HIGH-SPEED MEASUREMENTS
WITH AN OPTICAL SPECTRUM ANALYSER

Paolo Magni from Yokogawa Europe & Africa Test & Measurement describes the development, performance and functions of a spectrum analyser that represents state of the art in its class in optical performance and measurement speed

Wavelength division multiplexing (WDM) is increasingly being used in optical communications, and requires special tools, such as an optical spectrum analyser. This instrument is widely used for evaluating fibre-optic communications systems and devices, becoming indispensible for those who work on high-speed, large-capacity network infrastructure.

To ensure high transmission-quality in fibre networks, the optical components used in the system must also be of high quality, and their evaluation inevitably requires precise optical spectrum measurements. For these test instruments, minimising measuring time is a significant requirement because the man-hours required for inspection directly affect the cost of the end product based on the components or sub-assemblies under test.

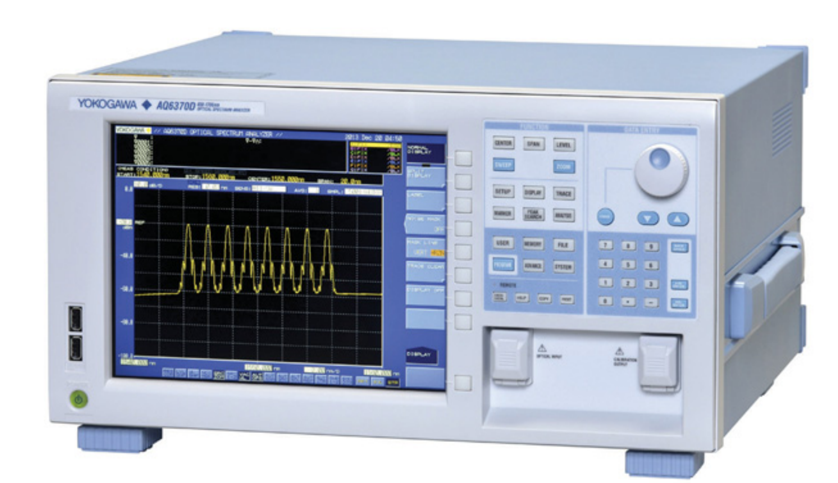

Figure 1: The Yokogawa AQ6370D optical spectrum analyser

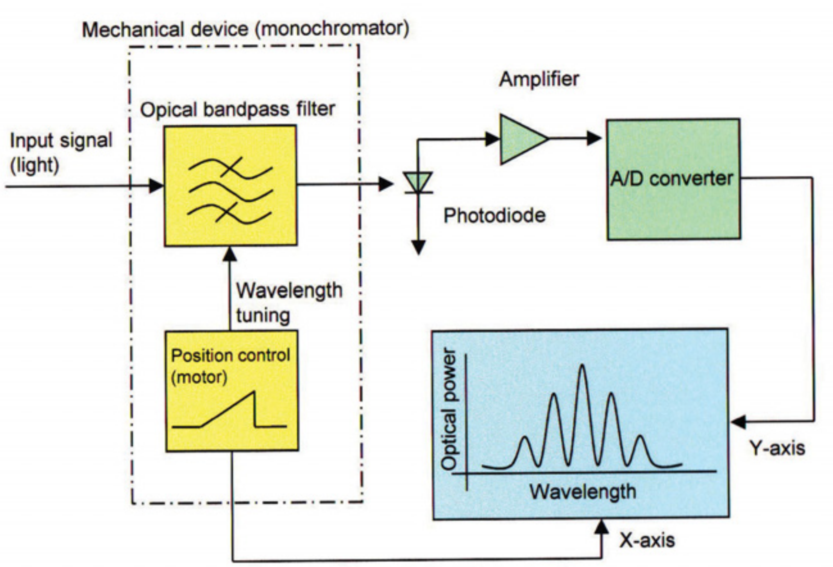

Figure 2: Principle of optical spectrum analyser

MEASUREMENT PRINCIPLE

Optical spectrum analysers spectroscopically measure and analyse optical power at a number of different wavelengths; Figure 2 shows the principle of this type measurement. The wavelength of the light input to the optical bandpass filter is restricted to be within a narrow slot range; the light that passes through is converted into electrical signals by the photodiode. The optical spectrum is determined by plotting the electrical signals while sweeping the centre wavelength of the optical bandpass filter. The filter is a high-precision electromechanical device called a monochromator, which includes an optical prism, or diffraction grating.

Higher-performance optical spectrum analysers are usually equipped with an optical bandpass filter with narrower bandwidth and steeper rolloff. The measurement accuracy will be higher when the accuracy of controlling the centre wavelength of the optical bandpass filter is higher.

Among the key performance indicators for optical spectrum analysers are:

- **Wavelength accuracy:** stable measurement of a wavelength with absolute accuracy;
- **Resolution:** the ability to distinguish two close line spectrums with wavelengths of λ and $\lambda + \Delta\lambda$;
- **Optical dynamic range (steepness characteristic of a filter):** the capability to suppress the optical power of light with wavelengths close to a targeted wavelength when filtering measured light;
- **Speed:** wavelength sweep speed.

HIGH WAVELENGTH ACCURACY

In a modern spectrum analyser, a monochromator rotates a chromatic dispersion element, or diffraction grating, to sweep across the wavelengths; the rotation angle of the diffraction grating corresponds to the wavelength to be measured.

The Yokogawa AQ6370D uses a servo system in which a DC motor drives the diffraction grating and an encoder detects the rotating angle for feedback control. An optical encoder is used, and the detected electrical pulses are multiplied by several thousands to precisely control the rotating angle of the diffraction grating with a resolution of 0.2 arc seconds or better. The analyser corrects any slight linearity errors caused by electrical multiplication to ensure a wavelength certainty within ±0.01nm.

Figure 3 shows an evaluation example of the wavelength certainty of the AQ6370D. The vertical axis is the measurement error in wavelength, and the horizontal axis is the wavelength.

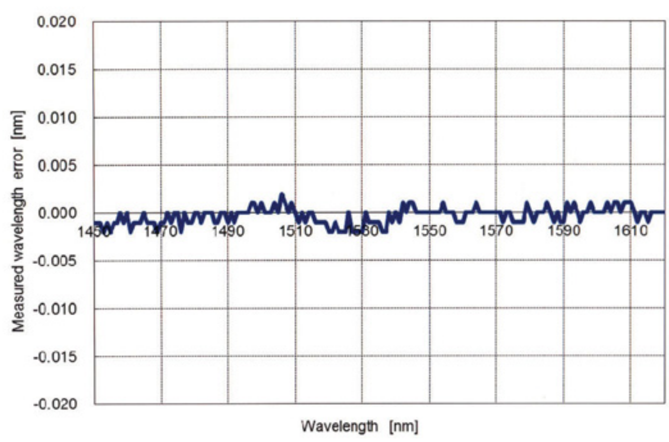

Figure 3: Evaluation example of AQ6370D wavelength accuracy

HIGH RESOLUTION

Figure 4 shows the basic configuration of the monochromator, which incorporates a planar grating and two concave mirrors: a collimating mirror and a focusing mirror. The incident light from the optical fibre is made parallel by the collimating mirror, and diffracted at the diffraction grating. This light then reflects on the focusing mirror and is dispersed to form a spectrum on the slit plane (in the horizontal direction in Figure 4). Only the light with the wavelength that focuses at the slit can pass through it. The resolution bandwidth (RBW) of the monochromator is given by:

In recent years, tunable lasers have been widely used as optical sources in high-capacity long-distance communication systems

$$RBW = \varepsilon \times \frac{d}{m \times f} \cos\beta$$

where d is the grating pitch of the diffraction grating, m is the diffraction order and β is the angle between the outgoing beam and the line normal to the reflection plane.

It is clear from the equation that a longer focal length f of the focusing mirror or narrower width ε of the slit can result in a better resolution

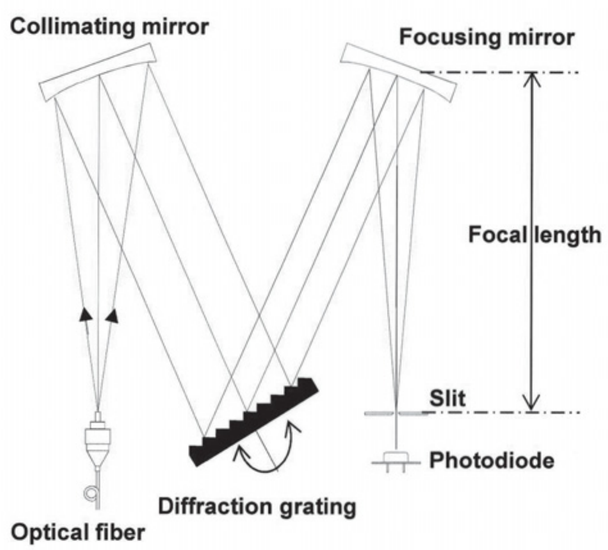

Figure 4: Basic configuration of a monochromator

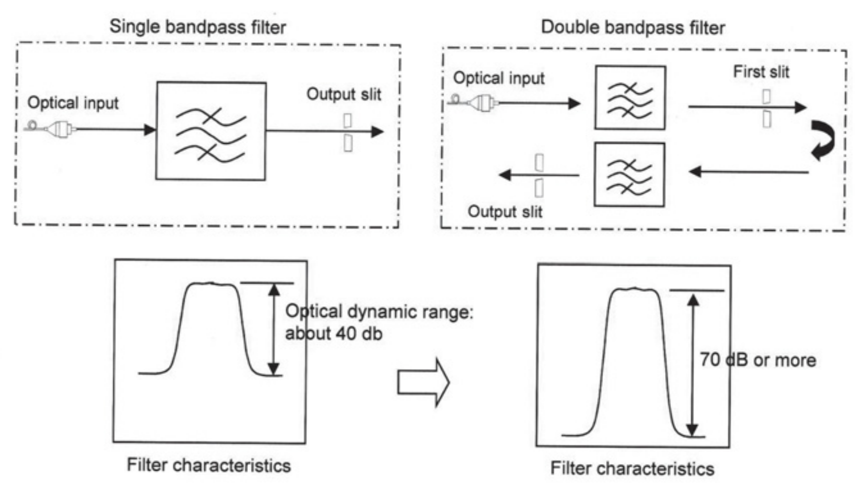

Figure 5: Improvement of dynamic range

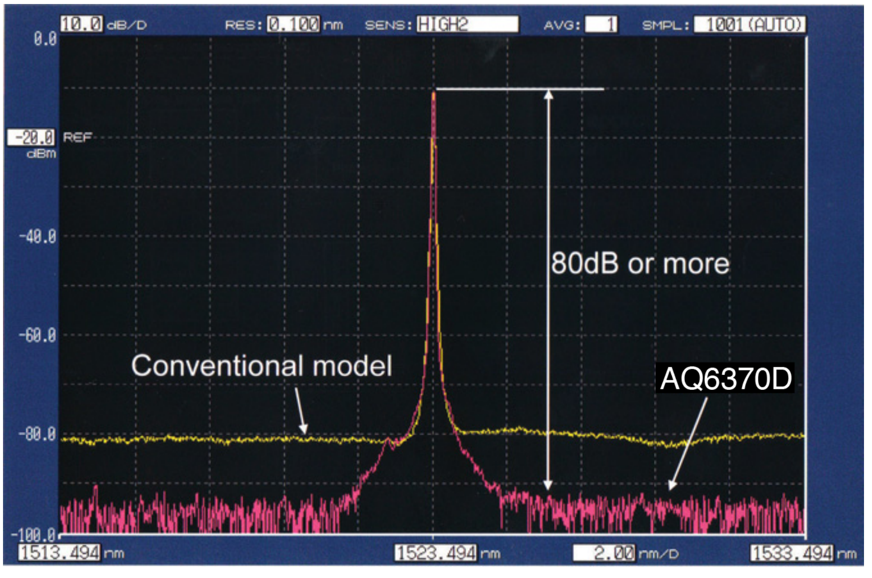

Figure 6: Dynamic range in the normal measurement mode of the AQ6370D

bandwidth. However, a focusing mirror with a longer focal length makes the monochromator larger. As a result, the additive-dispersion double path method is generally used to reflect light in the monochromator.

However, high resolution cannot be obtained with a beam of large diameter focused on the slit. In the AQ6370D, the design of the collimating mirror and focusing mirror minimises aberrations of the optical components, resulting in a focused beam with a small diameter. As a result, the beam can focus on a 20μm slit or narrower, leading to a resolution of up to 0.02nm.

WIDE DYNAMIC RANGE

The left illustration in Figure 5 shows the filtering characteristics of a single bandpass filter. The difference between the passband and the stopband (optical dynamic range) is about 40dB. As shown at the right of Figure 5, adding another filter will dramatically improve the dynamic range.

Connecting filters in cascade is the basic design concept of the monochromator in the AQ6370D. Conventional double-pass (or multi-pass) monochromators have improved space efficiency. However, because of overlapping of the optical paths of the first and second filters in this design, undesirable optical effects such as scattered light generated by the first path enter the second one. This affects the dynamic range, with the result that ideal performance cannot be obtained in a cascaded connection.

On the other hand, the AQ6370D's monochromator completely separates the first optical path from the second by skillfully configuring optical parts, achieving performance close to the theoretical limit. In this system, wide dynamic range measurement (conventionally performed in a special measurement mode requiring significant time) can be achieved in a normal mode, thus shortening the measurement time.

HIGH-SPEED MEASUREMENT TECHNOLOGY

The measurement time of an optical spectrum analyser depends on the rotational speed of its diffraction grating. The diffraction grating of the AQ6370D is driven by a servo system. By optimising the motor design and using acceleration/deceleration control, the analyser achieves a sweep time of 0.2s or less for a 100nm wavelength range.

The instrument can be also used for high-speed measurements on tunable lasers. Tunable lasers are widely used as optical sources in high-capacity long-distance communication systems. During quality inspection of these lasers, it is crucial to measure how much the side mode of the main signal of the laser is suppressed. In this measurement, the main peak and side mode of the main signal of the laser need to be measured at the same time. It is therefore important to measure with wide dynamic range and at high speed.

Optical spectrum analysers have an auto-range measuring function, which enables the measurement of optical power whilst automatically changing the gain of an internal amplifier, depending on the input light power level. The AQ6370D achieves high-speed measurement even in auto-range mode by optimising the internal time constant when switching the gain and the rotational speed of the diffraction grating.

When used with the smoothing function, the AQ6370D can improve the signal/noise ratio, especially when measuring side modes, without requiring extra time. The smoothing function of the AQ6370D can automatically identify the location in the measured spectrum where the signal/noise ratio is insufficient, and perform optimal smoothing. Hence, this function is effective when measuring the side modes of tunable lasers or distributed feedback (DFB) lasers.

Figure 7 shows an example of high-speed measurement of the spectrum of a DFB laser. The side mode of the laser is precisely measured in about 0.3s.

When the light to be measured is input to the optical spectrum analyser via the optical connector, the optical power level fluctuation when attaching and detaching the optical connector must be suppressed. When connecting an optical fibre, lower insertion loss is desirable for various applications – even with a multimode fibre such as GI62.5. Thus, a free-space structure is preferred for the optical input section. This free-space structure is implemented by optimising the layout of optical components. This arrangement suppresses the optical power level fluctuation that normally occurs when attaching or detaching an optical connector, and multimode fibres can be connected with little insertion loss.

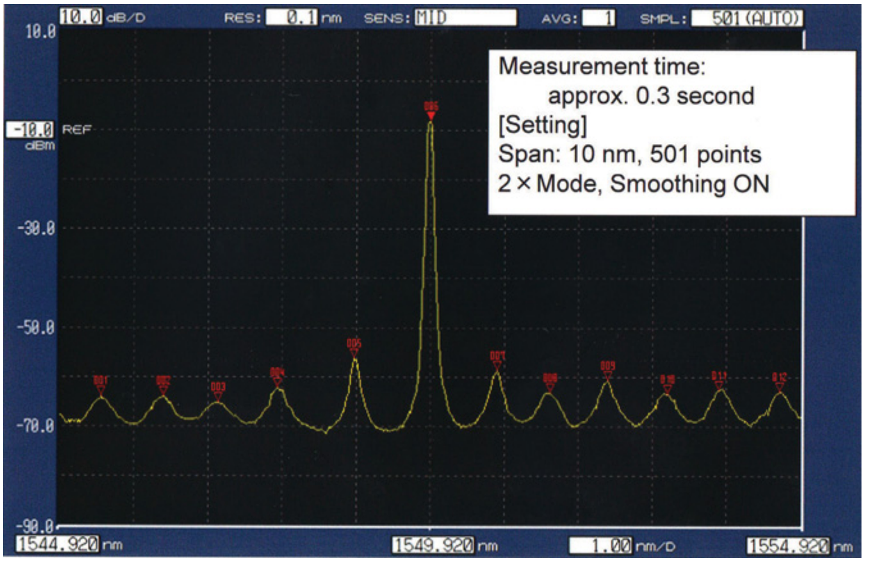

Figure 7: High-speed measurements on a DFB laser

APPLICATIONS

Because of the wide optical dynamic range of the analyser, the Optical Signal/Noise Ratio (OSNR) of 50GHz-spacing Dense Wavelength Division Multiplexing (DWDM) transmission systems can be precisely measured.

As the number of multiplexed signals increases, the OSNR cannot be accurately measured, owing to the limitation of the optical dynamic range of the monochromator. This requires choosing the special measurement mode (wide dynamic range), which makes the measuring time substantially longer. Because the AQ6370D has a wide optical dynamic range, it can accurately measure OSNR at high speed in normal mode, even if the number of multiplexed signals increases.

An example of analysis with the WDM analysis function of the AQ6370D is shown in Figure 8. The wavelengths, levels, spacing and OSNRs of the WDM signal are all measured, and the results are displayed in a table.

With the noise-figure analysis function, the analyser can measure gain and noise figure, key indicators for evaluating an optical fibre amplifier, for each channel at the same time. The output level of the amplified spontaneous emission (ASE) during the noise-figure measurement contains the Source Spontaneous Emission (SSE) of the WDM signal. The analyser can remove this SSE component with its SSE-suppression function to accurately measure noise-figure values. In addition, it can graphically display the values of the gain and noise figure of each channel, so that the differences among gains of each channel (gain tilt) can be visually verified.

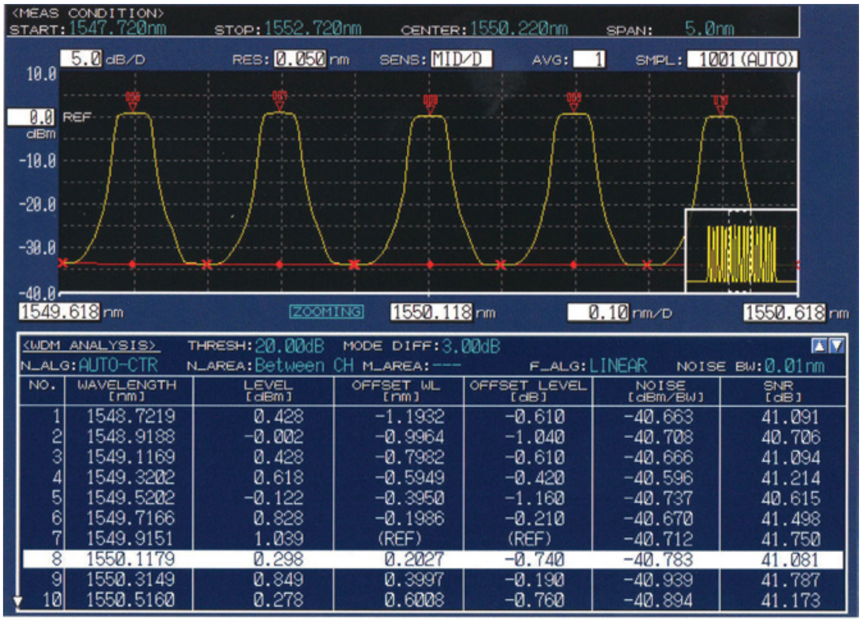

Figure 8: Results of WDM analysis

Optical spectrum analysers also find applications in areas other than the optical fibre communications market. For example, an instrument with a wavelength range of 350-1200nm is best suited for measuring laser spectra and the transmittance of optical filters in the medical and biotechnology fields. With a high wavelength resolution of 0.02nm, it is also suited to applications in the industrial field for laser processing machines and in the consumer electronic field for laser projectors and related equipment.

Instruments with the wavelength range from 1200-2400nm are used to measure optical absorption for obtaining the distribution and concentration of greenhouse gases such as CO2, SO2, NOX and methane, which are attracting attention as global environmental issues. Other applications are in the development and manufacture of semiconductor lasers and fibre lasers, which are used for sensing those gases. ●