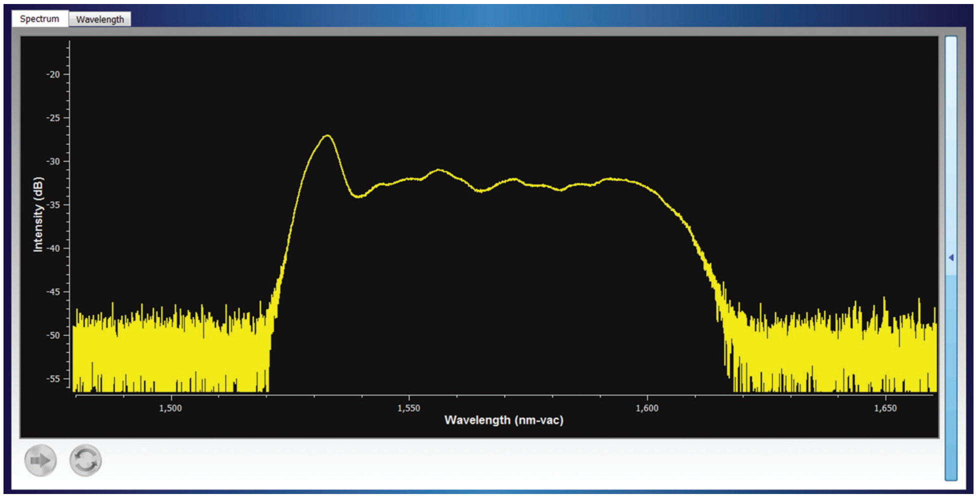

***Figure 9.* The same SLED measured with the model 771 that is not operating in broadband laser mode. Note the noise floor is now only 25 dB below the spectrum's peak intensity.**

Detailed Quantitative Analysis

The 771 Laser Spectrum Analyzer has the ability to analyze a spectrum quantitatively using up to 100 cursors and a pair of markers.

Each cursor is used to identify a specific spectral feature for which absolute wavelength, relative intensity, bandwidth (FWHM), and optical signal-to-noise ratio (OSNR) is calculated. Cursors can be placed manually by selecting any peak in the spectrum or using a threshold to automatically select all peaks above the desired intensity.

The markers provide absolute wavelength and relative intensity information about any single point of the spectrum. The marks are manually positioned to the point of interest.

The data generated by cursors and markers is reported in a table of values next to the spectrum display.

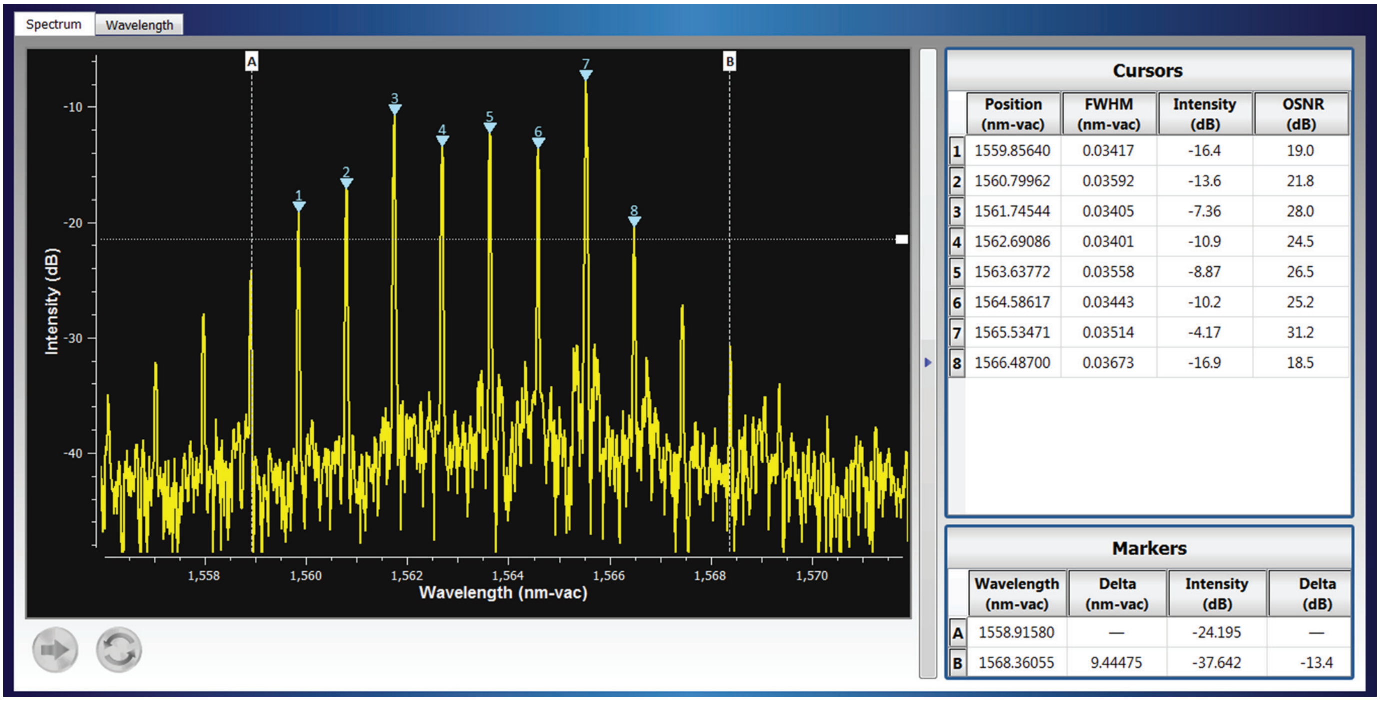

***Figure 10.** Fabry-Perot laser spectrum displayed in NuView™ software. A 10 nm wide Marker Window has identified 8 distinct peaks above the user defined threshold of 22 dBm.*

Spectral Stability Measurement

The 771 Laser Spectrum Analyzer has a unique feature that measures the frequency stability of the laser under test. When the Stability Feature is selected, the highest intensity for each point of the spectrum is recorded and overlayed with the current spectral measurement. The figure below shows the highest peak intentsity values in blue with the current spectra in yellow. For the blue plot , the width of the plateau at the spectral peak is the 'effective laser bandwidth'.

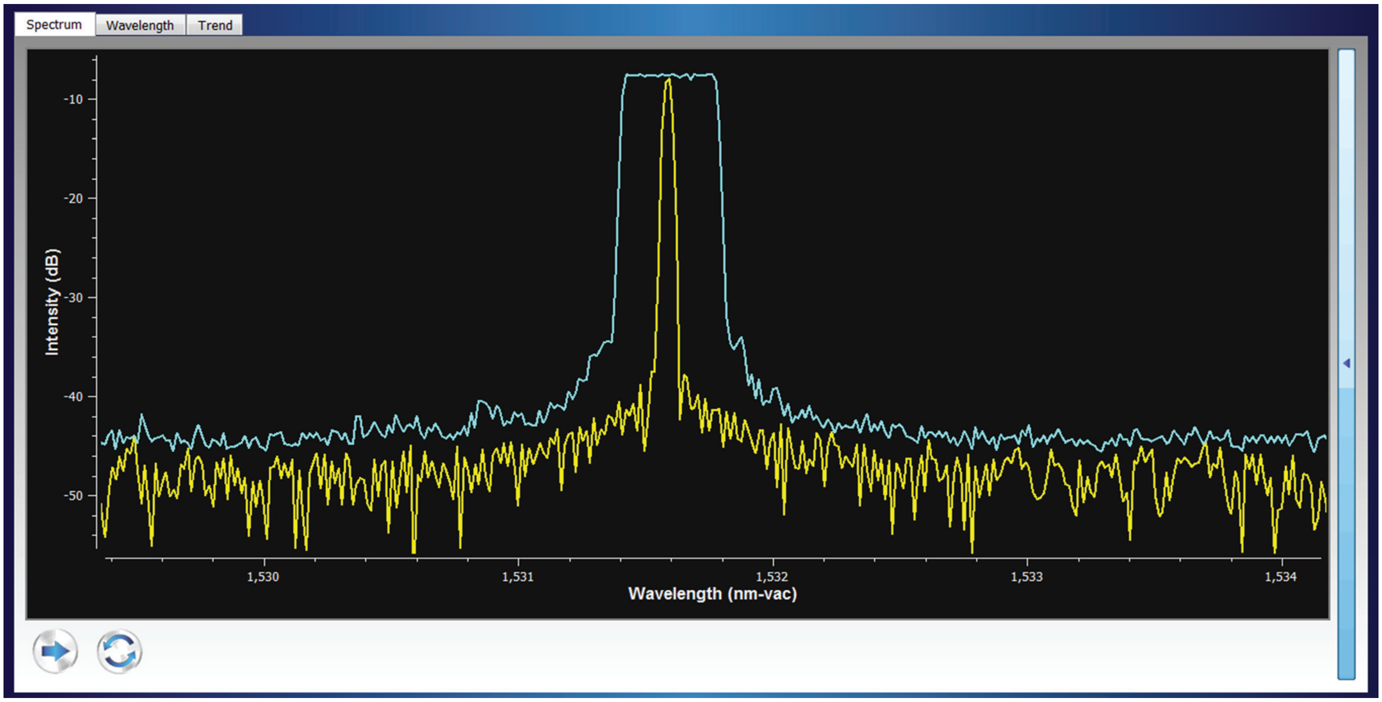

***Figure 11.** Temperature Tuned DFB Laser Results: Blue tracing shows the "effective" laser bandwidth. Last measured spectrum is shown in yellow.*

LASER WAVELENGTH MEASUREMENT

The 771 Laser Spectrum Analyzer also operates as a high-accuracy wavelength meter. It can report wavelength (nm), wavenumber (cm^{-1}), or frequency (GHz) of a laser's most prominent spectral feature. The accuracy of the model 771A is ± 0.2 parts per million for lasers with a bandwidth less than 1 GHz. The 771B system, a lower-priced alternative, provides an accuracy of ± 0.75 parts per million for lasers with a bandwidth less than 10 GHz. For wavelengths greater than 5 µm, the accuracy is limited to ± 1 part per million.

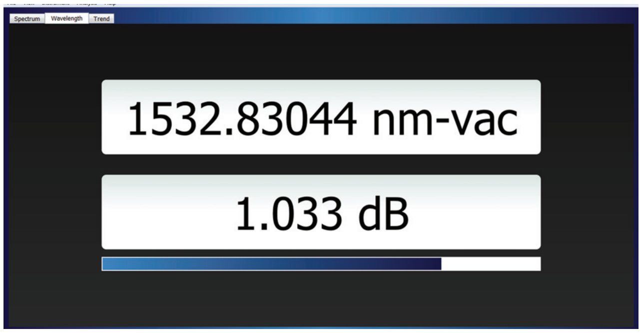

***Figure 12.** Representative NuView™ software screen shot showing laser wavelength measurement, relative power and intensity bar results for the VIS and NIR models of the 771.*
***Note:** NIR2, IR and MIR models of the 771 will only display the wavelength measurement and relative intensity bar.*

Guaranteed Accuracy

Bristol Instruments guarantees the accuracy of the 771 Laser Spectrum Analyzer by taking into account all factors that can affect wavelength measurement. Continuous calibration with a built-in wavelength standard corrects for potential sources of systematic error. Random errors are minimized with a robust Michelson interferometer design.

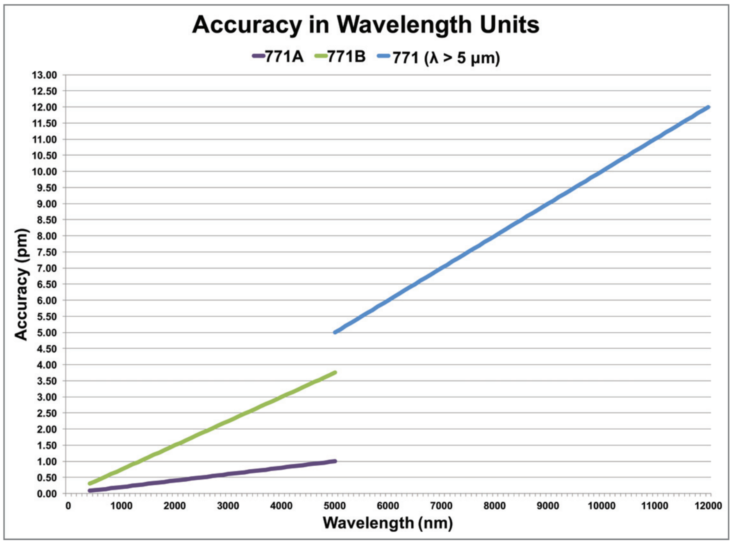

***Figure 13.** ± Accuracy (in picometers) vs. Wavelength for the 771 product family.*

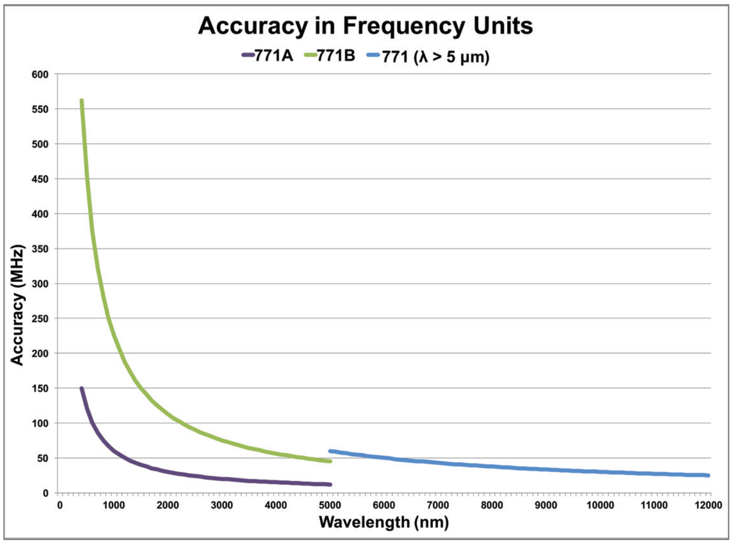

***Figure 14.** ± Accuracy (in MHz) vs. Wavelength for the 771 product family.*

Wavelength Measurement Trends

The *NuView*™ software included with the 771 Laser Spectrum Analyzer offers an integrated wavelength trending feature that automatically charts a laser's wavelength over time. A rolling graphical trace of up to 100,000 wavelength measurements can be displayed.

A variety of statistics over the measurement period are also computed. These include the maximum and minimum wavelength measurements, laser drift (current wavelength - start wavelength), standard deviation, and the mean. These values are reported in a table below the trend graph.

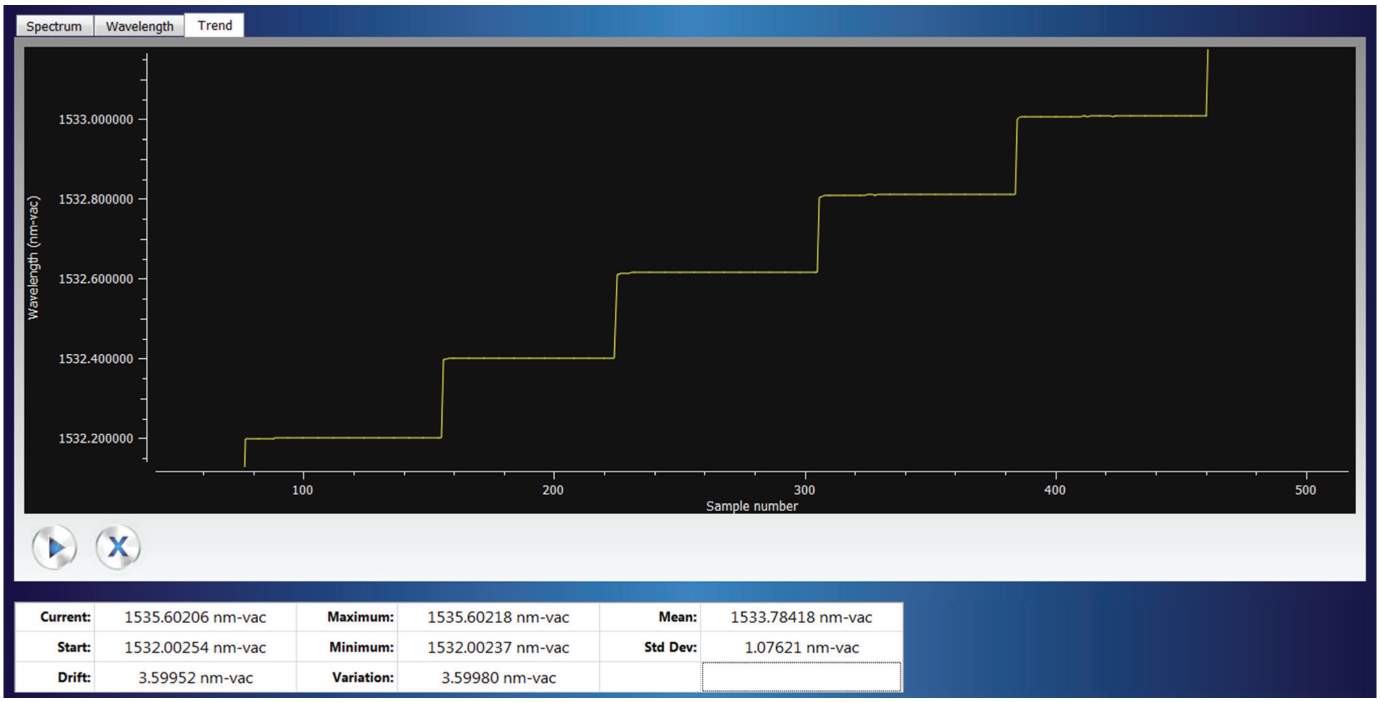

***Figure 15.** Wavelength Measurement Trend for a tunable laser. Graph shows tuning steps at regular intervals with a table of statistical results.*

OPERATION

The 771 Laser Spectrum Analyzer makes it easy to determine the spectral characteristics of a laser. Operation is straightforward using a PC running under Windows.

Using an on-board digital signal processor, the 771 system quickly generates a laser's spectrum, automatically calculates various quantitative data, and then transfers the information to the PC using a USB or Ethernet interface. Bristol *NuView*™ software is provided to control measurement parameters and to display the spectrum and report data in a variety of formats. The 771 system can also be integrated into custom software or LabVIEW programming using a library of (SCPI) commands.

Broad Wavelength Coverage

The 771 Laser Spectrum Analyzer is available in five broad wavelength configurations to satisfy virtually any experimental requirement.

- **VIS with a detection range of 375 – 1100 nm**
- **NIR with a detection range of 520 – 1700 nm**
- **NIR2 with a detection range of 1 – 2.6 µm**
- **IR with a detection range of 1 – 5 µm**
- **MIR with a detection range of 1 – 12 µm**

These configuration demonstrate the flexibility of a Fourier transform-based laser spectrum analyzer. Additionally, the 771 system can quickly generate a spectrum over its entire detection range in a single scan. For example, the spectrum shown below is of an optical signal comprised of three distinct lasers: (1) 633 nm, (2) 1064 nm, and (3) 1533 nm and was generated in less than two seconds.

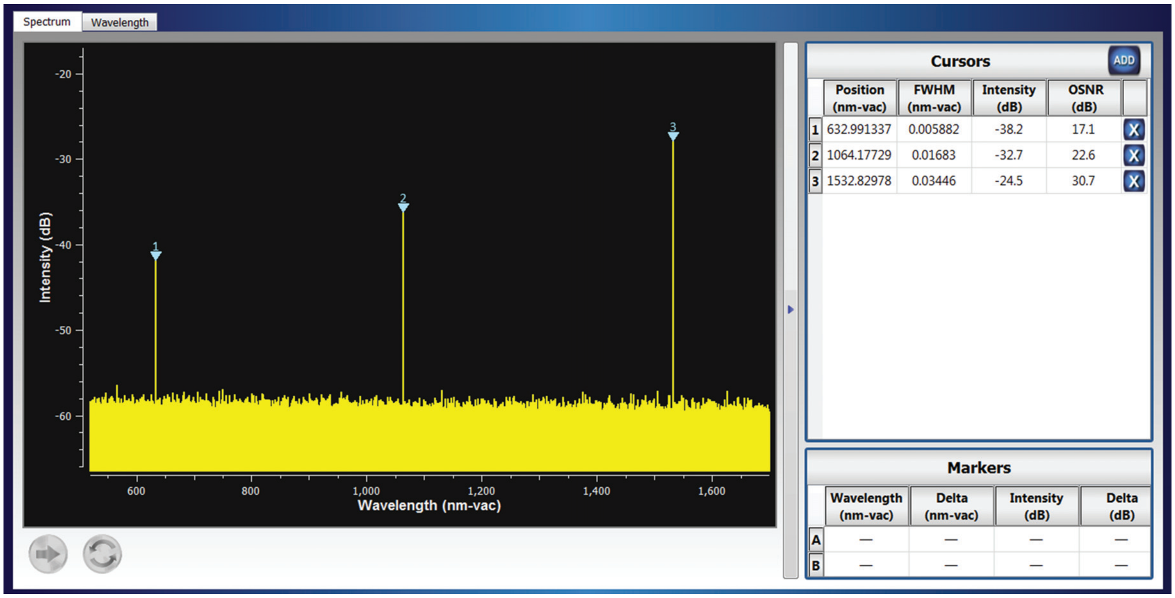

Figure 16. ***Results of a single scan of the entire detection range of a 771-NIR model. The scan took less than two seconds and identified 3 distinct lasers.***

Convenient Laser Input

A laser under test enters the VIS, NIR and NIR2 versions of the model 771 through a pre-aligned FC/UPC or FC/APC fiber-optic input connector. This ensures optimum alignment of the laser beam to the instrument's interferometer resulting in uncompromised accuracy. With fiber-optic input, the 771 system can be placed in an out of the way location, thereby conserving valuable optical bench space.

Figure 17. ***Front panel of the fiber coupled model.***

For free beam lasers, Bristol Instruments offers a variety of Fiber-Optic input coupling accessories that provide a simple way to launch a laser beam into fiber.

Since fiber is not readily available for infrared wavelengths, the laser under test enters the IR and MIR versions of the model 771 through a 2-3 μm input aperture. To facilitate alignment to the instrument, the internal HeNe reference laser is emitted from the input aperture as a visible tracer beam. The laser under test is simply superimposed on the tracer beam to optimize alignment. This is accomplished by using the three adjustable-height legs (± 0.25") of the 771 system.

Figure 18. ***Front panel of the free-space model, (Leg height is adjustable).***

High Sensitivity

The minimum input signal required by the 771 Laser Spectrum Analyzer is as low as 10 nW. However, since this specification is defined as the power necessary to achieve a signal-to-noise ratio of 1 dB, a higher input power is preferred. It is recommended to not exceed a maximum power input of 10 milliwatts.

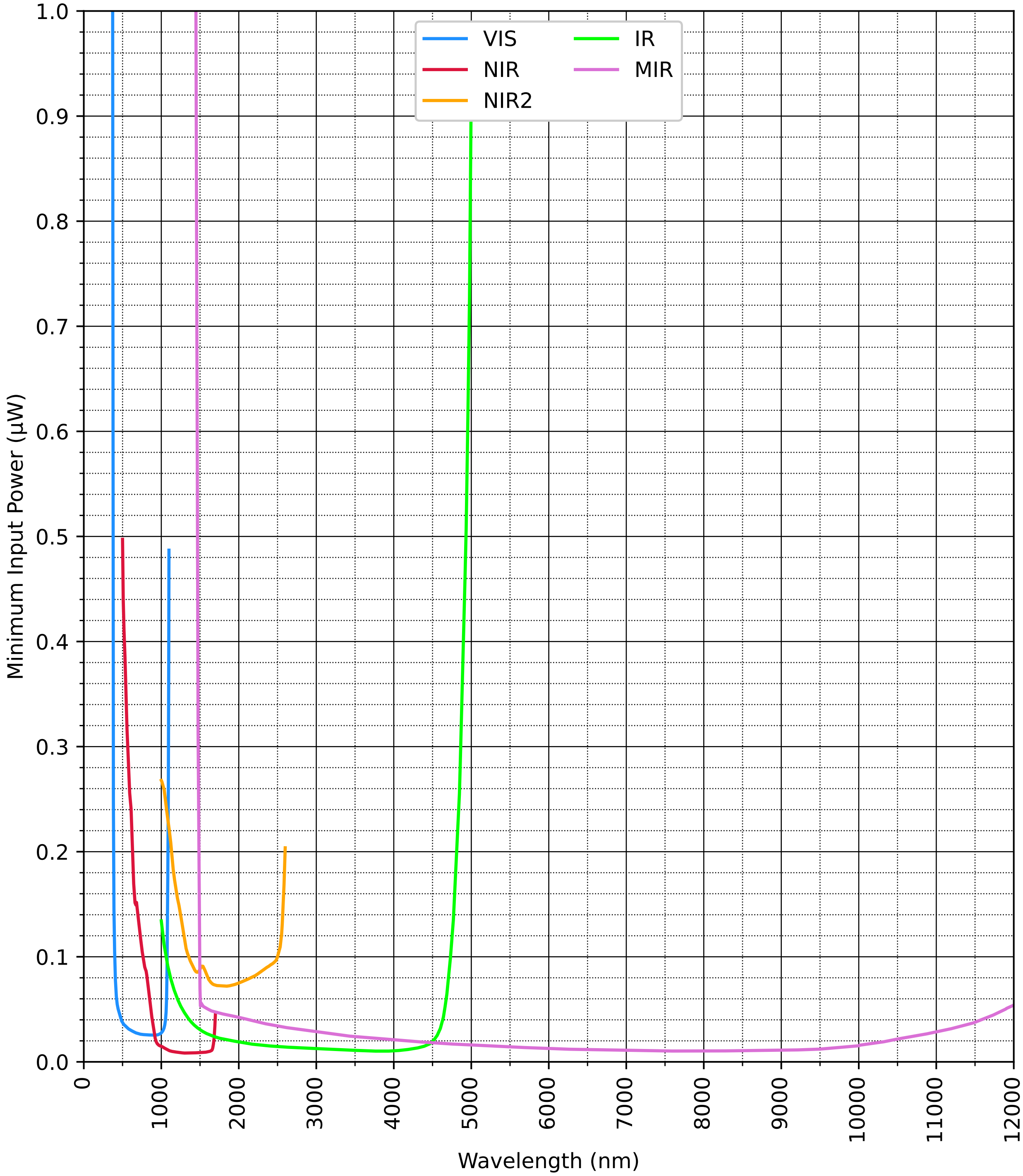

Figure 19. Minimum Input Power vs. Wavelength for the 771 instrument models.

Operation with CW and Pulsed Lasers

The 771 Laser Spectrum Analyzer is ideal for measuring the spectral characteristics of CW lasers. The model 771 will also operate with pulsed lasers that have a repetition rate greater than 50 kHz and a pulse length greater than 50 ns.

The following figure shows the spectrum of a pulsed quantum cascade laser generated by the 771B-MIR Laser Spectrum Analyzer. The laser is operating at a repetition rate of 50 kHz and a pulsed length of 50 ns.

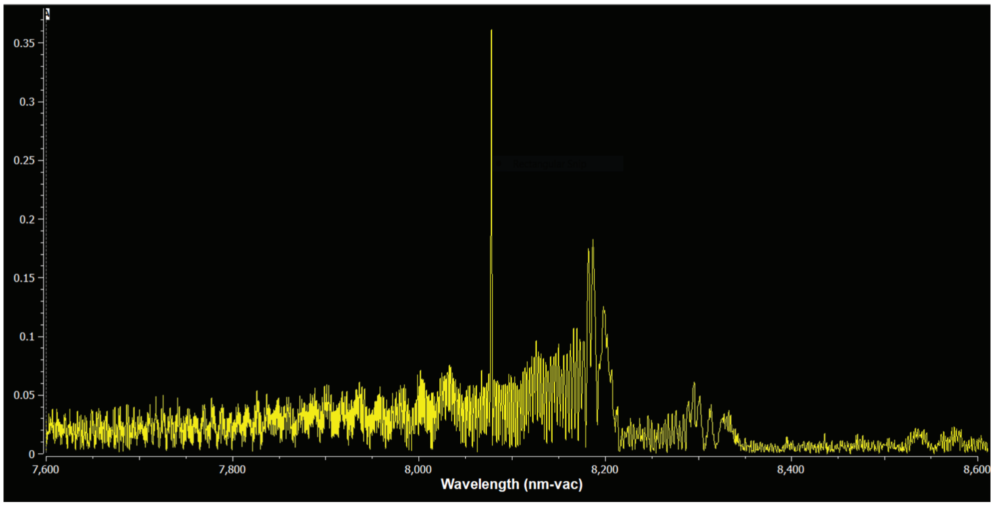

***Figure 20.** Pulsed quantum cascade laser spectrum - QCL is operating at a 50 kHz repetition rate and a pulse length of 50 ns.*

The analysis of pulsed lasers typically results in modulation artifacts in the form of false spectral peaks. However, these artifacts can be minimized using the system's special co-addition algorithm that calculates a spectrum from an average of as many as 100 measured interferograms. This is demonstrated in the following spectrum of the same quantum cascade laser generated by averaging 60 scans.

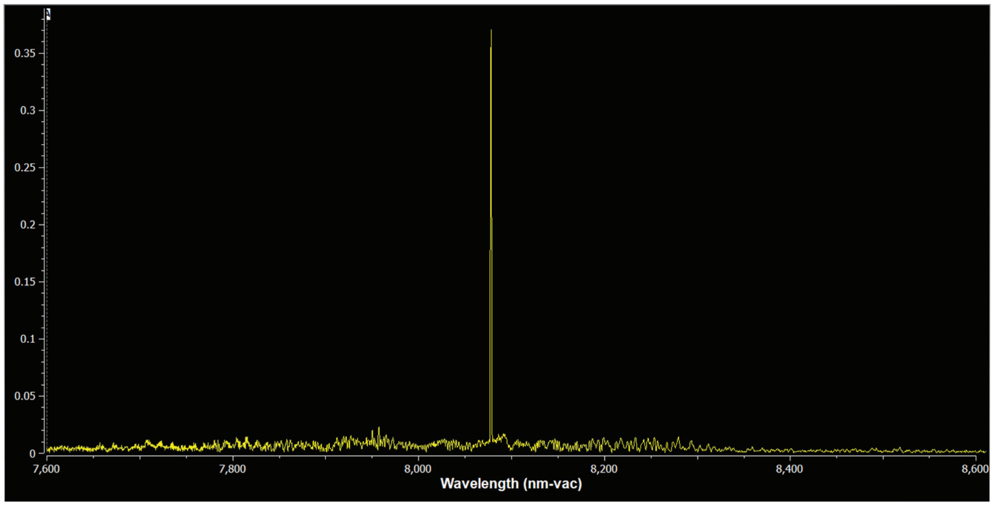

***Figure 21.** The same QCL spectrum displayed using the co-addition algorithm to average 60 scans. Pulsed laser spectral artifacts are greatly reduced.*

Fast Spectral Measurements

The time required for the 771 Laser Spectrum Analyzer to generate a spectrum over its entire operational wavelength range is two seconds. In order to reduce the measurement time to one second, there is a software option that limits the spectral analysis to a smaller wavelength range resulting in more efficient calculations.

Versatile Instrument Interface

The spectral information generated by the 771 Laser Spectrum Analyzer is transferred to a PC directly via a USB interface or a local area network using Ethernet.

Figure 22. 771 system rear panel connection layout.

Analysis is done with the included NuView™ Windows-based software. Alternatively, relative intensity versus wavelength data can be collected and saved using a *.csv format for analysis with other graphing programs. Data can also be collected using a convenient library of commands (SCPI) for custom or LabVIEW programming.

SPECIFICATIONS — 771 Series

MODEL	771A	771B
LASER TYPE [1]	CW, quasi-CW (repetition rate > 10 MHz), and pulsed (repetition rate > 50 kHz, pulse length > 50 ns)	
WAVELENGTH		
Range [2]	VIS: 375 - 1100 nm NIR: 520 - 1700 nm NIR2: 1 - 2.6 µm IR: 1 - 5 µm MIR: 1 - 12 µm	
Accuracy [3, 4, 5, 6]	± 0.2 ppm (± 1 ppm for λ > 5 µm) ± 0.0002 nm @ 1000 nm ± 0.002 cm^{-1} @ 10,000 cm^{-1} ± 60 MHz @ 300,000 GHz	± 0.75 ppm (± 1 ppm for λ > 5 µm) ± 0.0008 nm @ 1000 nm ± 0.008 cm^{-1} @ 10,000 cm^{-1} ± 225 MHz @ 300,000 GHz
Spectral Resolution [4, 7, 8]	4 GHz (for VIS, NIR, NIR2, MIR) 8 GHz (for IR)	
Calibration	Continuous - built-in stabilized single-frequency HeNe laser	Continuous - built-in standard HeNe laser
Display Resolution	9 digits	8 digits
Units [9]	nm, µm, cm^{-1}, GHz, THz	
OPTICAL REJECTION RATIO [4, 10, 11, 12]	> 40 dB (> 30 dB for MIR)	
MINIMUM INPUT POWER [12, 13, 14]	VIS: 0.025 - 1.1 µW NIR: 0.01 - 0.5 µW NIR2: 0.07 - 0.27 µW IR: 0.01 - 2.25 µW MIR: 0.01 - 13 µW	
MAXIMUM INPUT POWER	10 mW	
MEASUREMENT TIME [15]	< 2 s (1 s with smaller measurement ranges)	
INPUTS/OUTPUTS		
Optical Input [16]	VIS / NIR: Pre-aligned FC/UPC or FC/APC connector (9 µm core diameter) - optional free beam-to-fiber coupler NIR2: Pre-aligned FC/UPC or FC/APC connector (7 µm core diameter) - optional free beam-to-fiber coupler IR / MIR: Collimated beam, 2-3 mm diameter aperture, visible tracer beam to facilitate alignment	
Instrument Interface	USB and Ethernet with Windows-based display program Library of commands (SCPI) for custom and LabVIEW programming using any PC operating system	
COMPUTER REQUIREMENTS [17]	PC running Windows 10/11, 1 GB available RAM, USB 2.0 (or later) port, monitor, pointing device	
ENVIRONMENTAL [12]		
Warm-Up Time	< 15 minutes	None
Temperature | Pressure | Humidity	+15°C to +30°C (-10°C to +70°C storage) | 500 – 900 mm Hg | ≤ 90% R.H. at + 40°C (no condensation)	
DIMENSIONS AND WEIGHT		
Dimensions (H x W x D) [18]	VIS / NIR / NIR2: 5.6" x 6.5" x 15.0" (142 mm x 165 mm x 381 mm)	IR / MIR: 7.5" x 6.5" x 15.0" (191 mm x 165 mm x 381 mm)
Weight	14 lbs (6.3 kg)	
POWER REQUIREMENTS	90 - 264 VAC, 47 - 63 Hz, 50 VA max	
WARRANTY	5 Years (parts and labor)	

(1) Operation with pulsed lasers may result in modulation artifacts in the form of false spectral features. These modulation artifacts are reduced with averaging.
(2) MIR capable of operation to 14 µm. However, operation and specifications are not guaranteed beyond 12 µm.
(3) Defined as measurement uncertainty, or maximum wavelength error, with a confidence level of ≥ 99.7%.
(4) Using Approximate Blackman window function for FFT analysis.
(5) Wavelength Meter Mode: 771A - for laser spectral bandwidth less than 1 GHz (FWHM). 771B - for laser spectral bandwidth less than 10 GHz (FWHM).
(6) Spectrum Analyzer Mode: wavelength axis is calibrated to system's accuracy specification.
(7) Defined as the measured full width at half maximum intensity (FWHM) of an infinitely narrow optical signal.
(8) Spectral resolution as high as 2 GHz (4 GHZ for IR) can be achieved using other window functions. However, wavelength accuracy and optical rejection ratio may be reduced.
(9) Data in units of nm, µm, and cm^{-1} are given as vacuum values.
(10) For single measurement with CW lasers, FWHM < 10 GHz, and 10,000 times (1,000 times for MIR) minimum input power.
(11) A co-addition averaging feature can be used to reduce the noise level and therefore improve the optical rejection ratio.
(12) Characteristic performance, but non-warranted.
(13) Optical power required to achieve a signal-to-noise ratio of approximately 1 dB.
(14) Sensitivity at specific wavelengths can be determined from a graph provided in the 771 Series Product Details brochure.
(15) Time to generate a spectrum over the entire operational wavelength range. Smaller ranges are available to reduce measurement time to 1 s.
(16) IR and MIR required beam height is 5.4 ± 0.25".
(17) For use with Windows-based display program. Interface with SCPI can be done using any PC operating system.
(18) IR and MIR instrument height is adjustable (7.25 ± 0.25") for alignment purposes.

CLASS 1 LASER PRODUCT IEC 60825-1 (2014)

Bristol Instruments reserves the right to change the specifications as may be required to permit improvements in the design of its products.
Specifications are subject to change without notice.

REV 06-25