Dispersion Measurements of Chirped Fibre Gratings

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Abstract

A wavelength scanning interferometric technique has been used to provide phase dispersion and time delay measurements of photorefractive fibre gratings with sub-picosecond time-delay and 3pm wavelength resolutions for the first time. Chirped fibre grating filters for dispersion compensation in long fibre telecommunications links have been fully characterised.

1. Introduction

The development of chirped fibre gratings for dispersion compensation requires full and accurate amplitude and phase dispersion characterisation of these devices. We have recently demonstrated such a system based on an all-fibre Michelson interferometer [1]. The reference arm of the interferometer is phase-modulated with a saw-tooth function to generate an electric signal at the photodetector which carries the optical phase and amplitude information of the reflective fibre device under test, which is included in one arm of the interferometer. The amplitude response of the interferometer is directly proportional to the field reflection coefficient. The time delay is given by the derivative of the relative phase with respect to wavelength. A high wavelength resolution tunable laser source (HP8168A/C) is used in conjunction with a fully automated set-up to provide sub-picosecond resolution. The interferometer is stabilised to minimise temperature-dependent phase drifts [1]. Reflected and transmitted power are measured non-interferometrically, by blocking the reference arm of the interferometer. In this paper, we present measurements for different chirped fibre Bragg gratings, discuss the system resolution, and compare the results with an alternative direct group-delay measurement technique.

2. Experimental Results and Discussions

The set-up was used to measure the reflectivity/transmissivity and the phase-dispersion/time-delay characteristics of a wide-bandwidth step-chirped fibre grating fabricated at BT labs [2], as well as, a narrow-bandwidth externally-chirped fibre grating fabricated at Southampton. The first one was made using the phase-mask technique [2] and was 8mm long. Its 3dB reflection bandwidth was 14nm and the peak reflectivity 67%. The second was made using a holographic technique [3] and was 40mm long. At room temperature, its 3dB bandwidth and peak reflectivity were 0.09 nm and 31%, respectively. Variable amounts of chirp were externally induced in this grating by applying different temperature gradients to it.

Figure 1 shows the experimental results for the 8mm long chirped grating. Figure 1(a) shows the non-interferometric lock-in output, which is directly proportional to the transmitted power of the grating, as well as the interferometric lock-in phase response of the reflected field. The time delay of figure 1(b) is derived directly by differentiating this phase data. Fig. 1(a) demonstrates that the relative phase of the reflected light varies non-linearly (parabolically) with wavelength, corresponding on average to a quasi-linear decrease of the time delay (figures 1(b) and 1(c)) across the reflection bandwidth (i.e., negative dispersion). This indicates that shorter wavelengths are delayed more in the reflection process. The wavelength instability of the tunable laser source combined with path imbalance of the interferometer causes noise on top of the time delay curve. The amplitude of the noise is negligible at the central wavelength (~1560nm) where the path imbalance is zero. However, on either side of this wavelength, the added noise increases due to gradual shift of the effective reflecting point. From these results, the rms frequency noise of the laser is estimated to be around a GHz. Lower noise lasers should improve this technique. An averaged version of this data is shown in figure 1(c). As predicted by theory [4], small ripples are observed at the edges of the time delay curve. The pronounced peaks outside the grating stop-band in the time delay plots are related to Fabry-Perot-type resonances in the grating structure and wavelength instability of the tunable laser source. By adjusting the optical path difference between the interferometer arms, we can accurately vary the DC offset of the time delay slope to within 0.5ps, which demonstrates the sub-picosecond resolution of our experimental set-up. Measurement of the grating in the reverse direction showed an identical dispersion characteristic but, as expected, of opposite sign. The dispersion of this grating was measured to be ±5.7 ps/nm. A similar grating has been used for dispersion compensation of 400 fs pulses with recompression ratio greater than 0.98 [5], indicating the high quality of its linear dispersion characteristics and accuracy of our technique.

The grating of figure 1 was also measured using an instrument designed for high-accuracy measurements of fibre chromatic dispersion (York S19). This instrument measures the group-delay directly, as compared to the interferometric technique, which measures the phase delay [6,7]. Figure 1(c) shows the results which are also in very good agreement with our interferometric measurements.

Figures 2-4 are all related to the narrow-band 40mm long holographic grating. Different temperature gradients were applied to it in order to induce variable external chirp. The gradient was achieved by placing the grating in a 45mm long V-groove made on an aluminium slab, and heating its left and right sides with two separate peltier elements. Although, the grating was pre-chirped in the fabrication process, we were able to cancel the built-in chirp and achieve the narrowest bandwidth with the temperature gradient of figure 2. The time delay response (fig 2(b)) exhibits the characteristic sharp peaks close to the stopband edges which further proves the cancellation of the built-in initial chirp. Further increasing the temperature gradient (fig 3), the grating spectrum broadens, its peak reflectivity reduces and a positive time delay slope of +1200 ps/nm is induced. Reversing the temperature gradient (fig 4), the chirp is reversed and the delay slope changes sign. Spectral broadening and decrease in the peak reflectivity are also observed (c.f. fig 2). The measured dispersion in this case is -1100 ps/nm. The ripples in the delay slope edges are in good agreement with theoretical predictions [4]. Several different temperature gradients were characterised and the results will be discussed in the presentation.

In the measurements related to the 8mm long grating (fig 1(b) and 1(c)), we notice that the average total time delay across the full reflection bandwidth of the grating is about 80ps, whereas for the 40mm long grating (fig 2(b)-4(b)) it is about 400ps. These correspond to delays obtained by fibre lengths of about 16mm and 80mm, respectively, which, as anticipated, are twice the grating lengths.

3. Conclusions

We have demonstrated an interferometric technique capable of measuring the dispersion of fibre gratings with sub-picosecond time-delay and 3pm wavelength resolutions. We have used it to characterise fibre gratings with built-in, fixed, as well as applied, variable chirp for dispersion compensation purposes. Measurements of a wide-bandwidth step-chirped fibre grating indicate its high quality linear dispersion characteristic. Measurements of a narrow-bandwidth externally-chirped fibre grating indicate that by applying variable temperature gradients to a **4 cm** long grating, dispersion up to ±2050 ps/nm (3-dB bandwidth = 0.08nm) is induced, which is capable of compensating the dispersion of over **120 km** of standard telecom fibre. Although this grating can be chirped further, we have noticed that this causes ripples in the time delay slope which degrade its dispersion compensation capability. Our results are very repeatable and have proved to be in very good agreement with other time delay measuring techniques, as well as with theory and recent system measurements. The wavelength resolution and instability of the tunable laser source are the main source of noise and major limitation in our measurements.

4. Acknowledgements

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5. References

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Figures

Figure 1: Experimental results for the 8mm long wide-bandwidth step-chirped fibre Bragg grating: (a) transmitted power (a.u. = arbitrary units) and interferometric phase response of the reflected field (reflection coefficient); (b) time delay response; (c) averaged time delay (left side) and measurement results using the York S19 instrument.

Figure 1

(a)

(b)

(c)

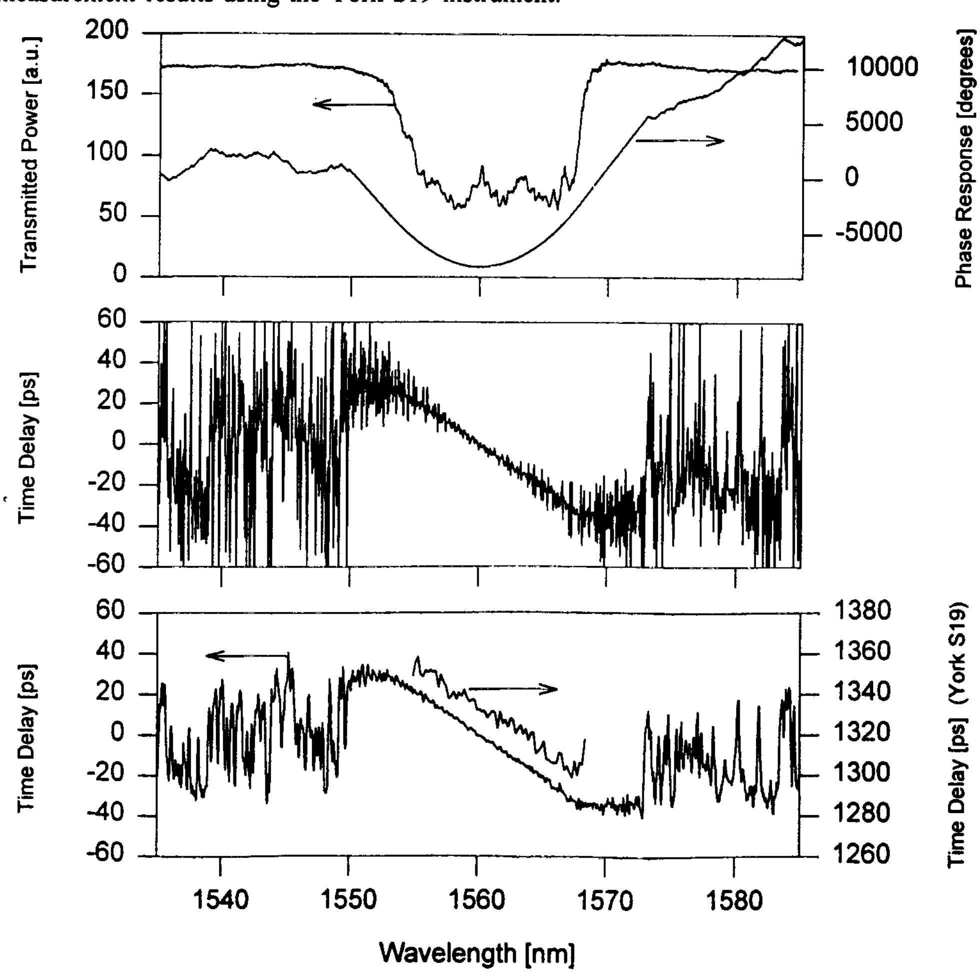

Figure 2: Experimental results for the 40mm long fibre grating with a temperature gradient of 15°C/45mm applied to it (left and right side temperatures = 17.5° and 32.5°C, respectively): (a) Reflected power intensity (~ reflectivity); (b) time delay response.

Figure 3: Grating response for a temperature gradient of 50°C/45mm (left side = 0°C, right side = 50°C).

Figure 4: Grating response for a temperature gradient of -25°C/45mm (left = 37.5°C, right = 12.5°C).

Figure 2

(a)

(b)

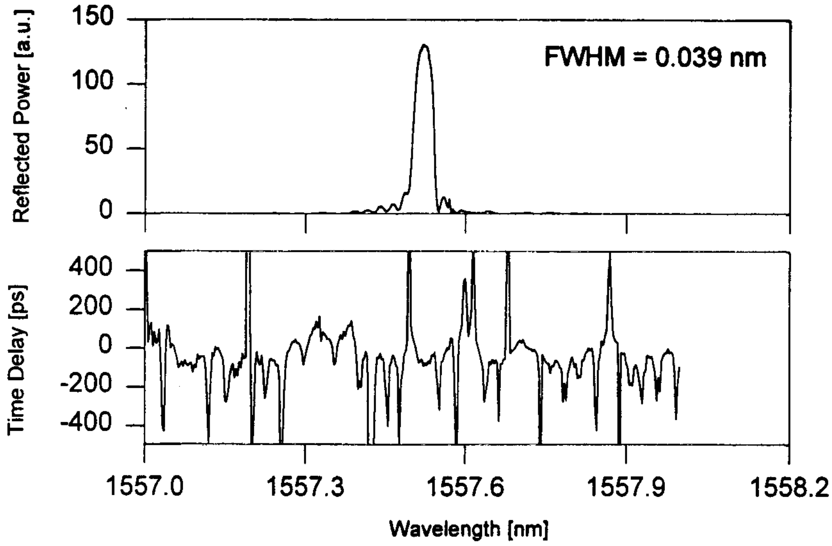

Figure 3

(a)

(b)

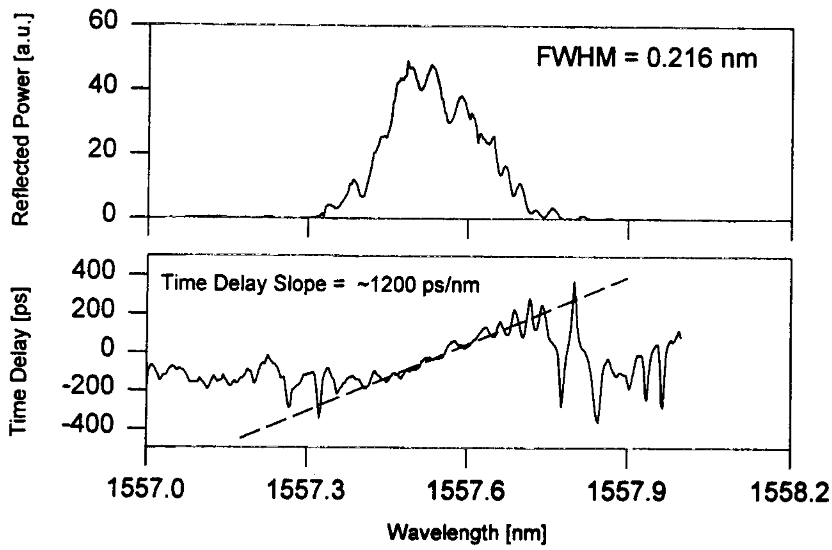

Figure 4

(a)

(b)