Optical Spectrum Analysers
The Monochromator band pass filter

The monochromator of an optical spectrum analyser (OSA) acts as a tuneable bandpass filter, where the width of the bandpass determines the spectral resolution of the OSA. The width of the bandpass filter is user-determined by the OSA resolution setting –achieved by selecting the appropriate monochromator exit slit. For OSAs with a so-called “free space” input, the bandpass filter can also be affected by the input fibretype. Here, a narrow core input fibre provides the highest resolution performance, and a large core input fibre can be used to produce a stronger input signal with a setup that is more tolerant to misalignment.

By Yokogawa Europe Optical Product Marketing

The main property that describes the quality of an optical spectrum analyser (OSA) is its ability to produce the exact spectrum of the light offered at the input. This is more commonly described as the ability to separate two closely spaced spectral lines. For an OSA, this quality is mainly determined by the internal monochromator.

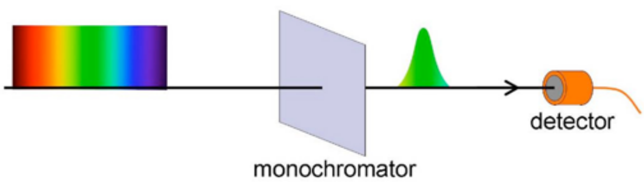


Figure 1–The monochromator in an OSA acts as a tuneable bandpass filter

As implied by its name, a monochromator isolates a single wavelength out of the complete spectrum that is offered and allows it to exit. A monochromator, therefore, can be considered to be a narrow optical bandpass filter (Fig.1). For the demanding applications in which OSAs are typically used, the shape and size of the bandpass filter is very important, since it determines the limitations in the spectral resolution of the instrument.

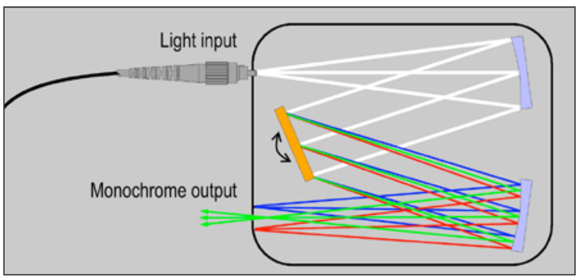


Figure 2–A basic version of the Czerny-Turner monochromator

Typically, OSAs are based on the Czerny-Turner monochromator (Fig.2), in which input wavelengths are spatially separated by a diffraction grating. The majority of the diffracted wavelengths are blocked, and only a narrow portion is allowed to pass through a slit (spatial filter) and exit the monochromator. In reality, an OSA monochromator is much more sophisticated than the simplified diagram in Fig.2, with a folded beam path that passes a single grating multiple times before leaving the device.

The instrumental bandpass

Assume that a perfect single wavelength (i.e. pure monochrome) light is injected into the monochromator. The light that is emitted by the fibre is imaged onto the exit slit. This produces a light spot that is shifted across the slit when performing a wavelength sweep (Fig.3). In this situation, the recorded spectrum is identical to the input spectrum only when a perfect Czerny-Turner monochromator is used (Fig.4a). This perfect monochromator has the following properties:

1. The diameter of the input beam is infinitely small, i.e. a point source.
2. All optics are infinitely large, i.e. collecting all light with no edges and no unwanted diffraction (stray light).
3. Optics are perfectly shaped and positioned; i.e. aberrations and misalignments do not exist.
4. Blocked light is completely absorbed, i.e. no internal reflections (stray light).
5. The exit slit is infinitely narrow.

It is clear that these are requirements that cannot be met in practice.

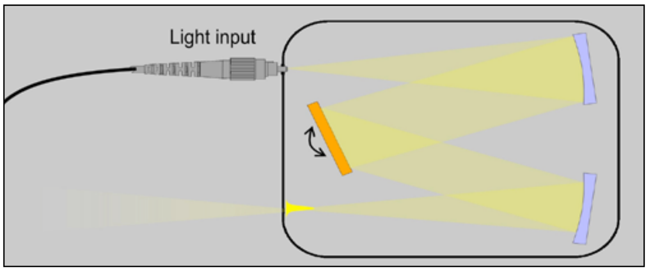


Figure 3–A perfect single wavelength is injected into the monochromator. The end face of the fibre is imaged on the exit slit. Rotating the grating shifts the light spot across the exit slit

Typically, an optical fibre is used to couple light into an OSA. The diameter of the input light beam is therefore not a point source, but is given by the mode field diameter (MFD) of the input fibre. For convenience, the size of the input light is assumed to be equal to the core diameter of the input fibre, i.e. a value closely related to the mode field diameter.
The input light is imaged onto the exit slit, producing a light spot that is further broadened due to small misalignment of optics, aberrations and stray light (internal reflections and diffraction).

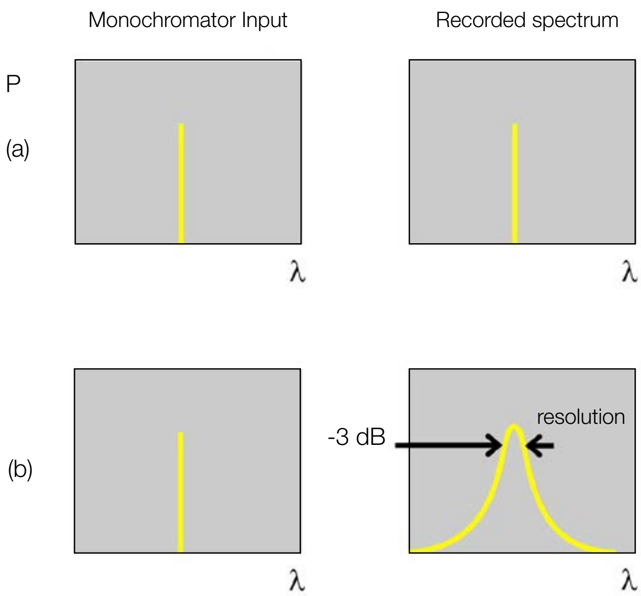


Figure 4–(a) A perfect monochromator displays the exact input spectrum with infinite detail.
(b) Offering the same single wavelength input, an actual monochromator shows a broadened profile –i.e. the instrumental bandpass

Due to the size of the light spot, the OSA trace will show a peak that is much broader than the infinitely narrow input spectrum (Fig.4b). The recorded peak is known as the "instrumental bandpass", and the FWHM (full-width/half-maximum) of the bandpass is defined as the spectral resolution of the instrument.

Spectral blurring

The limitations of the optical setup cause a "blurring"of the recorded spectrum, potentially obscuring detailed information; for example, two closely spaced spectral lines may appear as a single line (Fig.5a).

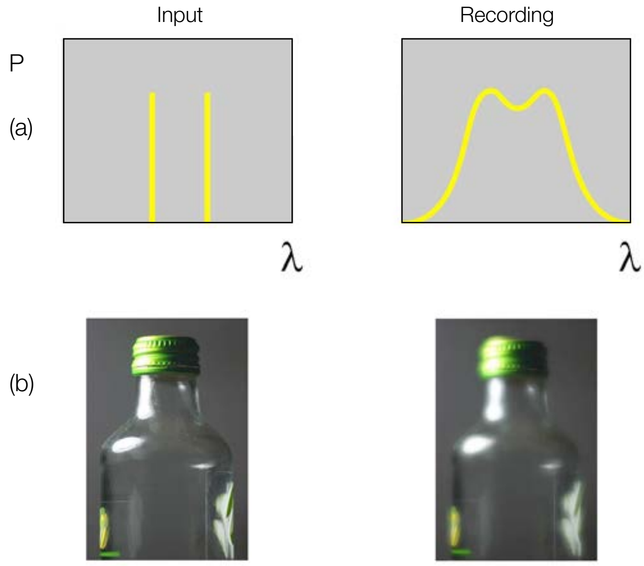


Figure 5– (a) Spectral information is lost due to spectral blurring.
(b) An effect that can be compared to the blurring effect of an out-of-focus camera

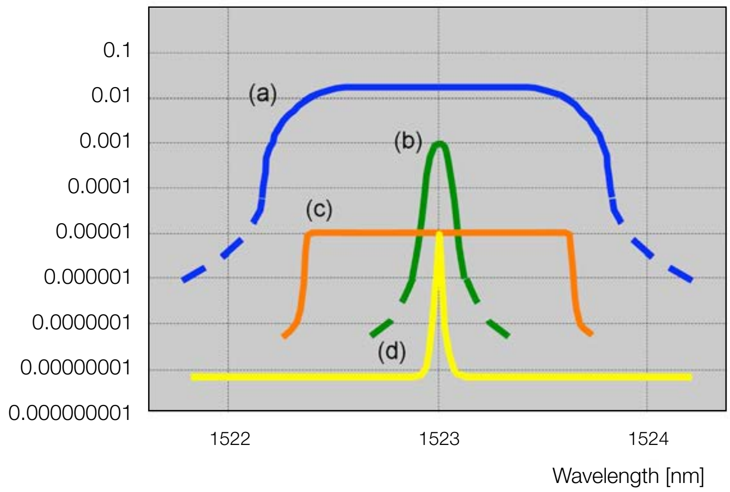
Any input spectrum can be considered to be a sum of many perfectsingle wavelengths, each travelling through the monochromatorand producing its own line profile. The recorded spectrum is therefore the result of the convolution of the input spectrum and the instrumental bandpassfilter. The result is a blurred version of the input spectrum that can be compared to photography using an out-of-focus camera (Fig.5b).

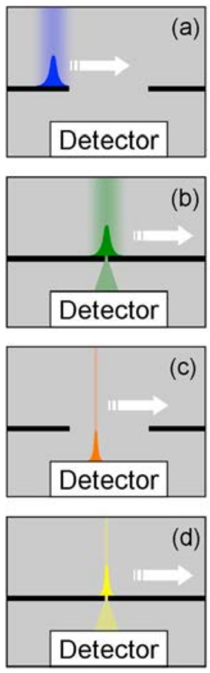
Controlling the filter shape

The resolution setting on an OSA refers to a specific width of the exit slit. For the majority of the commercially available OSAs, the selection of the exit slit is the only influence a user has on the shape of the bandpass filter.

In these OSAs, an internal fibre is used to guide the light from the input fibreto the monochromator block, so that the size of the input light is pre-determined and fixed. Only OSAs with a so called "free space input"offer an extra influence on the shape of the bandpass filter. Here, the light that exits the input fibre immediately enters the monochromator–i.e. the diameter of the input beam is user-selectable.

The advantages and disadvantages of the different bandpass filters are illustrated by a simple experiment in which the spectrum of the extremely narrow 1523nm line of a Helium-Neon laser is recorded. The laser light is collected without making use of focusing optics (fibrelauncher) for maximising the amount of light coupled into the fibre. By using different fibre sizes and different resolution settings, the different filter shapes are clearly visible (Fig. 6).





Trace	Fibre core diam.	Resolution setting	Effective resolution
(a)	800 µm	2.00 nm	1.26 nm
(b)	800 µm	0.020 nm	0.085 nm
(c)	9 µm	2.00 nm	1.26 nm
(d)	9 µm	0.020 nm	0.017 nm

Figure 6–Experimentally determined bandpass filter of the model AQ6370 at 1523nm using different input fibres and resolution settings

Narrow-core input fibre

The highest resolution performance is obtained by using the most narrow core input fibre available, in combination with the highest resolution setting of the instrument (Fig.6d). At 1523nm the measured resolution is 17pm. Notice that the effective resolution is higher than the resolution setting.

When using a narrow core input fibre, the bandpass filter curve is guaranteed by the “Close-in Dynamic Range” specification, also referred to as Optical Rejection Ratio. Here, the bandpass filter suppression (i.e. rejection) is specified at specific intervals from the selected wavelength.

When a flat top is observed on a spectral peak, it can be concluded that all the power inside the peak is captured by the internal photodetector; i.e. the complete light spot fits through the monochromator exit slit.

Large-core input fibre

With a large surface area (i.e. effective area) of the input fibre, collection of light from a source is very efficient. Typically, this produces a much stronger signal than can be offered by a narrow core input fibre. In Fig.6, the signal in trace (a) is much stronger than that in trace (c).

Note that the freedom to choose the monochromator input fibre is only provided by an OSA with a free space optical input such a Yokogawa AQ6370 series.

The loss of resolution caused by using a large core fibre may be acceptable. From Fig.6b and 6d, it follows that going from a 9 µm to an 800 µm core fibre results in the effective resolution dropping from 17 to 85 pm.

Another thing to consider is that a large-core fibre is tolerant to misalignment. Using a narrow core fibre, the amount of injected light often needs to be maximised using focusing optics and a sophisticated alignment stage. A large core fibre, however, can often be used without such an alignment critical fibre launcher.

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