43 Sparta Avenue
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SA201 - April 6, 2023

Item # SA201 was discontinued on April 6, 2023. For informational purposes, this is a copy of the website content at that time and is valid only for the stated product.

▶ Operating Wavelength Ranges from UV to MIR
▶ Custom Mirror Coatings from UV to Mid-IR Available
▶ Controller for Scanning Fabry-Perot Interferometers

SA210-8B
10 GHz FSR, 820 - 1275 nm

SA201
Voltage Controller
(Sold Separately)

Application Idea
Mounting components on an optical rail system reduces the degrees of freedom while aligning the beam to the cavity. The SA200, focusing lens, and laser are each mounted to an XT66C4 clamping platform which centers the optical axis

SA200-2B
1.5 GHz FSR, 290 - 355 nm & 520 - 545 nm

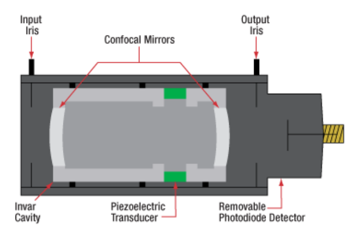
Hide Overview

OVERVIEW

Features

- Analyze Fine Spectral Features of CW Lasers
- Optical Coatings for Wavelengths from 290 nm to 4400 nm (See the *Graphs* Tab for More Details)
- Free Spectral Range of 1.5 or 10 GHz
- Minimum Finesse Values of 150, 200, or 1500 Available
- Factory-Calibrated Finesse
- Ultrastable Athermal Invar® Cavity
- SMA- or BNC-Coupled for Connection to an Oscilloscope
- SA201 Controller (Sold Separately) Provides Triangle or Sawtooth Scan Voltage for Piezoelectric Transducer
- Custom Mirror Coatings from UV to Mid-IR (Contact Tech Support)

Each Fabry-Perot interferometer features a thermally stable Invar® cavity.



Schematic Representation of a Confocal Fabry-Perot Interferometer

Thorlabs' Scanning Fabry-Perot Interferometers are spectrum analyzers that are ideal for examining fine spectral characteristics of CW lasers. Interferometers are available with a Free Spectral Range (FSR) of 1.5 GHz or 10 GHz. The resolution, which varies with the FSR and the finesse, ranges from <1 MHz to 67 MHz. For information on these quantities and their applications in Fabry-Perot interferometry, see the *Fabry-Perot Tutorial* tab.

The Fabry-Perot cavity transmits only very specific frequencies. These transmission frequencies are tuned by adjusting the length of the cavity using piezoelectric transducers, as shown in the diagram to the right. The transmitted light intensity is measured using a photodiode, amplified by the transimpedence amplifier in the SA201 controller (or equivalent amplifier), and then displayed or recorded by an oscilloscope or data acquisition card. Each Fabry-Perot interferometer has a cable ending in a BNC connector for controlling the piezo.

The mirrors in the SA30-144, SA200-18C, and SA210-18C interferometers are made of IR-grade fused silica (Infrasil®), the mirrors in the SA200-30C are made of yttrium aluminum garnet (YAG), and the mirrors on all other models are made of UV fused silica. Each Fabry-Perot interferometer also features an internal housing made of thermally stable invar to eliminate misalignment due to temperature fluctuations.

The SA200 and SA30 models feature SM1 (1.035"-40) threading on the back of the instrument for detector mounting, while the SA210 models include SM05 (0.535"-40) threading. Except for the SA200-30C, each Fabry-Perot scanning interferometer comes with a photodiode detector included, as well as an SMA-to-BNC cable to connect the detector to an amplifier. This photodiode can be removed for alignment purposes or for replacement with another detector.


Click to Enlarge
[APPLIST]
[APPLIST]
SA200-18C Mounted on KS2 Kinematic Mount


Click to Enlarge
[APPLIST]
[APPLIST]
SA200-18C with Included Photodiode Removed


Click to Enlarge
[APPLIST]
[APPLIST]
SA200-18C with PDA10PT Detector Installed

Alignment
The confocal (SA200/SA210 series) or near-confocal (SA30 series) design of the Fabry-Perot interferometer cavity allows for easy alignment of the input beam. The optical axis of the Fabry-Perot interferometer can be aligned to the input beam with sufficient accuracy by mounting the interferometer on a standard kinematic mirror mount and following the steps on the *Alignment Guide* tab. An example of our SA200 Fabry-Perot interferometer mounted in a KS2 kinematic mount is shown to the right.

For the SA30 series with a near confocal design, additional steps are necessary to ensure proper alignment of the interferometer. The system will need to be fine-tuned while observing a transmission mode in order to suppress higher order modes. For more details, see the *Alignment Guide* tab.

Controller
The SA201 controller (sold separately) generates a sawtooth or triangle wave voltage required to repetitively scan the length of the Fabry-Perot cavity in order to sweep through one FSR of the interferometer. The SA201 controller also houses a transimpedance amplifier that can be used to amplify the output of the photodiode detector in the Fabry-Perot interferometer; this detector measures the intensity of the light transmitted through the Fabry-Perot cavity. The controller also provides a trigger signal to the oscilloscope, which allows the oscilloscope to easily trigger at the beginning or the middle of the scan. The time axis of the oscilloscope can be precisely calibrated by observing two instances of a given spectral feature separated by one FSR (see the *Calibration* tab for more details). For more information on connecting the Fabry-Perot to the controller and an oscilloscope, see the *Connections* tab.

Hide Graphs

GRAPHS

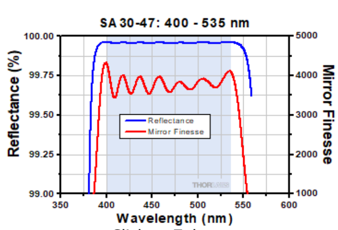
The plots below show the reflectance of the mirrors in our Fabry-Perot interferometers. "Mirror Finesse" refers to the contribution to the total finesse value due to the reflectance of the mirrors. In a system with near-perfect alignment, the finesse of the Fabry-Perot cavity will be limited by the reflectance of the mirrors, and the finesse values will approach those shown on the plots below. For more information on finesse, please see the *Fabry-Perot Tutorial* tab.

Please remember that the actual reflectance of the mirror will vary slightly from coating run to coating run within the specified region and can vary significantly from coating run to coating run outside of the specified region. The total cavity finesse depends on additional factors. Please see the *Fabry-Perot Tutorial* tab for more information.

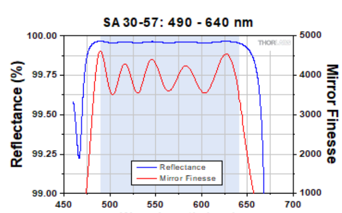
Custom mirror coatings for wavelengths from the UV to the mid-IR (200 nm to 4700 nm) are available upon request. If the coatings represented in the graphs below do not suit the needs of your application, please contact Tech Support.

Interferometers with ≥1500 Finesse

Theoretical reflectance and mirror finesse data. The mirror finesse is calculated using Eq. 8 from the *Fabry-Perot Tutorial* tab. Note that the actual finesse of the instrument will be lower than the curves presented here due to contributions from the substrate surface figure; see Eq. 10 on the *Fabry-Perot Tutorial* tab.



Click to Enlarge
Click Here for Theoretically Calculated Data



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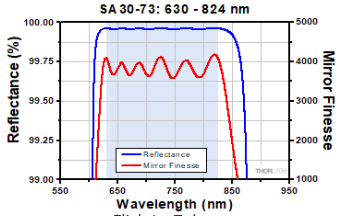

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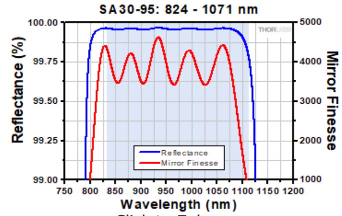

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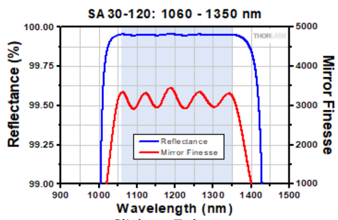

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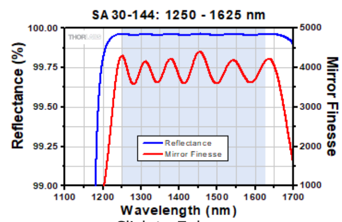
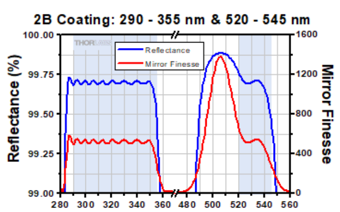


Click to Enlarge
Click Here for Theoretically Calculated Data

Interferometers with >150 or >200 Finesse

Theoretical reflectance and mirror finesse data. The mirror finesse is calculated using Eq. 8 from the *Fabry-Perot Tutorial* tab. Note that the actual finesse of the instrument will be lower than the curves presented here due to contributions from the substrate surface figure; see Eq. 10 on the *Fabry-Perot Tutorial* tab.



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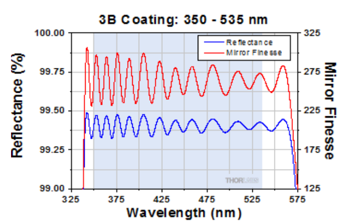

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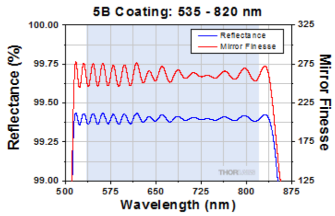

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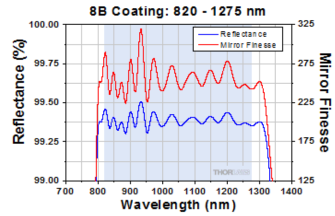

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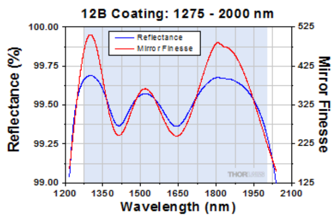

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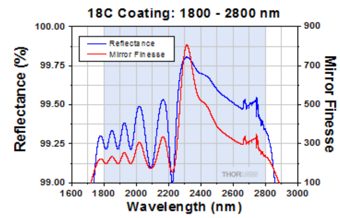

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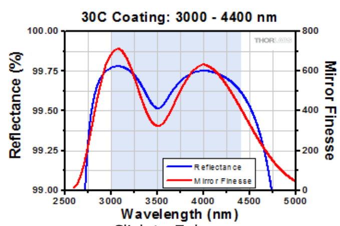
Click Here for Measured Reflectance Data and Calculated Mirror Finesse
This data has been smoothed in the wavelength region from 2.65 - 2.7 µm due to measurement inaccuracies introduced by absorption by water vapor in the air.



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Click Here for Theoretically Calculated Data

Hide Alignment Guide

ALIGNMENT GUIDE

The sections below outline how to align our Fabry-Perot Interferometers. Use the following links to jump to a specific section:

- General Instructions
- SA30 Series Beam Waist and Lens Recommendation
- Coupling a Free-Space Beam into a Scanning Fabry-Perot Interferometer
- Alignment Procedure
- Additional Alignment Steps for the SA30 Series

Recommended Beam Sizes and Lenses for FP Interferometers		
Item # Prefix	EFL[a]	Waist Diameter[b]
SA200	250 mm	600 µm (Max)
SA210	100 mm	150 µm (Max)
SA30	See *SA30 Series Recommendation*	

a. The recommended effective focal length of the lens, assuming a well collimated beam before the lens. The lens should be placed this length away from the center groove of the FP interferometer.
b. The maximum allowed waist diameter to meet the finesse and mode width specifications.

General Instructions

The Thorlabs scanning Fabry-Pérot interferometers can be aligned by mounting the instrument in a standard kinematic mirror mount (KS2 for SA200 and SA30, KS1 for SA210), which is then placed in a free-space beam after a fold mirror.

While the cavity is being scanned, iteratively adjust the position of the mirror and FP interferometer until the cavity is aligned with the input beam. After the cavity is aligned to the beam, a lens should be placed in the beam so that a beam waist with the specified diameter is formed in the center of the cavity, which is marked on the outer housing of the instrument with a groove as shown in Figures 1 and 2.

Click to Enlarge
Figure 1: The center of the SA200 interferometer is indicated by a groove on the instument body. The SA30 series items have the same instument body and groove.

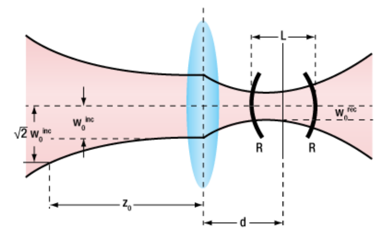
Click to Enlarge
Figure 2: The center of the SA210 interferometer is indicated by a groove on the instrument body.

SA30 Series Beam Waist and Lens Recommendations
For the SA30 series, the EFL and position of the lens depend on the beam parameters before the lens and have to be chosen in a way to obtain the recommended waist radius. The recommended waist radius of the incident lens is given by

$$w_0^{inc} = \frac{\lambda f}{\pi w_0^{rec}} \frac{1}{\sqrt{1+\frac{f^2}{(z_0^{inc})^2}}}, \quad (1)$$

where $\mathbf{w_0^{inc}}$, $\mathbf{w_0^{rec}}$, $\mathbf{z_0^{inc}}$, **λ**, and **f** are the waist size of the beam incident on the lens, the recommended beam waist radius at the center of the instrument, the Rayleigh range of the incident beam on the lens, the wavelength of the incident light, and the focal length of the lens. For a well-collimated beam, i.e., when the Rayleigh range of the incident beam on the lens is much larger than the focal length of the lens and the beam is only weakly diverging, Equation (1) reduces to

$$w_0^{inc} = \frac{\lambda f}{\pi w_0^{rec}} \quad (2)$$



Click to Enlarge
Figure 3: Schematic showing the beam waist incident on the focusing lens, $\mathbf{w_0^{inc}}$, and the recommended beam waist, $\mathbf{w_0^{rec}}$, at the center of the interferometer body.

The lens should be placed at a distance **D**

$$D = \frac{f}{1+\frac{f^2}{(z_0^{inc})^2}} \quad (3)$$

away from the center groove. This reduces to **D** = **f** for a well collimated beam[1]. Please note that the Rayleigh range of a Gaussian beam is given by $\mathbf{z_0 = \pi w_0^2/\lambda}$, where $\mathbf{w_0}$ is the beam waist radius and **λ** is the wavelength of the incident light.

The recommended waist radius for the SA30 series is given by

$$w_0^{rec} = \sqrt{\frac{\lambda}{2\pi}\sqrt{d(2R-d)}}, \quad (4)$$

where **R** is the radius of curvature of the mirrors (50 mm), **d** is the distance between the two resonator mirrors (50 mm), and **λ** is the wavelength of the incident beam[2].

Coupling a Free-Space Beam into a Scanning Fabry-Perot Interferometer

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Figure 4: SA210 FP Interferometer Free-Space System

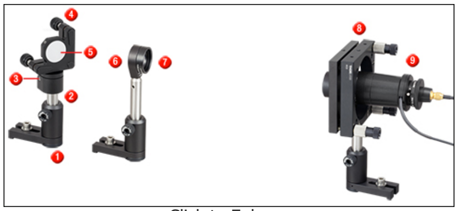

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Figure 5: SA200 FP Interferometer Free-Space System

Fabry-Perot Alignment Setup Parts List							
Callout #	Item #	Qty.	Description	Callout #	Item #	Qty.	Description
1	UPH2	3	Universal Post Holder, L = 2.00"	6	LMR1	1	Lens Mount for Ø1" Optics
2	TR3	3	Ø1/2" × 3" Stainless Steel Optical Post	7	LA1461-A-ML[b] LA1509-A-ML[b]	1	f = 250 mm Mounted, Visible Plano-Convex Lens (SA200) f = 100 mm Mounted, Visible Plano-Convex Lens (SA210)
3	FM90	1	Flip Mount	8	KC2 KC1	1	Kinematic Cage Mount for 2" Components (SA200) Kinematic Cage Mount for 1" Components (SA210)
4	KM100	1	Kinematic Mount for Ø1" Optics	9	SA200 SA30 SA210	1	Fabry-Perot Interferometer
5	BB1-E02[a]	1	Ø1" Broadband Dielectric Mirror				

[View Metric Product List]

a. In addition to the visible (350-700 nm) spectral range broadband dielectric mirror listed here, Thorlabs also sells Broadband Dielectric Mirrors suitable for other spectral ranges. Alternatively, a protected metallic mirror made from silver or aluminum could also be used.
b. In addition to the visible (400-700 nm) plano-convex lens listed here, Thorlabs also sells mounted and unmounted plano-convex lenses suitable for other spectral ranges.

Figure 4 above depicts a setup to integrate an SA210 FP Interferometer into a free-space system. Figure 5 shows a similar setup for the SA200. The easiest method for integration is through the use of a flipper mirror and kinematic interferometer mount. The advantage of the flipper mirror is that it allows normal system operation with the ability to measure the source spectrum when necessary, without repositioning optics and equipment. During normal operation, the mirror can simply be flipped out of the way of the beam, allowing the beam unobstructed propagation downstream. When necessary, the mirror can be flipped upright to intercept the beam and pass it down to the interferometer (see Figure 6). The system shown in Figure 4 is a single mirror system; here, the flipper mirror intercepts the beam, which is then directed toward the focusing lens and the interferometer in a kinematic mount. This minimizes space and components required, useful in a compact setup.

Click to Enlarge
Figure 6: Flipper Mirror in the Up Position (left) Intercepts Beam and Directs it to Interferometer Setup. Flipper Mirror in the Down Position (right) Allows Beam to Downstream Optics.

The SA210 FP Interferometer is shown mounted in a KC1(/M) (the KS1 would work equally as well) kinematic mount; the SA200 FP Interferometer is shown mounted in a KC2(/M) (the KS2 would work equally as well) kinematic mount. Figures 4 and 5 show a mounted lens threaded into the LMR1(/M) lens mount (an unmounted lens will work just as well). The specific optics (mirror and lens) will depend on the wavelength of the system.

Alignment Procedure

Measure the height of the beam from the table surface; in general, it is good practice to start with your optics centered at the height of your beam. Install the flipper mirror assembly (mirror mount with mirror, flip mount, post, and post holder) with the mirror in the up position at a 45° angle to the beam. 90° bounces make the initial alignment and walking the beam for fine-alignment much easier. The tapped holes of the optical table make an excellent guide for the initial setup.

With the flipper mirror installed and correctly deflecting the beam by 90°, secure the flipper mirror assembly to the table with a 1/4"-20 (M6) screw. Then mount the interferometer so that the beam enters the center of the aperture; the iris may be used to guide the alignment. While not necessary, if the vertical centerline of interferometer is set at the height of the beam, the initial setup should line up nicely and produce enough of a signal to simply use the kinematic mount of the flipper mirror and the kinematic interferometer mount to guide the beam into its optimal alignment.

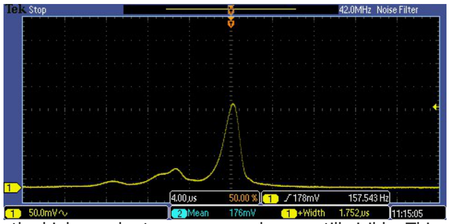
Turn on the Fabry-Perot controller box, and start scanning the length of the cavity (set the amplitude at >10 V to ensure that more than 1 peak is displayed) since light will only be transmitted when the cavity length is resonant with the wavelength of the light beam. Connect the detector output and the trigger or ramp signal to an oscilloscope. If no signal is detected at this point, it might be necessary to remove the detector from the back of the Fabry-Perot cavity in order to coarsely align the cavity. The iris located in the back of the interferometer can also be used to guide the alignment. However, this may be unnecessary if care is taken in the initial placement of the optics. Use the kinematic mount holding the interferometer and the flipper mirror to walk the beam until the Fabry-Perot cavity is correctly aligned.

Insert the lens (according to the table above) in the path at the specified distance so that the beam waist is centered in the Fabry-Perot cavity (marked by a groove on the FP housing, see Figures 1 and 2). Adjust the height and position of the lens to center the beam on the entrance aperture. The mirror and interferometer mount can be used to tweak the signal back into its optimal levels.

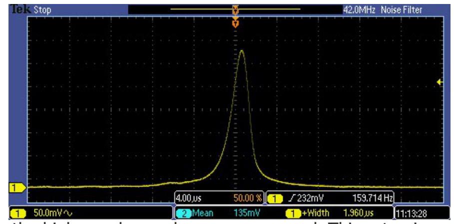
Additional Alignment Steps for the SA30 Series

Compared to the SA200 and SA210 series interferometers, the SA30 series requires several additional steps in order to properly align the system. After following the alignment steps above, zoom in on a single transmission mode and continue tweaking the alignment for maximum suppression of higher order modes; these higher order modes typically occur within a few MHz of the fundamental transmission mode. To do this, it is convenient to set the oscilloscope to one of the larger transmission modes in the spectrum. The lens position may also need to be adjusted slightly in order to achieve proper alignment and suppress the higher order modes. The images below show examples of transmission spectra before and after fine tuning the alignment for higher order mode suppression.

Please be careful that the output spectrum of the SA201 control box is not affected by the internal filters. The smallest possible time-based FWHM mode width is 4 µs for all gain settings. If you start to approach this value, you either have to change to a lower amplification level or change the PZT settings (amplitude, rise time, or sweep expansion) on the SA201 to achieve a slower sweep.



Here, the higher order transverse modes are still visible. This setup requires further tweaking to optimize alignment.



Here, the higher order modes are suppressed. This setup is properly aligned.

References

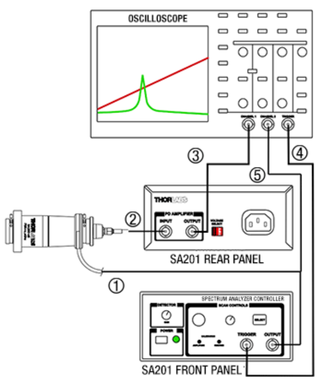
1. P. W. Milonni and J. H. Eberly, *Lasers* (John Wiley & Sons, Inc., 2010) p. 290.
2. H. Kogelnik and T. Li, "Laser Beams and Resonators," *Applied Optics*, vol. 5, no. 10, 1966.

Hide Connections

CONNECTIONS

Connections

This section describes the electrical connections between a Fabry-Perot (FP) interferometer, an SA201 control box, and an oscilloscope. The SA201 provides a voltage ramp to the piezoelectric transducer inside the FP cavity, which controls the cavity length. The oscilloscope is used to view the output from the scanning FP and the controller.



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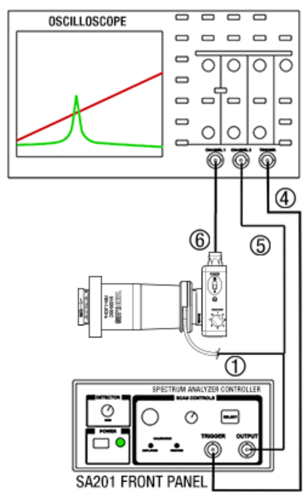
Recommended Setup for SA200 and SA30 Series Fabry-Perot Interferometers (Except SA200-30C; See Diagram to the Right)



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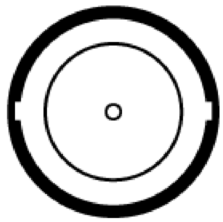
Recommended Setup for SA200-30C Fabry-Perot Interferometer

Connection	Description
1	Controller (BNC) to Piezo (Cable is Attached to FP Interferometer)
2[a]	Photodiode (SMA) to Controller (BNC) (Included with FP Interferometer)
3[a]	Amplified Photodiode Output (BNC) to Oscilloscope (Not Included)
4	Trigger Output of Controller (BNC) to Oscilloscope (Not Included)
5	Optional Connection that Allows the User to Monitor the Signal used to Drive the Piezoelectric Transducers (Not Included)
6[b]	PDAVJ5 Output (BNC) to Oscilloscope (Detector and Cable Not Included)

a. This connection is not part of the setup for the SA200-30C.
b. This connection is part of the setup only for the SA200-30C.

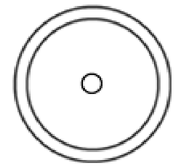
SA30, SA200, & SA210 Series Scanning Fabry-Perot Interferometers

Piezo (Ramp In) - BNC Male



150 V Maximum

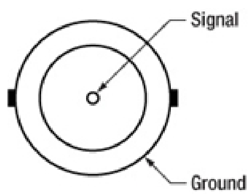
Photodiode Out - SMA Female



The SMA to BNC cable is included except for the SA200-30C, which does not include a detector. See the *-18C/30C Detectors* tab for more details.

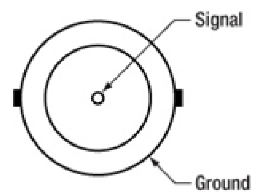
SA201 Control Box for Scanning Fabry-Perot Interferometers

Trigger Output BNC Female



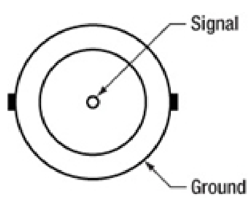
This trigger output signal may be used to externally trigger the oscilloscope. The trigger is capable of driving 50 Ω terminated cables, as well as Hi Z loads such as oscilloscopes. The trigger will provide an edge on the beginning and middle of the scanning ramp.

Output BNC Female



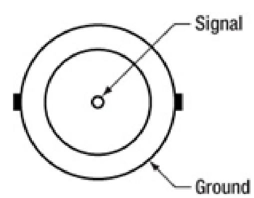
The output BNC is used to drive the SA200 scanning piezos from 1 to 45 V. The output is capable of driving 0.6 µF piezo loads at a ramp rate of 1 ms over the full voltage range. The output current is internally limited to prevent damage to the output drive.

PD Amplifier Input BNC



This input BNC is used to interface the photodetector, provided with the SA200 scanning heads, to the amplifier circuit. The photodiode amplifier is configured to operate with the Thorlabs supplied photo detectors; however, it is possible to operate user supplied photodetectors. To do so, the BNC center contact must be connected to the photo detector cathode and the BNC shell must be connected to the photodiode anode (unbiased operation). If a biased detector is to be used, the BNC shell must be connected to the bias ground and the bias voltage must be negative for the circuit to operate properly.

PD Amplifier Output BNC



This BNC is the amplifier output and may be connected directly to an oscilloscope to view the cavity spectrum. The amplifier gain will be set using the front panel 'DETECTOR' control knob. The amplifier output includes a 50 Ω series resistor to minimize noise when operating with a 50 Ω coax cable. For best results, a 50 Ω load resistor is recommended at the oscilloscope. Note, the amplifier gain will be halved with a 50 Ω load connected.

Hide Calibration

CALIBRATION

Calibrating the Oscilloscope Time Scale

Light transmitted through the Fabry-Perot interferometer can be displayed on an oscilloscope screen by following the setup shown on the *Connections* tab. Before taking a quantitative measurement for the laser or resonator mode widths, the time scale of the oscilloscope has to be calibrated so results can be determined in terms of optical frequency.

Figures 1 and 2 show the process for manual calibration of the time scale using the SA200-12B 1.5 GHz interferometer. Figure 1 shows the full free spectral range (FSR) of the interferometer (blue), with the two peaks separated by 1.5 GHz, and

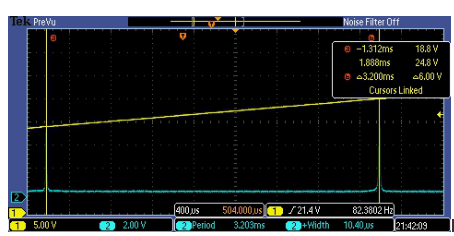


Figure 1: An FSR Plot, Using a 1550 nm DFB Laser (PRO8000 Series). Using the SA200-12B

the linear yellow line indicates the voltage ramp. By measuring the time between the peaks (3.2 ms in this example), the proper calibration can be calculated; 468.8 MHz/ms for our example. Once the time scale calibration is known, we can zoom in on one of the peaks to measure the FWHM in time (shown in Figure 2). The measured FWHM in this example is 10 µs (0.010 ms) and yields a linewidth of 4.7 MHz.

1.5 GHz interferometer, this plot is used to calibrate the time-base of the oscilloscope. Knowing that the FSR of the interferometer is 1.5 GHz, the calibration factor is found by setting 1.5 GHz = 3.2 ms between the two peaks.

For some of the more advanced oscilloscopes, linewidth and period analysis are automatic. These oscilloscopes will typically display the information somewhere on the screen, as shown in Figure 3 (in this case, the values are displayed at the bottom).

It may be beneficial to express either the FSR or the linewidth in terms of wavelength. The conversion is given by

$$\delta\lambda = \delta\nu \times \frac{\lambda^2}{c}$$

where *δλ* is the FSR or linewidth in space, *δv* is the FSR or linewidth in frequency, *λ* is the wavelength of the laser, and *c* is the speed of light. For example, in Figure 2 we have a FSR of 1.5 GHz for a 1550 nm laser. Converting to wavelength, we find that the FSR is 0.0121 nm. Likewise, the linewidth from Figure 3 is 5.1 MHz, which yields a linewidth of 0.000038 nm.

Please note that Thorlabs factory-calibrates the finesse, and a calibration sheet is included with each unit.

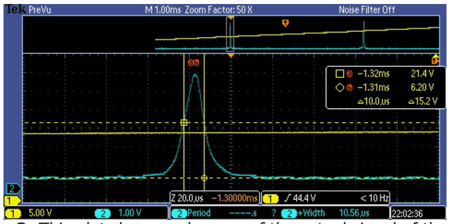


Figure 2: This plot shows a close-up of the actual signal of the laser, which results from the convolution of the laser linewidth and finesse of the cavity; with the oscilloscope timebase calibrated from Figure 1, at 468.8 MHz/ms, we determine the FWHM for the interferometer to be 0.010 ms x 468.8 MHz/ms for a FWHM of 4.7 MHz.

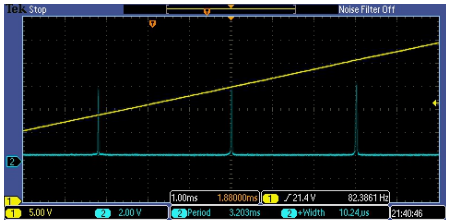


Figure 3: This plot shows an FSR plot on a scope that automatically analyzes pulse width and period. The linear yellow line shows the voltage ramp, the blue line shows the FSR trace.

Hide Fabry-Perot Tutorial

FABRY-PEROT TUTORIAL

Scanning Fabry-Pérot Interferometers

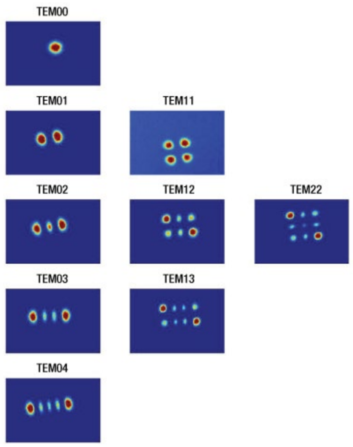
Fabry-Pérot interferometers are optical resonators used for high-resolution spectroscopy. With the ability to detect and resolve the fine features of a transmission spectrum with high precision, these devices are commonly used to determine the resonant modes of a laser cavity, which often feature closely-spaced spectral peaks with narrow line widths.

Spatial Mode Structure

The most common configuration of a Fabry-Pérot interferometer is a resonator consisting of two highly reflective, but partially transmitting, spherical mirrors that are facing one another. This type of resonator can be fully characterized by the following set of parameters:

- the resonator length or mirror spacing, **L**
- the radii of curvature of the input and output mirror, $\mathbf{R_1}$ and $\mathbf{R_2}$, respectively
- the transmission, reflection, and loss coefficients of the input and output mirror, $\mathbf{t_{1,2}}$, $\mathbf{r_{1,2}}$, and $\mathbf{l_{1,2}}$, respectively, related to each other in such a way that $\mathbf{t_{1,2} + r_{1,2} + l_{1,2} = 1}$ is fulfilled

Light waves entering the resonator through the input mirror will, depending on the mirror reflectivity, travel a large number of round-trips between the two mirrors. During this time, the waves also undergo either constructive or destructive interference. Constructive interference reinforces the wave and builds up an intracavity electric field. This corresponds to the case where a standing wave pattern is formed between the resonator mirrors, which occurs when the resonator length **L** is equal to an integer multiple of half the wavelength, **qλ/2**. All other wavelengths that do not fit this criteria are not supported by the resonator and destructively interfere.



Click to Enlarge

Figure 1: Spatial mode structure for lowest-order TEM modes. Figure reproduced from *Further Development of NICE-OHMs.*[2]

By assuming a general Gaussian beam solution to the paraxial wave equation, it can be shown[1] that only the following frequencies, $\mathbf{v_{qmn}}$, can exist inside the resonator:

$$v_{qmn} = \frac{c}{2L}\left[q + \frac{1}{\pi}(m+n+1)\cos^{-1}\sqrt{g_1 g_2}\right] \qquad (1)$$

where **q**, **m**, and **n** are mode numbers that can take on positive integers or zero and **c** is the speed of light. The g-parameters of the resonator $\mathbf{g_{1,2}}$ are given by

$$g_{1,2} := 1 - \frac{L}{R_{1,2}}, \qquad (2)$$

where $\mathbf{R_{1,2}} > 0$ for concave mirrors and $\mathbf{R_{1,2}} < 0$ for convex mirrors. These frequencies are referred to as Gaussian transverse electromagnetic (TEM) modes of order (**m**,**n**), or the Hermite-Gaussian modes, and are typically denoted as $\mathbf{TEM_{m,n}}$. The mode numbers **m** and **n** are associated with transverse modes, which describe the intensity pattern perpendicular to the optical axis, while **q** corresponds to the longitudinal mode. The TEM_{00} modes with **m** = **n** = 0 are called the fundamental TEM modes, or longitudinal modes, while TEM modes with **m**,**n** > 0 are called higher-order TEM modes. Figure 1 shows the spatial intensity pattern for a number of modes. Indices **m** and **n** correspond to the number of nodes in the vertical and horizontal directions respectively. For the case of light in the near infrared region, the parameter **q** is on the order of 10^6. The g-parameters of a resonator are often found in the so-called stability criterion. A resonator is called stable when its g-parameters fulfill the condition $0 \leq g_1 g_2 \leq 1$.[1]

Transmission Spectrum of a Fabry-Pérot Interferometer

For the case where light is spatially mode matched to the fundamental TEM_{00} mode, i.e., when the wave fronts of the Gaussian beam perfectly match with the mirror surfaces and the incoming beam is aligned to the optical axis of the resonator, no higher order modes (**m**,**n** > 0) are evoked. The transmission spectrum of the resonator consists only of TEM_{00} modes that differ from each other by different values of the parameter **q**. The distance between two consecutive TEM_{00} modes $\mathbf{\nu_{q00}}$ and $\mathbf{\nu_{q+1\,00}}$ is called the free spectral range (**FSR**) of the resonator and is given by

$$\nu_{\mathrm{FSR}} \equiv \nu_{q+1\,00} - \nu_{q\,00} = \frac{c}{2L}. \qquad (3)$$

This equation holds for all linear resonators comprised of two mirrors. The transmission intensity of a resonator, $\mathbf{I_t}$, as a function of the frequency detuning from mode **q**, $\mathbf{\Delta_q = \nu - \nu_q}$, is given by the well-known Airy-formula[3]

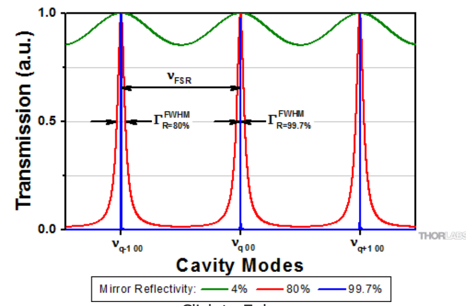


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Figure 2: Mode spectrum of a Fabry-Pérot interferometer for mirror reflectances of 99.7%, 80%, and 4%, illustrated by a blue, red, and green curve, respectively. 99.7% reflectance corresponds to the case for the SA200 series, which has a free spectral range of 1.5 GHz. The 4% reflectance corresponds to a typical "fringing effect" arising from reflections between parallel surfaces on glass plates.

$$I_t(\Delta\nu_q) = \frac{t_1 t_2}{(1-\sqrt{r_1 r_2})^2} \frac{I_0}{1 + \frac{4\sqrt{r_1 r_2}}{(1-\sqrt{r_1 r_2})^2} sin^2\left(\frac{\pi \Delta\nu_q}{\nu_{\mathrm{FSR}}}\right)}, \qquad (4)$$

where $\mathbf{I_0}$ is the intensity of the light incident on the instrument and all other variables are as described above. Figure 2 to the right shows the typical transmission spectrum of a Fabry-Pérot interferometer. From the above equation it can be seen that the on-resonance transmission, $\mathbf{T^c_{res}}$, is given by

$$T^c_{res} = \frac{I_t(0)}{I_0} = \frac{t_1 t_2}{(1-\sqrt{r_1 r_2})^2}, \qquad (5)$$

which also makes clear that the on-resonance transmission not only depends on the transmission of a single mirror, but also on the mirror's reflection and loss coefficients, since all mirror coefficients are connected through $\mathbf{t_{1,2} + r_{1,2} + l_{1,2} = 1}$ by definition. One always strives to keep absorption losses as small as possible to obtain maximum transmission for a given set of $\mathbf{r_{1,2}}$.

It can be seen from Equations (1) and (2) that the position of higher order transverse modes strongly depends on mirror spacing, **L**, and the radii of curvature of the mirrors, $\mathbf{R_{1,2}}$. For the special case when the two mirrors have the same radius, i.e. $\mathbf{R_1}$ = $\mathbf{R_2}$ = **R**, and the distance between the mirrors is equal to the mirror radius, i.e. **L**= **R**, the resonator is called a confocal resonator. Figure 3 shows a typical ray trace for a beam entering the resonator parallel to the optical axis at a distance H. All Thorlabs Fabry-Pérot interferometer models are based on such a confocal resonator design. For such a configuration, Equation (1) above simplifies to

$$\nu_{qmn} = \frac{c}{2L}\left[q + \frac{1}{2}(m+n+1)\right]. \qquad (6)$$

Two important conclusions can be drawn from this equation. First, all modes are degenerate, i.e., there exist higher order TEM modes that share the same frequency as the fundamental TEM_{00} (e.g. $TEM_{q'\,00}$, $TEM_{q'-1\,02}$, $TEM_{q'-1\,11}$, $TEM_{q'-1\,20}$, $TEM_{q'-2\,40}$, $TEM_{q'-2\,31}$, $TEM_{q'-2\,22}$, … all share the same frequency).

Second, the spectrum shows a regular, equidistant mode structure and the spacing between two consecutive modes is given by **c/4L**. If special care is not taken to obtain spatial mode matching, it is highly unlikely that higher order modes are suppressed. As a result, several higher order modes exist between two consecutive fundamental modes (TEM_{q00} and $TEM_{q+1\ 00}$) and the equidistant spacing between modes makes it appear that this FSR is equal to **c/4L**. To account for the existence of higher order modes, all values given for the FSR of the Thorlabs Fabry-Pérot interferometers are referring to the so-called confocal free spectral range, $\boldsymbol{\nu_{FSR,conf}}$ = **c/4L**. The arrows in Figure 4 highlight the difference between $\boldsymbol{\nu_{FSR}}$ and $\boldsymbol{\nu_{FSR,conf}}$. With careful alignment along the resonator's optical axis and near-perfect spatial mode matching of the incident light, it is possible to extinguish every other mode in the spectrum. Figure 4 below shows a configuration with near perfect mode matching. Higher order modes still exist, but they are smaller than the fundamental modes. Further tweaking of the alignment will eventually distinguish every other mode in the spectrum.

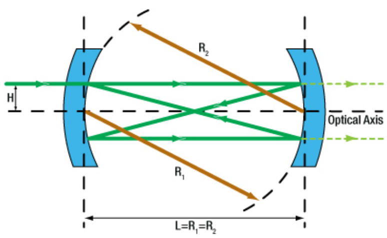

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Figure 3: Schematic of a confocal Fabry-Pérot resonator. Mirrors with radius $R_1 = R_2$ (brown arrows) are separated by a distance L that is equal to the mirror radius. The solid green lines show a ray-trace of an off-axis input beam entering the resonator at a height H. The dashed light green lines represent the beam transmitted through the second mirror; light transmitted through the first mirror is not pictured.

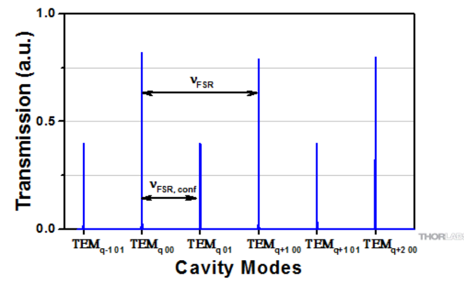

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Figure 4: Spectrum of a confocal resonator with near perfect spatial mode matching, where every other mode is extinguished as only the fundamental mode is excited. The TEM_{qmn} labels represent only one mode contained at that particular frequency; all modes are degenerate and, as described in the text, there are other modes sharing the same frequency.

Finesse and Mode Width (Resolution)

A Fabry-Pérot interferometer's performance, to a large extent[a], depends on the mirror reflectivity. Low-reflectivity mirrors will yield broader transmission peaks, while high-reflectivity mirrors will yield narrower transmission peaks. The mirror reflectivity plays a significant role in how well the interferometer can distinguish features of the transmission spectrum. Beyond the free spectral range, two more important quantities of a Fabry-Pérot interferometer are its finesse and mode width. The finesse, **F**, for mirrors having identical reflection coefficients, **r**, is given by

$$F = \frac{\pi\sqrt{r}}{(1-r)} \qquad (7)$$

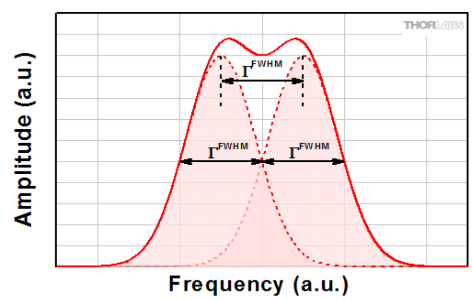

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Figure 5: When two Lorentzian lineshapes are separated by their FWHM, they meet the Rayleigh criteria for being resolvable.

For the case of a confocal interferometer, it can sometimes be convenient to express the finesse as

$$F_{conf} = \frac{F}{2} = \frac{\pi\sqrt{r}}{2(1-r)} \qquad (8)$$

An interferometer with a higher finesse will produce narrower transmission peaks than one with a lower finesse. Thus, a higher finesse increases the resolution of the interferometer, allowing it to more easily distinguish closely spaced transmission peaks from one another. According to the Rayleigh criterion (see Figure 5), two identical Lorentzian line shapes are resolvable when the peaks are separated by the full width at half maximum (FWHM) of each peak, denoted as $\boldsymbol{\Gamma^{FWHM}}$. The FWHM mode width, also called resolution, is related to the finesse and the FSR of a confocal resonator by

$$\Gamma^{FWHM} = \frac{\nu_{FSR}}{F} = \frac{\nu_{FSR,conf}}{F_{conf}} \qquad (9)$$

which is a measure of the minimum allowed spacing between two peaks to be resolved. For example, an interferometer with an FSR of 1.5 GHz and a finesse of 250 will have a FWHM of 6 MHz, and thus it will be able to distinguish features of the transmission spectrum as long as the peak values are at least 6 MHz apart. For visible light, this corresponds to a wavelength resolution of about 10 fm (10^{-14} m).

Thorlabs offers mirrors with crystalline coatings that achieve 99.999% reflection at 1550 nm, which equates to a reflection coefficient of 0.99999 or a finesse of 314,158. An interferometer using these crystalline mirrors would have a resolution of approximately 4.8 kHz, four orders of magnitude finer than the previous example, given the same FSR of 1.5 GHz.

Further Considerations on the Finesse

In fact, a measured finesse has a number of contributing factors: the mirror reflectivity finesse, simply denoted **F** above, the mirror surface quality finesse $\mathbf{F_Q}$, and the finesse due to the illumination conditions (beam alignment and diameter) of the mirrors $\mathbf{F_i}$. The overall finesse of a system, $\mathbf{F_t}$, is given by the relation[4]

$$\frac{1}{F_t} = \frac{1}{F} + \frac{1}{F_Q} + \frac{1}{F_i} \quad (10)$$

Often, the reflectivity finesse, Equation (8), is presented as an effective finesse, which is true for the case when the other contributing factors are negligible. For Thorlabs' interferometers, the reflectivity finesse dominates when operating with proper illumination.[b]

The second term in Equation (10) involves, $\mathbf{F_Q}$, which accounts for mirror irregularities that cause a symmetric broadening of the lineshape. The effect of these irregularities is a random position-dependent path length difference that blurs the lineshape. The manufacturing process that is used to produce the cavity mirror substrates always has to ensure that the contribution from $\mathbf{F_Q}$ is negligible in comparison to the specified total finesse of a resonator; in other words, the substrates surface figure should never be the limiting factor for the finesse.

The final term in Equation (10), which deals with the illumination finesse, $\mathbf{F_i}$, will reduce the resolution as the beam diameter is increased or as the input beam is offset. When the finesse is limited by the $\mathbf{F_i}$ term, the measured lineshape will appear asymmetric. The asymmetry is due to the path length difference between an on-axis beam and an off-axis beam, resulting in different mirror spacings to satisfy the maximum transmission criteria.

To quantify the effects of the variable path length on $\mathbf{F_i}$, consider an ideal monochromatic input, a delta function in wavelength with unit amplitude, entering the Fabry-Pérot cavity coaxial to the optic axis and having a beam radius **a**. The light entering the interferometer at H = +e, where e is infinitesimally small but not zero, will negligibly contribute to a deviation in the transmitted spectrum. Light entering the cavity at H = +a will cause a shift in the transmitted output spectrum, since the optical path length of the cavity will be less by an approximate distance of a^4/R^3. Assuming the input beam has a uniform intensity distribution, the transmitted spectrum will appear uniform in intensity and broader due to the shifts in the optical path length. As a result, the wavelength input delta function will produce an output peak with a FWHM of H^4/R^3 (Ref. 6).

Assuming that only $\mathbf{F_i}$ contributes significantly to the total finesse, then Eq. (9) can be used to calculate $\mathbf{F_i}$ for the idealized input beam. Substituting λ/4 for the **FSR**, and (H^4/R^3) for **FWHM**, yields:

$$F_i = \frac{\nu_{\mathrm{FSR,conf}}}{\Gamma_{\mathrm{FWHM}}} = \frac{\lambda R^3}{4H^4} \quad (11)$$

The λ/4 substitution for the FSR is understood by considering that the cavity expands by λ/4 to change from one longitudinal mode to the next. For an input beam with a real spectral distribution, the effect of the shift will be a continuous series of shifted lineshapes. It should be noted that the shift is always in one direction, leading to a broadened or assymmetric lineshape due to the over-sized or misaligned beam.

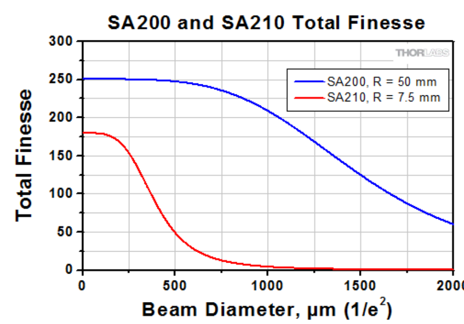

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Figure 6: The total finesse $\mathbf{F_t}$ as a function of beam diameter, **2H**, for the SA200 and SA210 Fabry-Pérot Interferometers using Equation (12). The finesse is calculated for a wavelength λ of 633 nm.

Now, the total finesse for the case of high reflectivity mirrors (r ≈ 1) can be found using Equation (10), which includes significant contributions from both **F** and $\mathbf{F_i}$ (Note: $\mathbf{F_q}$ is still considered to have a negligible effect on $\mathbf{F_t}$):

$$\frac{1}{F_t} = \frac{1}{F} + \frac{1}{F_i} = \frac{1-r}{\pi} + \frac{4H^4}{\lambda R^3} \quad (12)$$

Equation (12) is used to provide an estimate, in general an overestimate, of beam diameter effects on the total finesse of a Fabry-Pérot Interferometer, and several assumptions have been made. The first assumption is that the diameter of the beam is the same as the diameter of the mirror. In practice, the diameter of the beam is typically significantly smaller than that of the mirror, which also helps to reduce spherical aberration.[5] A second assumption is that the light is focused down to an infinitesimally small waist size. Even for monochromatic light, the minimum waist size is limited by diffraction, and in multimode applications the waist size can be quite large at the focus. Figure 6 provides a plot of Equation (12) evaluated at 633 nm for the SA200 and SA210 Fabry-Pérot Interferometers, which have cavity lengths of 50 mm and 7.5 mm respectively. The traces in the plot assume that the reflectivity finesse is equal to 250 for the SA200 and 180 for the SA210, which are typical values obtained for mirrors used in our interferometers.

Cavity Ring-Down Time and Intracavity Power Build-Up

As a light wave travels many round-trips inside the resonator, the light is stored inside for a certain amount of time, and only a small portion of its energy leaks out as it impinges on either the input or the output mirror. In other words, the light wave has a certain life-time inside the resonator. This time is called the cavity ring-down time or cavity storage time, τ_{cav}, and is given by

$$\tau_{cav} = \frac{1}{\pi \Gamma^{FWHM}} = \frac{F}{\pi\, \nu_{FSR}} \qquad (13)$$

This relation can show that τ_{cav} increases with the cavity finesse, i.e., the higher the finesse and the mirror reflectivity, the longer light is stored inside the resonator. In-line with this, another important quantity is the so-called intracavity power build-up, defined by the ratio of the intracavity intensity, I_c, and the incident intensity according to

$$\kappa = \frac{I_c}{I_0} \qquad (14)$$

which is given by **F/π** for a impedance-matched cavity (i.e., with a vanishing on-resonance reflection). This relates the intracavity intensity to the finesse by

$$I_c = \frac{I_0 F}{\pi} \qquad (15)$$

The fact that the power stored inside the cavity increases with finesse has to be kept in mind, when beams with high incident power are evaluated with a Fabry-Pérot interferometer.

Spectral Resolving Power and Étendue

The spectral resolving power of an interferometer is a metric to quantify the spectral resolution of an interferometer, and is an extension of the Rayleigh criterion. The spectral resolving power, **SR**, is defined as:

$$SR = \frac{\nu}{\Delta\nu} = \frac{\lambda}{\Delta\lambda} \qquad (16)$$

where **v** is the frequency of light and **λ** is its wavelength. It can be shown that for a confocal Fabry-Pérot interferometer, the **SR** is given by:

$$SR = \frac{4RF}{\lambda} \qquad (17)$$

where **F** is the finesse of the interferometer, **R** is the radius of curvature of the mirrors, and **λ** is the wavelength. However, to achieve this maximum instrumental profile while the interferometer is in scanning mode, the aperture of the detector would need to be infinitesimally small; as the size of the aperture is increased, the spectral resolving power begins to decrease. The spectral resolving power must be balanced with the étendue of the interferometer. The étendue (**U**) is the metric for the net light-gathering power of the interferometer. When the light source is a laser beam, the étendue provides a measure of the alignment tolerance between the interferometer and the laser beam. The étendue is defined as the product of the maximum allowed solid angle divergance (Ω) and the maximum allowed aperture area (A). For the confocal system, the étendue is given by:

$$U = \frac{\pi^2 \lambda L}{F} \qquad (18)$$

where **F** is the finesse of the interferometer, **λ** is the wavelength, and **L** is the mirror spacing. The spectral resolving power and étendue need to be balanced for the interferometer to work correctly. The accepted compromise for this balance is to increase the mirror aperture until the the spectral resolving power is decreased by 70% (0.7*SR) (Ref. 4). Under this condition the "ideal" étendue becomes **π2λR/F**, where **R** is the mirror's radius.

For more information on our Fabry-Pérot interferometers, including typical application examples, please see the full web presentation here.

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Footnotes

a. It can be seen from Equation (1) above, that the optical path length and subsequently the free spectral range, finesse, and mode width depend on the beam offset, **h**, from the optical axis of the interferometer. Hence, best performance is achieved for the beam being well aligned to the optical axis. Also, the radius of curvature of the Gaussian beam impinging on the interferometer should equal the radius of curvature of the mirrors on the corresponding reflective surface. Provided a well collimated beam, this can be achieved sufficiently well by following the lens recommendations in the *Alignment Guide* tab on our full Fabry-Pérot Interferometers web presentation.
b. The reflective coatings in all Thorlabs Fabry-Pérot interferometers have been designed so that the minimum **F** is better than 1.5 times the minimum specified finesse across their entire operating wavelength range for each model.

Hide Applications

APPLICATIONS

Thorlabs Scanning Fabry-Pérot Interferometers can be used in a wide range of applications, of which three examples are presented below. The linewidth measurement examples are valid for a laser emitting a single mode spectrum or an individual mode from a multimode laser with nonoverlapping modes.

Application 1: Determining the Laser Mode Linewidth Through Scanning

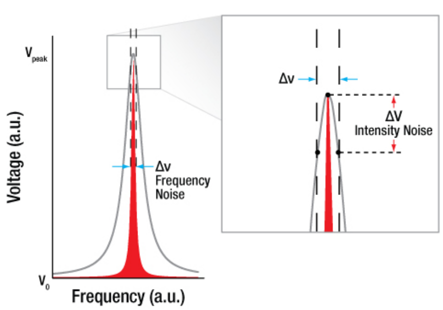
As described in the *Calibration* tab, laser mode linewidth can be measured using an oscilloscope by calibrating the time axis, zooming into the mode, and measuring the full width at half max (FWHM). However, there are three regimes that need to be considered when making this measurement, which are defined by the ratio of the laser line width Γ_{FWHM}^{laser} to the Fabry-Pérot resonator mode width Γ^{FWHM}.

Regime	Comments
$\Gamma_{FWHM}^{laser} >> \Gamma^{FWHM}$	**This is the preferred mode of operation.** The measured FWHM is the laser mode width since the line shape is dominated by the laser linewidth; contributions from the resonator mode width are negligible.
$\Gamma_{FWHM}^{laser} \approx \Gamma^{FWHM}$	The FWHM extracted from the oscilloscope is a convolution of the laser line shape and the resonator mode. A deconvolution procedure is needed to determine the true laser linewidth.
$\Gamma_{FWHM}^{laser} << \Gamma^{FWHM}$	The line shape is dominated by the resonator mode width; therefore the measured FWHM is the resonator mode width. In this case, for an assessment of the laser linewidth, a Fabry-Pérot resonator with a higher finesse must be chosen. Another possibility is to make an estimate of the linewidth with the so called side-of-mode technique described in Application 2.

Application 2: Determining the Laser Mode Linewidth Through Side-of-Mode Locking

An estimate for the laser linewidth can be determined by knowing the slope of the Fabry-Pérot resonator mode and measuring the intensity fluctuations that occur when the laser and resonator modes are offset from one another. This technique should be used in cases where the laser linewidth is much less than the Fabry-Pérot resonator mode width. For example, if a laser has a 500 kHz linewidth, it will be difficult to determine the linewidth using an SA200, which has a 7.5 MHz mode width. Note that the measurement described in this section cannot be done with the SA201 controller, which does not provide a pure DC output. Instead, a low-noise PZT driver that is able to provide a constant and stable DC output, e.g. the MDT694B Single-Channel, Open-Loop Piezo Controller, should be used.

The illustrations below show the origin of the intensity noise used in this technique. In Figure 1, the laser (red) is tuned to the center of the Fabry-Pérot resonator mode (gray). The laser inherently has frequency noise **Δv**, defined by the FWHM, and as a result the intensity of the light transmitted through the interferometer fluctuates. The black dotted lines drawn from the FWHM of the laser up through the Fabry-Pérot cavity mode profile show that fluctuations in the frequency (blue arrows) lead to small amounts of noise in the intensity (red arrow). For the same amount of frequency noise **Δv**, a laser tuned to the side of the resonator mode will produce a larger amount of intensity noise **ΔV**, as shown in Figure 2.



Click to Enlarge
Figure 1: Illustration of frequency-to-noise amplitude conversion. Frequency noise **Δv** (blue arrows) creates a small amount of intensity noise **ΔV** (red arrow) when the laser is tuned to the center of the resonator mode. The gray and red peaks illustrate the Fabry-Pérot resonator and laser modes

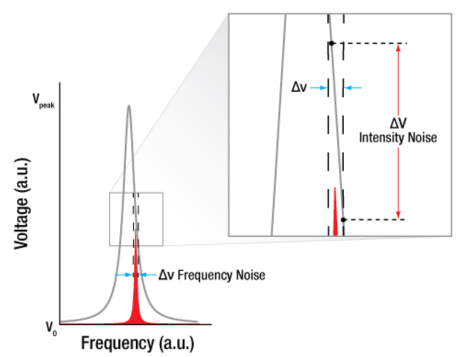


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Figure 2: Illustration of frequency-to-noise amplitude conversion. The same frequency noise **Δv** (blue arrows) from Figure 1 creates larger intensity noise **ΔV** (red arrow) when the laser is tuned to the side of the resonator mode. The gray and red peaks illustrate the Fabry-Pérot resonator and laser modes respectively.

respectively.

Because the laser is tuned to the side of the Fabry-Pérot cavity mode, it is possible to estimate the linewidth by relating the voltage fluctuations to the slope of the cavity mode. Figure 3 shows a visual representation of this relationship; the green lines indicate the two slopes that are assumed to be equal for this calculation. The Fabry-Pérot resonator mode has a Lorentzian line shape[1]

$$\gamma_{q,L} = \frac{\Gamma_L^2}{\Gamma_L^2 + (\Delta\nu)^2},$$

where Γ_L is the half-width-at-half-maximum (HWHM) of the mode and Δv is $v\text{-}v_q$. By taking the first derivative of the lineshape, the slope $\gamma'_{q,L}$ of the resonator mode at the HWHM point (point in Figure 3) can be found to be

$$\gamma'_{q,L}(-\Gamma_L) = \frac{1}{2\Gamma_L},$$

The Γ_L of the Fabry-Pérot resonator can be calculated by $\Gamma^{FWHM}/2$, which refers to equation (8) on the *Tutorial* tab and is also given in the specifications for all Thorlabs Fabry-Pérot interferometers. The linewidth (FWHM) of the laser, Γ_{FWHM}^{laser}, can be found by taking

$$\Gamma_{FWHM}^{laser} = \frac{\Delta V}{\gamma'_{q,L}(-\Gamma_L) \times C} = \frac{2\Gamma_L \Delta V}{C},$$

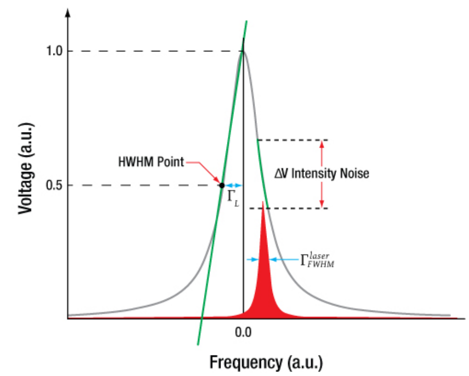

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Figure 3: Illustration showing the relationship between the slope of the Lorentzian Fabry-Pérot resonator mode profile and the intensity noise. The gray, red, and green lines represent the Fabry-Pérot resonator mode, laser mode, and slope respectively. The blue arrows indicate the frequency noise Γ_{FWHM}^{laser} (**Δv** from Figure 2), while red arrows highlight the intensity noise **ΔV**.

where **ΔV** is the intensity variation that can be determined from the oscilloscope reading, $\gamma'_{q,L}(-\Gamma_L)$ is the cavity mode slope a the HWHM point, and the factor **C** accounts for an estimate of the relationship between the peak-to-peak value and the root-mean-square of the noise type present in the measurement. For white noise, the C factor is found to be sqrt(2). It should be noted that the C factor results in an overestimate of the linewidth of the laser, so the calculated linewidth will never be smaller than the actual physical value.

Application 3: Measuring Mode Spectra

As a high-resolution spectrum analyzer, the scanning Fabry-Pérot interferometer is a useful tool for monitoring the performance of a laser. In a manufacturing environment, it could be used during production to ensure side modes are sufficiently suppressed or desired modulation depths are obtained. The Fabry-Pérot interferometers can also be used in an educational setting, specifically as a method to observe HeNe resonator modes while a HeNe laser is warming up, as well as to determine properties such as the free spectral range (FSR) and the actual resonator length inside the HeNe.

To demonstrate the importance of choosing an interferometer with an FSR larger than the laser mode spectrum, Figures 4 and 5 below show simulated HeNe spectra of an unpolarized HNL100RB laser and how they would be detected by SA210-5B and SA200-5B interferometers respectively. With a ~1.3 GHz gain profile, the HeNe laser spectrum is better viewed on the SA210-5B, where the spectrum is sensed by two consecutive modes of the Fabry-Pérot resonator that are spaced out by 10 GHz. The individual modes are shown in gray, while the red dotted line in the figure indicates the laser gain profile. Please note that the red dotted line has been included to highlight the envelope of the gain profile but will not be visible on the scope. In contrast, when viewed on the SA200-5B that has a 1.5 GHz free spectral range, the laser mode profiles overlap. Since the line indicating the gain profile will not be visible on the oscilloscope, it is difficult to distinguish an individual laser spectrum from the neighboring spectra. This is a result of the gain profile being larger than the free spectral range of the scanning Fabry-Pérot Interferometer. Note that the dashed black line in Figure 4 shows a possible gain threshold, and only modes above this threshold will lase and appear in the spectrum. When the laser is warming up, the HeNe resonator expands due to thermal expansion, changing the resonator's resonance frequencies. As a result, the modes under the gain profile will move, becoming stronger towards the center and vanishing when they fall below the threshold.

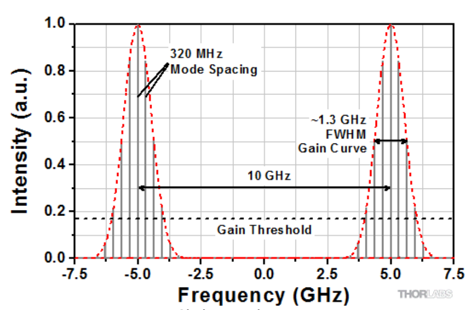

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Figure 4: Simulation showing two consecutive modes of the SA210-5B detecting the mode spectrum of a HeNe laser with a ~1.3 GHz gain profile. With a 10 GHz FSR that is much larger than the gain profile, the laser spectra do not overlap. The dotted red, solid gray, and dotted black lines correspond to the gain profile, longitudinal modes, and gain threshold respectively.

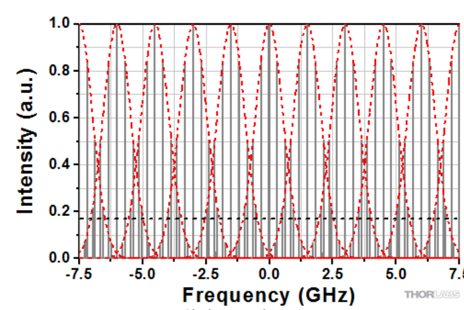

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Figure 5: Simulation showing consecutive modes of the SA200-5B detecting the mode spectrum of a HeNe laser with a ~1.3 GHz gain profile. With a 1.5 GHz FSR, the observed laser spectra overlap with one another, making it difficult to extract information. The dotted red, solid gray, and dotted black lines correspond to the gain profile, longitudinal modes, and gain threshold respectively.

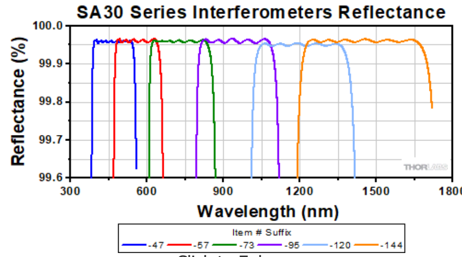
References

1. N.Ismail, C.C. Kores, D. Geskus, and M. Pollnau,"Fabry-Pérot resonator:spectral line shapes, generic and related Airy distributions, linewidths, finesses, and performance at low or frequency-dependent reflectivity," *Optics Express*, vol. 24, no. 15, 2016.

Hide Scanning Fabry-Perot Interferometers: 1.5 GHz FSR, ≥1500 Finesse

Scanning Fabry-Perot Interferometers: 1.5 GHz FSR, ≥1500 Finesse

- Near-Confocal Fabry-Perot Design with Sub-MHz Resolution
- High Finesse: ≥1500
- 10% to 20% On-Resonance Transmission (Typical)
- Ultrastable Athermal Invar Cavity
- Low Scan Voltage (2.5 V per FSR @ 633 nm)
- Ø2" Flange for Mounting in Thorlabs' KS2 or KC2 (KC2/M) Mounts
- SMA-to-BNC Cable Included



Click to Enlarge
SA30 Series Interferometer Mirror Reflectance

The SA30 series Fabry-Perot Interferometers have a free spectral range of 1.5 GHz. With a minimum finesse of 1500, the resolution of these interferometers is <1 MHz. Six wavelength ranges are available, which are listed in the table below and illustrated in the graph to the right. See the *Graphs* tab for more information.

Custom mirror coatings for wavelengths from the UV to the mid-IR (200 nm to 4700 nm) are available upon request. If these coatings do not suit the needs of your application, please contact Tech Support.

Item #	Wavelength Range	Free Spectral Range[a]	Total Finesse	Resolution	Cavity Length[b]	Mirror Substrate	Detector
SA30-47	400 - 535 nm	1.5 GHz	≥1500	<1 MHz	50 mm	UV Fused Silica	Yes
SA30-57	490 - 640 nm						
SA30-73	630 - 824 nm						
SA30-95	824 - 1071 nm						
SA30-120	1060 - 1350 nm						
SA30-144	1250 - 1625 nm					IR-Grade Fused Silica (Infrasil®)	

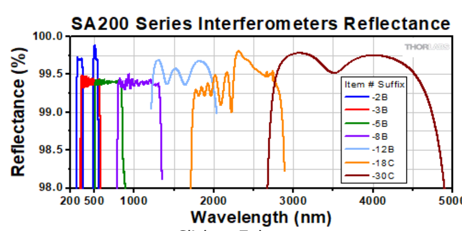
a. Free Spectral Range (FSR) is set by the length of the near-confocal cavity and is given by FSR=c/4R, where R is the radius of curvature of the mirrors; in this case R = 50 mm.
b. Nominal Distance Between Mirrors

Part Number	Description	Price	Availability
SA30-47	Scanning Fabry-Perot Interferometer, Finesse ≥ 1500, 400 - 535 nm, 1.5 GHz FSR	$3,664.64	7-10 Days
SA30-57	NEW! Scanning Fabry-Perot Interferometer, Finesse ≥ 1500, 490 - 640 nm, 1.5 GHz FSR	$3,653.74	Today
SA30-73	Scanning Fabry-Perot Interferometer, Finesse ≥ 1500, 630 - 824 nm, 1.5 GHz FSR	$3,760.42	Today
SA30-95	Scanning Fabry-Perot Interferometer, Finesse ≥ 1500, 824 - 1071 nm, 1.5 GHz FSR	$3,800.24	Today
SA30-120	Scanning Fabry-Perot Interferometer, Finesse ≥ 1500, 1060 - 1350 nm, 1.5 GHz FSR	$3,868.04	Today
SA30-144	Scanning Fabry-Perot Interferometer, Finesse ≥ 1500, 1250 - 1625 nm, 1.5 GHz FSR	$3,983.21	Today

Hide Scanning Fabry-Perot Interferometers: 1.5 GHz FSR, >200 Finesse

Scanning Fabry-Perot Interferometers: 1.5 GHz FSR, >200 Finesse

- Confocal Fabry-Perot Design
- Wavelength Ranges from UV to MIR
- Ultrastable Athermal Invar Cavity
- Low Scan Voltage (2.5 V per FSR @ 633 nm)
- Ø2" Flange for Mounting in Thorlabs' KS2 or KC2 (KC2/M) Mounts
- SMA-to-BNC Cable Included (Except for SA200-30C)



Click to Enlarge
SA200 Series Interferometer Mirror Reflectance

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[APPLIST]
[APPLIST]
SA200-30C with PDAVJ5 Detector Installed

The SA200 series of Fabry-Perot interferometers have a free spectral range of 1.5 GHz. With a minimum finesse of 200, the resolution of these interferometers is 7.5 MHz. Seven optical coatings are available with operating ranges from 290 to 4400 nm, including one dual-wavelength coating (SA200-2B). These are listed in the table below and illustrated in the graph to the right. See the *Graphs* tab for more information. Custom mirror coatings for wavelengths from the UV to the mid-IR (200 nm to 4700 nm) are available upon request. If these coatings do not suit the needs of your application, please contact Tech Support.

For the SA200-18C, the included photodiode detector is sensitive to wavelengths from 1.8 - 2.6 µm. Since the reflectance of the mirrors inside this device remains over 99.0% in the 2.6 - 2.8 µm range, an alternative detector can be installed to use the instrument over an extended wavelength range. For this purpose, we recommend Thorlabs' PDA10PT (PDA10PT-EC) detector, which can be attached to the Fabry-Perot interferometer using an SM1T2 lens tube coupler.

The SA200-30C has a coating designed for 3.0 - 4.4 µm and does not include a detector. We recommend using the PDAVJ5 HgCdTe Amplified Photodetector, which is sensitive to wavelengths in the 2.7 - 5.0 µm range. The PDAVJ5 and the SA200-30C, which have external and internal SM1-threading respectively, can be directly mounted together without using additional threaded adapters. Please note that the PDAVJ5 includes a transimpedance amplifier, so the detector should not be connected to the transimpedance amplifier of the SA201 controller when operating the interferometer. Additionally, due to saturation effects of the diode inside the PDAVJ5 detector, the optical power entering the SA200-30C should be kept below 200 µW in order to avoid saturation.

Item #	Wavelength Range	Free Spectral Range	Total Finesse	Resolution	Cavity Length[a]	Mirror Substrate	Detector
SA200-2B	290 - 355 nm; 520 - 545 nm	1.5 GHz	>200 (250 Typ.)	7.5 MHz	50 mm	UV Fused Silica	Yes
SA200-3B	350 - 535 nm						
SA200-5B	535 - 820 nm						
SA200-8B	820 - 1275 nm						
SA200-12B	1275 - 2000 nm						
SA200-18C	1800 - 2600 nm					IR-Grade Fused Silica (Infrasil®)	
SA200-30C	3000 - 4400 nm					Yttrium Aluminum Garnet (YAG)	No

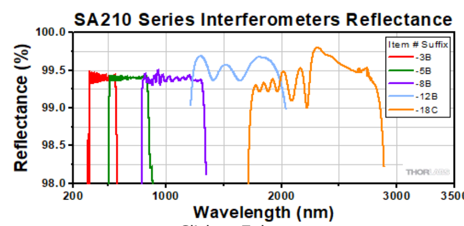
a. Nominal Distance Between Mirrors

Part Number	Description	Price	Availability
SA200-2B	Scanning Fabry-Perot Interferometer, 290-355 nm & 520-545 nm, 1.5 GHz FSR	$3,311.21	Today
SA200-3B	Scanning Fabry-Perot Interferometer, 350-535 nm, 1.5 GHz FSR	$3,120.05	Today
SA200-5B	Scanning Fabry Perot Interferometer, 535-820 nm, 1.5 GHz FSR	$3,322.68	Today
SA200-8B	Scanning Fabry Perot Interferometer, 820-1275 nm, 1.5 GHz FSR	$3,525.34	Today
SA200-12B	Scanning Fabry Perot Interferometer, 1275-2000 nm, 1.5 GHz FSR	$3,727.98	Today
SA200-18C	Scanning Fabry-Perot Interferometer, 1800-2600 nm, 1.5 GHz FSR	$4,001.67	Today
SA200-30C	Scanning Fabry-Perot Interferometer, 3000-4400 nm, 1.5 GHz FSR, No Detector	$3,987.14	Today

Hide Scanning Fabry-Perot Interferometers: 10 GHz FSR, >150 Finesse

Scanning Fabry-Perot Interferometers: 10 GHz FSR, >150 Finesse

- Confocal Fabry-Perot Design
- Ultrastable Athermal Invar Cavity
- Low Scan Voltage (2.5 V per FSR @ 633 nm)
- Ø1" Flange for Mounting in Thorlabs' KS1 or KC1 (KC1/M) Mounts
- SMA-to-BNC-Cable Included



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SA210 Series Interferometer Mirror Reflectance

The SA210 series of Fabry-Perot interferometers have a free spectral range of 10 GHz. With a minimum finesse of 150, the resolution of these interferometers is 67 MHz. Five wavelength ranges are available which are listed in the table below and illustrated in the graph to the right. See the *Graphs* tab for more information. Custom mirror coatings for wavelengths from the UV to the mid-IR (200 nm to 4700 nm) are available upon request. If these coatings do not suit the needs of your application, please contact Tech Support.

For the SA210-18C, the included photodiode detector is sensitive to wavelengths from 1.8 - 2.6 µm. Since the reflectance of the mirrors inside this device remains over 99.0% in the 2.6 - 2.8 µm range, an alternative detector can be installed to use the instrument over an extended wavelength range. For this purpose, we recommend Thorlabs' PDA10PT (PDA10PT-EC) detector, which can be attached to the Fabry-Perot interferometer using an SM1T2 lens tube coupler.

Item #	Wavelength Range	Free Spectral Range	Total Finesse	Resolution	Cavity Length[a]	Mirror Substrate	Detector
SA210-3B	350 - 535 nm	10 GHz	>150 (180 Typ.)	67 MHz	7.5 mm	UV Fused Silica	Yes
SA210-5B	535 - 820 nm						
SA210-8B	820 - 1275 nm						
SA210-12B	1275 - 2000 nm						
SA210-18C	1800 - 2600 nm					IR-Grade Fused Silica (Infrasil®)	

a. Nominal Distance Between Mirrors

Part Number	Description	Price	Availability
SA210-3B	Scanning Fabry-Perot Interferometer, 350-535 nm, 10 GHz FSR	$2,918.55	Today
SA210-5B	Scanning Fabry-Perot Interferometer, 535-820 nm, 10 GHz FSR	$3,120.05	Today
SA210-8B	Scanning Fabry-Perot Interferometer, 820-1275 nm, 10 GHz FSR	$3,322.68	Today
SA210-12B	Scanning Fabry-Perot Interferometer, 1275-2000 nm, 10 GHz FSR	$3,525.34	7-10 Days
SA210-18C	Scanning Fabry-Perot Interferometer, 1800-2600 nm, 10 GHz FSR	$3,683.73	Today

Hide Control Box for Scanning Fabry-Perot Interferometers

Control Box for Scanning Fabry-Perot Interferometers

- TTL Trigger Output
  - Trigger on Rise for Start of Scan
  - Trigger on Fall for Midpoint of Scan
- Adjustable DC Offset of Scan Voltage (Center Signal on Scan Midpoint)
- Adjustable (0.01 - 10 s) Scan Time
- Triangle or Sawtooth Scan Voltage
- Transimpedance Gain Amplifier for Photodiode Output
- Switch-Selectable Input: 100, 115, or 230 VAC

Ramp Specifications	
Waveform	Sawtooth or Triangle
Output Voltage Range	1 - 45 V (Offset + Amplitude)
Offset Adjustment Range	0 - 15 VDC
Amplitude Adjustment Range	1 - 30 V
Rise Time Adjustment Range	1X Sweep Expansion: 0.01 - 0.1 s 100X Sweep Expansion: 1 - 10 s
Sweep Expansion	1X, 2X, 5X, 10X, 20X, 50X, 100X
Sweep Scale Error	±0.5%
Output Noise	1 mV (RMS) ~6.6 mV (Peak to Peak)
Trigger	Ramp Start or Midpoint

Photoamplifier Specifications	
Gain Steps	0, 10, 20 dB
Transimpedance Gain (Hi-Z)	10, 100, or 1000 kV/A
Transimpedance Gain (50 Ohms)	5, 50, or 500 kV/A
Output Voltage (Hi-Z)	0 - 10 V (Minimum Range)
Output Voltage (50 Ohms)	0 - 5 V (Minimum Range)
Bandwidth	250 kHz
Noise (RMS)	<0.1 mV @ 10 kV/A 0.2 mV @ 100 kV/A 1.5 mV @ 1000 kV/A

The SA201 is specifically designed to control Thorlabs' Fabry-Perot interferometers by generating a highly stable, low-noise voltage ramp. This ramp signal is used to scan the separation between the two cavity mirrors.

The controller, which features a power supply with a 100, 115, or 230 VAC switch-selectable input, provides adjustment of the ramp voltage and scan time, allowing the user to choose the scan range and speed, while an offset control is provided to allow the spectrum displayed on the oscilloscope to be shifted right or left.

The output trigger allows the user to externally trigger an oscilloscope on either the beginning or midpoint of the ramp waveform. The ability to trigger the oscilloscope from the midpoint makes zooming in on a line shape more convenient; just place the spectral component of interest on the center of the screen and increase the timebase of the scope. There is no need to use the offset to re-center the signal; the scope expands about the point of interest. A calibrated zoom capability provides a 1X, 2X, 5X, 10X, 20X, 50X, or 100X increase in the length of the ramp signal, thus allowing an extremely wide range of scan times.

The SA201 also includes a high precision photodetector amplifier circuit used to monitor the transmission of the cavity. The amplifier provides an adjustable transimpedance gain of 10 kV/A, 100 kV/A, or 1000 kV/A when driving a high impedance load, such as an oscilloscope. Using the output sync signal from the controller, an oscilloscope can be used to display the spectrum of the input laser. The detector circuitry incorporates a blanking circuit, which disables the photodiode response during the falling edge of the sawtooth waveform.

The SA201 is shipped with a 120 VAC power supply line cord for use in the US, while the SA201-EC is shipped with a 230 VAC power supply line cord for use in Europe.

Part Number	Description	Price	Availability
SA201-EC	**Control Box for Scanning Fabry-Perot Interferometers, 230 VAC Power Cord**	**$1,040.03**	**Lead Time**
SA201	**Control Box for Scanning Fabry-Perot Interferometers, 120 VAC Power Cord**	**$1,040.03**	**Lead Time**