# Accurately Measure Laser Spectral Characteristics

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Faster transmission rates, increased channel counts and increased transmission distances are driving the continual advancements of laser transmitter technology. Whether it's a fixed-wavelength distributed-feedback laser (DFB), a tunable distributed Bragg reflector (DBR) or a vertical-cavity surface-emitting laser (VCSEL), accurate analysis of the transmitter's spectral characteristics is crucial to the development and manufacturing processes.

Many different technologies can be used for spectral analysis, but the preferred method for highest-resolution spectral analysis is the scanning Fabry-Perot interferometer technique. As the Fabry-Perot interferometer is a very simple device that relies on the interference of multiple beams, it is ideal for measuring laser linewidth, longitudinal mode structure and frequency stability of a laser source. The device consists of two partially transmitting mirrors that are precisely aligned to form a reflective cavity. Incident light enters the Fabry-Perot cavity and undergoes multiple reflections between the mirrors so that the light can interfere with itself many times. If the frequency of the incident light is such that constructive interference occurs within the Fabry-Perot cavity, the light will be transmitted. Otherwise, destructive interference will not allow any light through the Fabry-Perot interferometer.

The condition for constructive interference within a Fabry-Perot interferometer is that the light forms a standing wave between the two mirrors (Figure 1). In other words, the optical distance between the two mirrors must equal an integral number of half wavelengths of the incident light. The constructive interference condition therefore is defined by the equation:

$$nd\cos\theta = m\lambda/2$$

where $m$ is an integer termed the order of interference, $n$ is the refractive index of the medium between the two mirrors, $d$ is the mirror separation and $\theta$ is the inclination of the direction of the incoming radiation to the normal of the mirrors. Because air ($n$ = 1) typically is the medium between most Fabry-Perot mirrors, and the incident light usually is aligned normal to the mirrors ($\cos\theta = 1$), the constructive interference equation can be reduced to:

$$d = m\lambda/2$$

This equation shows that the wavelength transmitted by a Fabry-Perot interferometer depends on the physical separation between the interferometer's mirrors. Therefore, by employing piezoelectric mirror spacers to which a voltage is applied (to smoothly adjust the mirror separation), the transmitted wavelength of a Fabry-Perot interferometer can be tuned precisely.

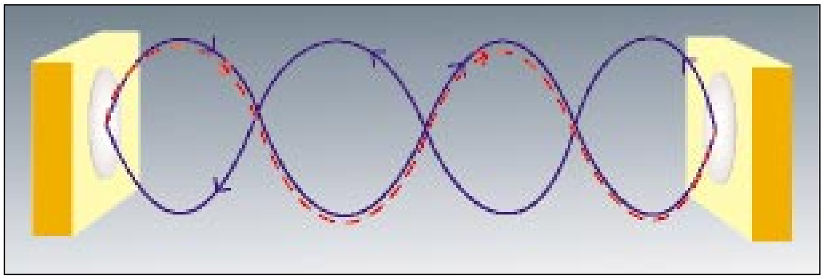

*Figure 1: Standing wave within a Fabry-Perot cavity allows for constructive interference.*

For many applications, it is useful to apply a ramp voltage to the piezoelectric spacers to continuously vary the transmitted wavelength. In this case, the mirror separation usually is scanned over several half wavelengths of the incident light resulting in an interference pattern, or spectrum, that displays a transmission peak every time the constructive interference equation is satisfied (Figure 2). The adjacent peaks of this repeating pattern are simply different orders of interference (*m*) of the same incident wavelength.

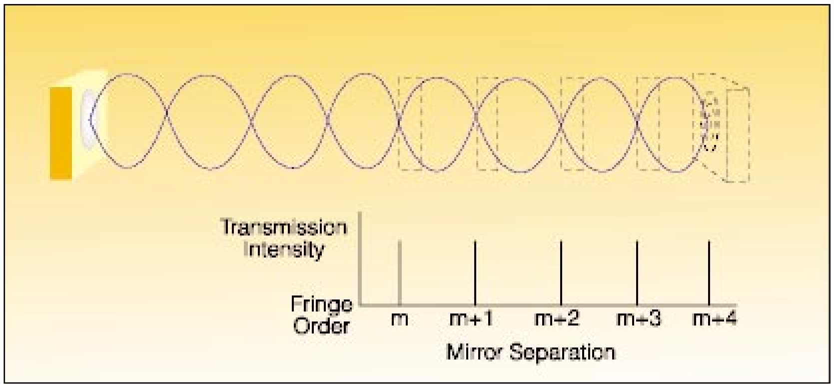


*Figure 2: Transmission pattern of a scanning mirror Fabry-Perot interferometer as mirror separation is changed.*

## Fabry-Perot Interferometer Figures of Merit[1]

The infinitely narrow transmission peaks shown in Figure 2 are not typical of a Fabry-Perot interference pattern. Instead, the transmission peaks are better described in the spectrum shown in Figure 3. The finite width of these peaks, as well as the difference in frequency between adjacent interference orders, define the performance of the interferometer. The terms that define Fabry-Perot performance include:

- Free Spectral Range
- Finesse
- Minimum Resolvable Bandwidth

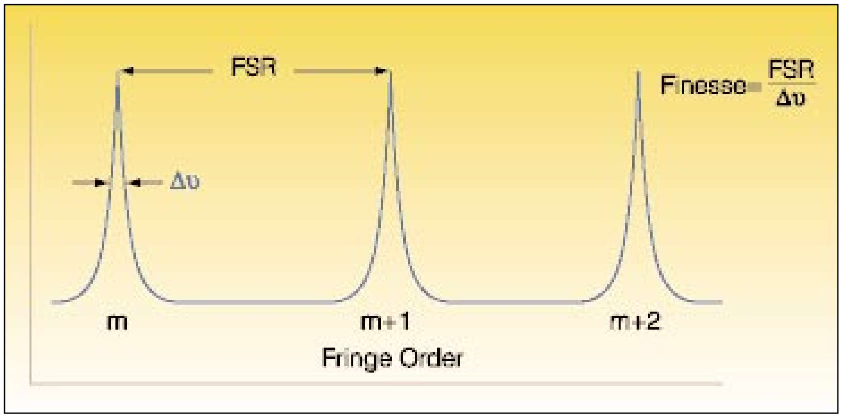


*Figure 3: Transmission pattern of a typical Fabry-Perot interferometer. The interference fringes are equally spaced as a function of frequency. The frequency separation between adjacent fringes is termed the free spectral range (FSR). The width of the fringe generated by a perfectly monochromatic light source is termed the minimum resolvable bandwidth (Δν). Finesse is the ratio of free spectral range and minimum resolvable bandwidth.*

[1] *Figures of merit are performance criteria that determine the applicability of a device*

***Free Spectral Range***

The difference in frequency between consecutive interference fringes is defined as the free spectral range (FSR). It is a function of the physical mirror separation and is given by the equation:

FSR = c/2d

where *c* is the velocity of light.

In effect, the FSR is the interferometer's measurement window or the frequency bandwidth over which it is possible to measure without overlapping different interference orders (Figure 4).

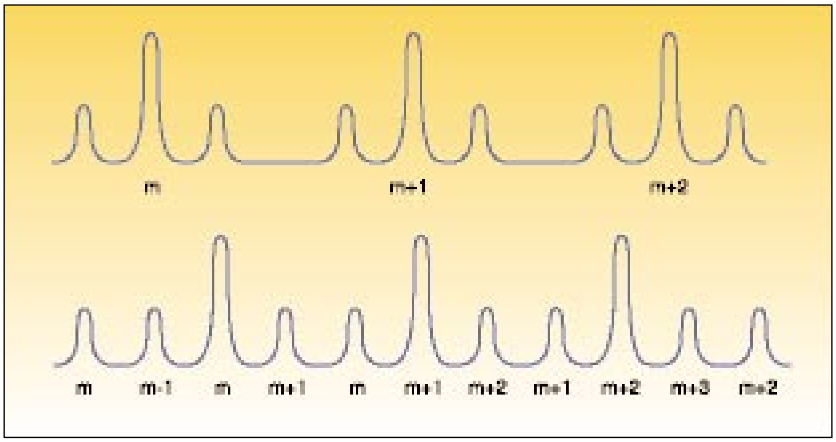


*Figure 4: Transmission pattern of a typical HeNe laser displaying three interference orders of the laser longitudinal modes. If the FSR is greater than the entire operating bandwidth of the laser (top), the different interference orders are easily identified. If the FSR is smaller than the bandwidth (bottom), it is impossible to determine which peaks are associated with the same order of interference.*

A spectrum with overlapping interference orders is confusing and difficult to interpret. Therefore, in order to obtain meaningful measurements from a Fabry-Perot interferometer, its FSR must be greater than the frequency range or bandwidth of the incident light source.

***Finesse***

Finesse (*F*) is a factor given to quantify the performance of a Fabry-Perot interferometer. Conceptually, finesse can be thought of as the number of interfering beams within the Fabry-Perot cavity. A higher finesse value, indicating a greater number of interfering beams, results in a more complete interference process and therefore higher resolution measurements. The primary factor that affects finesse is the reflectivity of the interferometer's mirrors because it directly affects the number of beams oscillating within the cavity; thus, finesse can be increased simply by increasing Fabry-Perot mirror reflectivity. However, this is not done without consequence because higher mirror reflectivity results in a reduction in the transmission of the incident light source. In addition to mirror reflectivity, factors that limit the finesse of a Fabry-Perot interferometer include the mirror surface quality, as well as the vibrational and thermal stability of the interferometer.

***Minimum Resolvable Bandwidth***

The minimum resolvable bandwidth ($\Delta v$), or resolution, is the width (full width at half maximum peak intensity) of an interference fringe generated when a perfectly monochromatic light source is transmitted by a Fabry-Perot interferometer. It is a function of the interferometer's FSR and finesse and is defined by the equation:

$\Delta v$ = FSR/F

The highest possible resolution (smallest minimum resolvable bandwidth) is achieved when a Fabry-Perot interferometer has the smallest FSR and the highest finesse appropriate for the incident light source.

## Fabry-Perot Interferometer Configurations

In order to satisfy the many different FSR and finesse requirements of the various Fabry-Perot interferometer applications, many configurations are available. Each configuration offers different advantages due to the type of mirrors used to form the Fabry-Perot cavity.

***Plano-Mirror System***

The plano-mirror Fabry-Perot interferometer uses a pair of very flat mirrors, which are precisely aligned parallel to each other. Its primary advantage is that it is the most versatile system available and therefore satisfies the requirements of virtually any Fabry-Perot application.

One aspect of this system's versatility is that it provides a variable FSR because there are no restrictions on the distance by which plano-mirrors can be separated. Consequently, the resolution of this type of Fabry-Perot interferometer can be optimized by minimizing the FSR with respect to a specific light source. In addition, because plano-mirrors can be positioned with a very small separation, which results in a large FSR, plano-mirror Fabry-Perot interferometers can operate effectively with broad-bandwidth light sources.

The plano-mirror Fabry-Perot interferometer also provides a large clear aperture. This is important for applications using large beams, when low signal strengths require a large solid angle of viewing, or when high background conditions require a multipass configuration.

***Confocal Mirror System***

The confocal mirror Fabry-Perot interferometer is a special type of spherical mirror system that uses a pair of concave mirrors whose radii of curvature are equal to their separation, resulting in a common focus. This type of system is, by far, the most user-friendly. High finesse is achieved easily, not only because the focusing of the incident beam reduces possible finesse degradation due to mirror surface imperfections, but also because the common focus of the mirrors results in a simple alignment procedure. The only limitation of a confocal mirror system is that its FSR is fixed by the radii of curvature of the mirrors. In order to change the FSR, the mirrors must be replaced by mirrors with different radii of curvature.

For confocal-mirror Fabry-Perot interferometers, the constructive interference condition is different. This results in an FSR that is half that of the plano-mirror systems, and is given by the equation:

FSR = c/4d

The physical reason for this can be described geometrically by the path of the incident light in a confocal-mirror Fabry-Perot interferometer. As shown in Figure 5, the beam undergoes four mirror traversals (instead of two) before it interferes with the incident beam. This results in the following constructive interference equation:

$d = m\lambda/4$

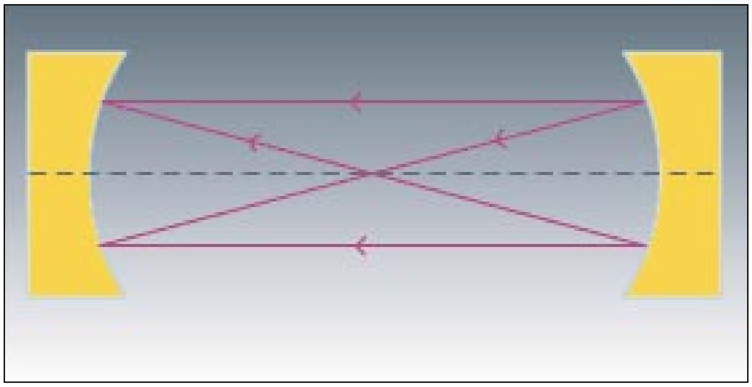

*Figure 5: The path of incident light in a confocal-mirror Fabry-Perot interferometer.*

## Conclusion

The factors described above are key in performing successful spectral analysis. Taking all these elements into consideration, EXFO Burleigh Products Group has used its expertise in interferometry to develop a unique family of high-performance laser spectrum analyzers that can precisely characterize the spectral features of virtually any telecommunication laser source. EXFO's SA[Plus] and TL series laser spectrum analyzers provide the highest possible resolution measurements of laser linewidth, longitudinal mode structure and frequency stability.


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