Chromatic Dispersion Measurement: The EXFO Phase-Shift Method

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CHROMATIC DISPERSION MEASUREMENT METHODS

It is usually necessary to measure relative propagation delays as a function of wavelength in order to determine the chromatic dispersion (CD) curve of an optical fiber. For instance, if short optical pulses are generated simultaneously at a number of wavelengths, then launched into a long fiber, CD will cause the pulses at different wavelengths to propagate through the fiber at different speeds—leading to relative delays in arrival times. This is the basic principle underlying most CD measurement instruments used for characterizing fiber spools or telecom fiber links.

Directly measuring the relative delays between the pulses of different wavelengths is known as the time-of-flight method (FOTP-168) and requires extremely accurate timing of pulse arrival times. The accuracy of this method, also referred to as the pulsed light method, also depends on the pulse's shape. Short pulses spread and distort, making it difficult to determine the exact time of arrival. This technique, although conceptually very simple, is therefore relatively inaccurate.

A more commonly used and standardized (FOTP-169 and FOTP-175A) technique is referred to as the phase-shift method, in which light is sinusoidal-intensity modulated. Phase variations related to wavelength are measured at a given high frequency (typically 10 MHz to 100 MHz). Because we can obtain highly precise phase-shift measurements, this technique is more accurate than the pulsed-light (time-of-flight) approach. The reference signal, with respect to which phase-shifts are measured, can come directly from an electronic oscillator or optical signal.

The phase-shift method can also be modified to measure the much smaller relative delays (<1 ps) typical of most fiber-optic components when used with a tunable laser, an electric network analyzer, as well as modulation frequencies of up to many GHz.

With both the conventional pulsed-light and phase-shift methods, time intervals (or phase variations) are measured in the electrical domain. An optical receiver (or receivers, if the reference comes from an optical signal) detects the modulated light (pulsed or sinusoidal) and converts it into an electrical signal. Since the reference and the wavelength-varying signals do not generally follow the same electrical path (filters, amplifiers, etc.), extra relative electrical delays lead to measurement errors. EXFO's approach is to use a single photodetector and apply different light signals, which are intensity-modulated at the same frequency, separately and in combination—and to then measure the peak modulation amplitudes. This reduces the electrical delays that affect time measurement accuracy.

OPTIMIZING THE METHOD

To ensure electronic delays do not hamper the accuracy of optical delay measurements, EXFO has devised an alternate way to obtain phase-shift information. High-frequency, intensity-modulated broadband signals travel through the fiber under test (FUT) or device under test (DUT). Once the light is inside the receiver, it is split into two or more optical paths. On one of the paths, the light will be optically filtered before reaching a combining device; this filtering is wavelength tunable. It constitutes the variable in our measurements. The light traveling along the other paths is also filtered, but at a fixed reference wavelength. The use of two reference paths enhances delay measurement accuracy. These signals are recombined in different ways by using a rotating wheel (chopper) with a special hole pattern.

Measurements are obtained of the amplitudes for different combinations of the modulated signals: A00, A12, A13, A23, A01, A02 and A03 (assuming 0 = no light, 1 = tunable signal, 2 and 3 = reference signals). The amplitude of a sum (combination) of modulations, all at the same frequency, is a function of the phase difference between the modulations and their respective amplitudes. When the above measurements are combined, the phase difference between a reference signal and a wavelength-tunable signal can be isolated without the errors caused by electronic delays. Varying the wavelengths of filtered light and computing a series of wavelength-dependent-phase differences enables us to compute CD in the standard ways. The optical filter is tunable between 1530 nm and 1625 nm. And, since a combination sequence is only a few milliseconds long, the averaging time can be set from a fraction of a second to several seconds. Low-frequency chopping thus enables the user to set the appropriate level of averaging needed to improve the system's accuracy—without worrying about electronic 1/f noise.

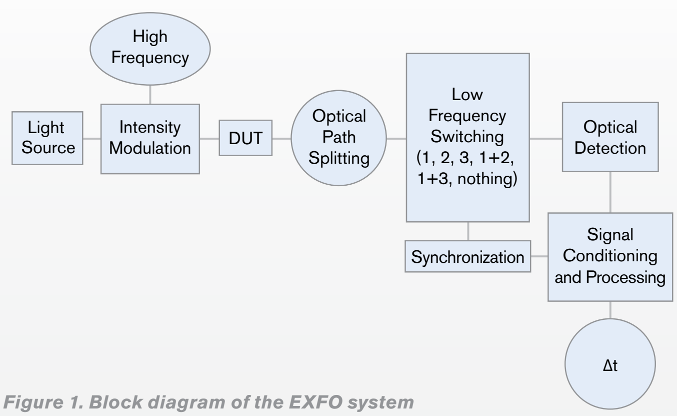

Figure 1. Block diagram of the EXFO system

FROM THEORY TO REALITY

The light source is a multiwavelength source, typically a broadband source that is intensity-modulated at a high frequency. This light is then injected into the FUT and the modulated light travels along the fiber. The high-frequency intensity modulation propagates at a speed that is dependent on wavelength and polarization–and values are obtained for the differences in travel time between modulations at different wavelengths (to get exact values of these differences, polarization effects must be averaged out, calibrated or compensated). The higher the number of wavelengths at which this is done, the more accurate the CD result will be.

The first fixed filter in the receiver extracts the portion of the light that will follow an optical path. This path is then split in two, one of which will comprise an extra length of optical path, corresponding to a 90° phase-shift of the high-frequency modulation. A second filter, this time tunable, will extract a second part of the original signal and will then follow a third optical path.

Using a chopper, zero, one, two or three paths will be added on the detector (depending on the slot configuration at each chopper position). The amplitudes of the high-frequency signals are measured and digitized. From the different amplitudes, the phase difference is computed. The value of the high frequency is then used to compute the time difference; this value is stored along with the tunable filter's central wavelength value. Then the wavelength in the third path is changed with the tunable filter and a new measurement cycle begins. A new time delay is computed and stored with wavelength data. When sufficient data are accumulated, they are used to compute the CD.

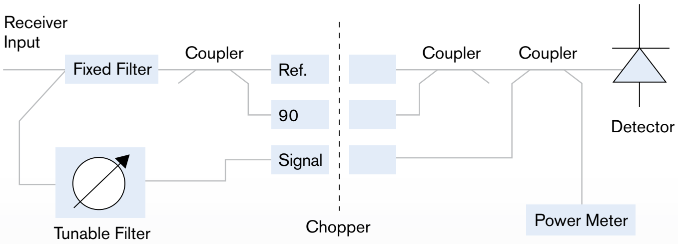

Figure 2. Once the light is split and the wavelength selected, a chopper couples the light from different paths onto the detector.

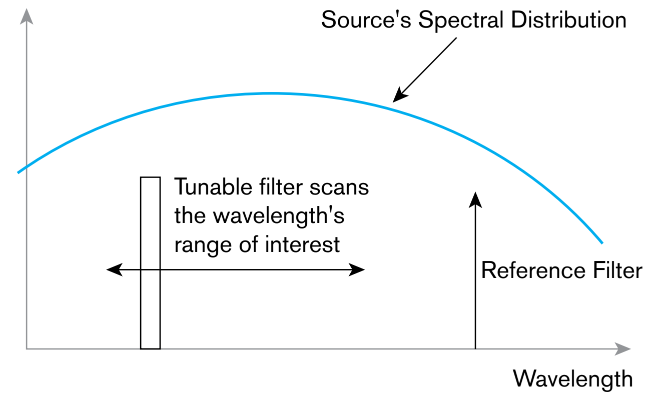

Figure 3. Relative phase differences between a reference wavelength and a series of selected wavelength are measured to obtain relative group delay

Up to now, most commercial CD test and measurement instruments select a wavelength to be measured in the source at the input end of the FUT–rather than at the output end, as is the case with EXFO's approach. However, having the wavelength selector in the source implies that the receiver cannot know which wavelength is being sent through the DUT. This limits the method, as the receiver and the source must be able to communicate with each other in order for the wavelength data to be translated, with time-delay data, into CD data. Consequently, a control signal must be sent backward through the fiber, preventing the measurement of CD through one-way devices such as isolators and EDFAs that may be present in the fiber link. A second fiber in loopback (or other means of communication) could overcome this problem; however, this is cumbersome and not often accepted by users. In contrast, EXFO's approach, which involves placing the wavelength selector at the receiver end, does not require any communication between the ends of the fiber link; this is because the modulated source is always active and transmitting over its full wavelength range.

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