Conference on Lasers and Electro-Optics, Pacific Rim, Jul 15-19, 2001, Chiba, Japan, Technical Digest, Vol.1, pp. 478-479

Fast and accurate characterization of optical components using low-coherence interferometry*

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Abstract: Low-coherence interferometry yields a high-resolution measurement of a component's spectral and dispersion properties. We show that this technique can be applied to cascaded components, and this measurement is not adversely affected by other components in the system.

1. Introduction

The data rate in a fiber optic telecommunications system is limited by the dispersion of the system. Fiber Bragg gratings (FBGs) have been proposed as dispersion compensators to increase the maximum data rate [1]. A fast and accurate technique is needed to characterize the dispersion of components such as FBGs. In a low-coherence interferometric measurement, all wavelengths are measured simultaneously using a broadband source. The dispersion of the component under test creates a wavelength-dependent delay in one arm of the interferometer, and this leads to a chirped and asymmetric interferogram. The dispersion and spectral characteristics are calculated from a Fourier transform of the interferogram.

Low-coherence interferometry has several advantages over conventional techniques, such as the modulation-phase-shift method [2], for the characterization of components such as fiber Bragg gratings (FBGs). A key advantage is the rapidity with which group delay and reflectance measurements can be obtained. The interferogram is obtained in less than a second, and processing the interferogram to obtain group delay or reflectance takes less than 60 seconds [3], compared with the conventional modulation-phase shift measurement, which can take several hours [2].

In this paper, we demonstrate the measurement of the dispersion and reflectance of cascaded components using low-coherence interferometry [4]. We also show that this measurement is not adversely affected by other reflective components in the system, regardless of overlapping reflection bands. This is important for fiber optic telecommunications applications where several gratings are used in series as add/drop multiplexers [5] and in cases where several gratings are concatenated to achieve desired dispersion characteristics [6].

2. Measurement Method

A diagram of the low-coherence interferometric system is shown in Fig. 1. A broadband erbium (Er) superfluorescent fiber source (SFS) provides the input signal. Fiber coupler 1 provides a comparison signal for the difference-over-sum (Δ/Σ) amplifier, as explained below. Fiber coupler 2 is part of a Michelson interferometer. Three FBGs are spliced onto the test arm of the interferometer. FBGs A and C have overlapping reflection bands; therefore, fiber coupler 3 separates these two gratings to eliminate Fabry-Perot and shadowing effects between the two gratings.

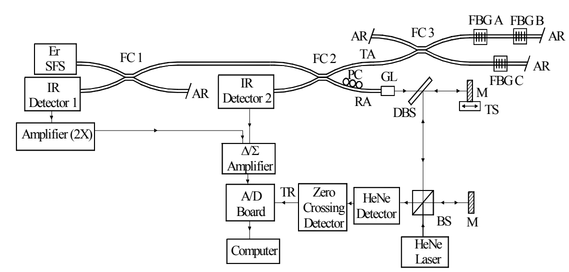

Fig. 1. Diagram of low-coherence interferometric system for measuring the dispersion of multiple FBGs. AR: anti-reflection coating, FC: fiber coupler, RA: reference arm, TA: test arm, PC: polarization controller, FBG: fiber Bragg grating, GL: grin lens, M: mirror, TS: translation stage, BS: beamsplitter, DBS: dichroic beamsplitter, Δ/Σ: difference over sum.

The reference arm of the interferometer contains a variable-length air path so that the total optical path difference (OPD) of the interferometer can be varied. A frequency-stabilized HeNe-laser interferometer monitors the position of the reference-arm mirror, and a zero-crossing circuit triggers sampling of the IR signal on positive-sloped zero crossings of the HeNe signal.

The light from the reference arm is recombined with the light from the test arm at fiber coupler 2, and the recombined light is directed onto the two IR detectors. The detected signals have similar source excess-noise characteristics, while the interference terms are 180º out of phase due to coupler 2. Therefore, the Δ/Σ amplifier reduces excess noise from the SFS, which is the dominant noise source.

This improves the interferogram's signal-to-noise ratio by a factor of 3, and yields a corresponding improvement in the group-delay SNR.

If the effective spatial separation between the FBGs exceeds the width of the individual interferometric signatures, then the output signal of the Δ/Σ amplifier, as a function of OPD, consists of three distinct signatures. Each of these signatures represents the interference of light reflected from one of the FBGs with light reflected from the reference-arm mirror.

The shape and extent of the interferometric signatures from FBGs A and C are determined by their reflection characteristics. To calculate the spectral reflectance and reflection group delay from the interferometric signatures, we first window the interferogram data around the interferometric signature of interest. We then take the Fourier transform of the windowed interferogram. The magnitude of the Fourier transform is proportional to the magnitude of the field reflection coefficient of the FBG. The relative reflection group delay of the FBG is determined by differentiating the phase of the Fourier transform.

The light transmitted by grating A and reflected by grating B sees the effects of both gratings A and B, but the processing to obtain the group delay is the same. The resultant group delay is the product of the reflection group delay of B with the double-pass transmission group delay of A.

3. Experimental Results

We used our interferometric system to determine the spectral reflectance and group delay of a network of three gratings. The center wavelengths, reflection bandwidths, and reflectances of the three gratings are shown in Table 1. We calculated magnitude of the Fourier transform of each windowed interferogram. We divided the magnitude data by the Er source spectrum, and then squared the result to obtain the power reflectance of each grating [3]. The spectral reflectance results are shown in Fig. 2. We also calculated the relative group delay of each grating as described above; the results are shown in Fig. 3.

Table 1. Specifications of the three gratings.

Grating	Center Wavelength (nm)	Reflection Bandwidth , FWHM (nm)	Reflectance (%)
A	1555.6	5.4	99
B	1541.3	10.1	>97
C	1554.7	1.7	>99

4. Conclusions

We have demonstrated the measurement of the group delay of multiple cascaded components using low-coherence interferometry. We have shown that the group delay of individual components in series can be determined regardless of overlapping reflection bands. This is unique to the low-coherence technique; conventional dispersion measurements are incapable of distinguishing between individual components with overlapping reflection bands. Another advantage of the low-coherence technique is speed; it is possible to obtain the group delay of multiple components in less than 60 seconds.

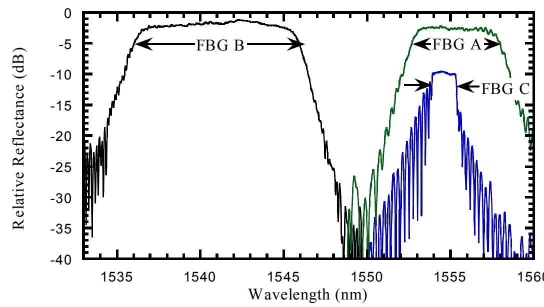

Figure 2. Relative spectral reflectance of each grating calculated from a single interferometric measurement of the three gratings.

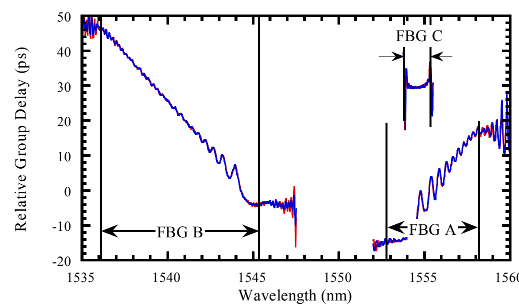

Figure 3. Relative group delay of the three gratings determined from a single interferometric measurement.

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