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Dispersion compensating fibre bragg gratings

Richard I. Laming, M.J. Cole, M. Durkin, M. Ibsen, M.N. Zervas, [1]V.Gusmeroli,
[1]A. Zuccala & [2]J. Roman

Optoelectronics Research Centre, University of Southampton

[1]Pirelli Cavi SpA, Milano, Italy & [2]Naval Research Laboratories, Washington, D.C.

Abstract **- Broadband Chirped fibre gratings allow the upgrade of the existing non-dispersion shifted fibre network to high data rate operation within the 1.55μm low-loss window. The latest progress in the development of these devices is reviewed.**

SUMMARY

Dispersion compensation allows the upgrade of the existing non-dispersion shifted fibre network to high data rate operation (e.g. 10-40 Gbit/s) within the 1.55μm low-loss window. These data rates would otherwise be prohibited due to the high chromatic dispersion (~17ps/nm×km) associated with this fibre. Chirped fibre Bragg gratings are one of the most attractive devices for this application as they are low loss, compact and polarisation insensitive [1]. Additionally, these devices do not suffer from optical non-linearity which is the primary drawback of the main competing technology i.e. dispersion compensating fibre (DCF).

To date there have been several techniques reported for producing chirped gratings. A major thrust for this work has been to increase the effective bandwidth of the gratings. This has been achieved either by sampling the grating to produce multiple identical dispersion compensated channels typically aligned to the ITU grid or by increasing the length of the gratings. In the latter case we have achieved 1 metre gratings with a continuous grating fabrication scheme, increased lengths are possible with a longer translation stage. More recently Nortel have announced record 2.4 metre gratings.

Authors address: Optoelectronics Research Centre, University of Southampton, Southampton SO17 1BJ, UK, Tel: +44 1703 592693, Fax: +44 1703 593142 - [1]Pirelli Cavi SpA, Milano, Italy - [2]Naval Research Laboratories, Washington, D.C.

Typically a 1 metre grating can provide the required dispersion to compensate for 80 km of standard fibre over a 7 nm bandwidth centered in the 1550 nm wavelength region.

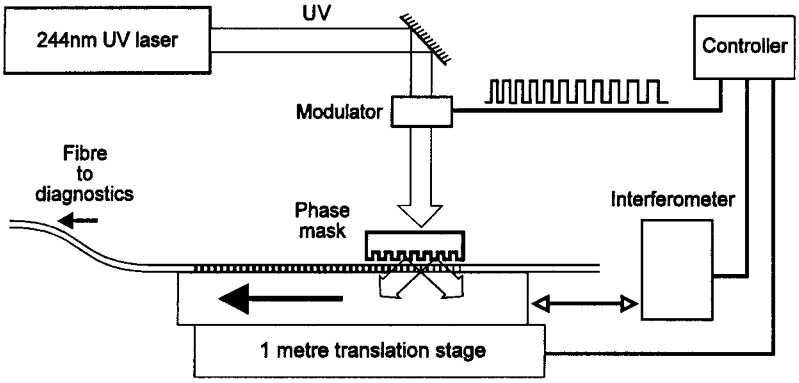
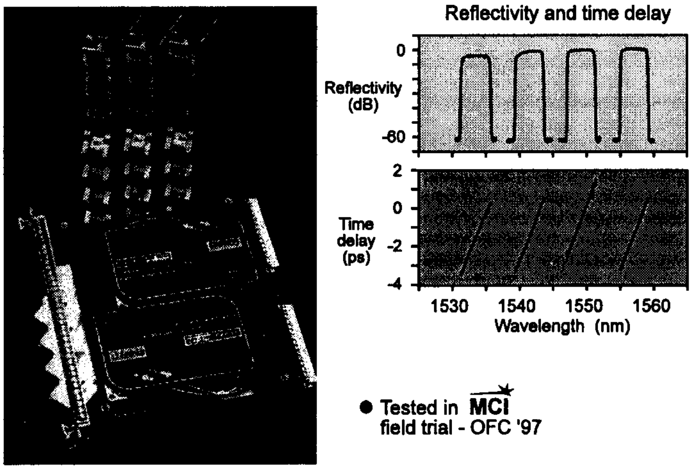


Figure 1: Continuous grating fabrication system

A continuous grating fabrication system was first reported by Stubbe in '95 [2]. A schematic of our fabrication system is shown in figure 1. The fibre is moved continuously behind a fixed phase mask and its position accurately tracked with an interferometer. The CW UV laser output (244 nm) is strobed using an acousto optic modulator with period corresponding to the desired grating pitch. In this way a long grating can be established. Each grating line is effectively written by many UV exposures, ultimately governed by the UV beam diameter. This averaging gives a significant improvement in the positional accuracy of the individual grating lines to better than 0.1 nm. The grating is chirped by gradually increasing the phase of the strobe beam along the grating whilst apodisation is achieved by dithering the phase of the strobe beam.



● Tested in MCI field trial - OFC '97

Figure 2: Packaged dispersion compensator and characteristics of four early WDM gratings

Figure 2 shows the typical characteristics of four gratings from a batch of early WDM gratings fabricated and packaged by Southampton University and Pirelli for a successful field trial in the MCI network , the results of which were reported in early '97. The gratings were each 40cm long and exhibit a bandwidth of ~4.5 nm and dispersion of ~ 850 ps/nm.

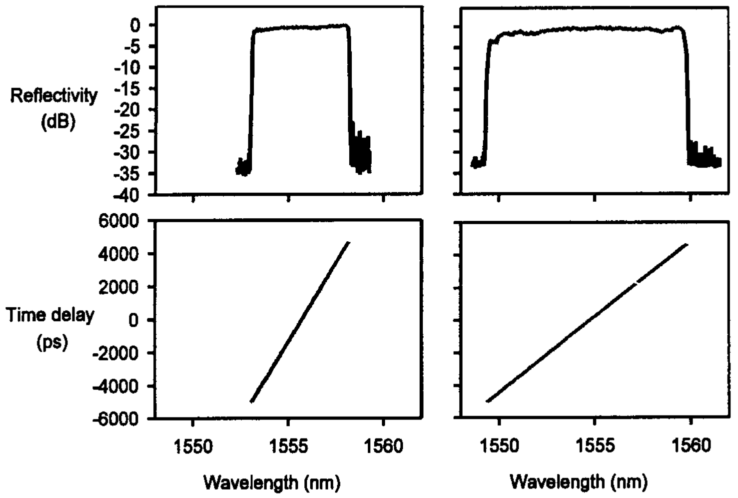


Figure 3: 5 and 10 nm bandwidth 1 metre gratings

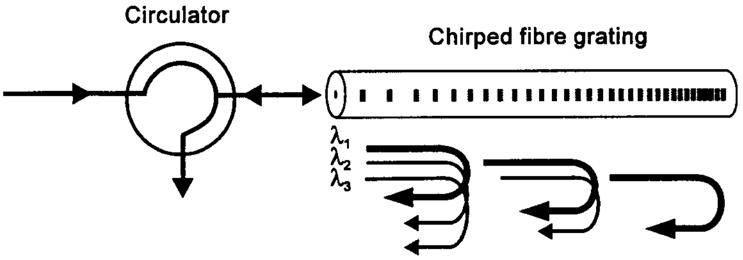


Figure 4: The effect of small random errors in the position of the grating lines

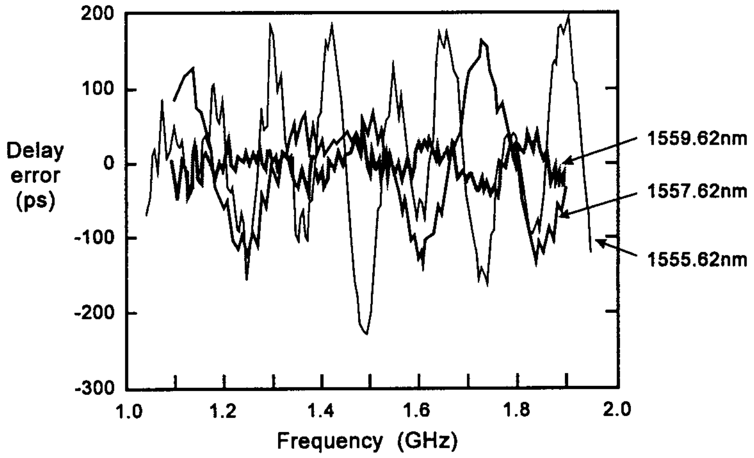


Figure 5: Delay error for a 1 metre grating measured from the long wavelength side by Jose Roman, US Naval Research Laboratories

Figure 3 shows the characteristics of 1 metre 5 and 10 nm bandwidth gratings. The gratings exhibit excellent square reflection characteristics and on average linear time delay characteristics however high frequency structure is observed in the time delay. In theory with apodisation it is possible to effectively eliminate this time delay noise. However small random fluctuations in the position of each grating line arising due to uncontrolled effects such as fibre fluctuations and mechanical vibrations give rise to interferometric like noise. Figure 4 shows the effect schematically. At any region within in the grating the design wavelength is reflected. However, in addition there is also a weak reflection (scattering) of other wavelengths due to imperfections in the precise position of the individual grating lines. Short wavelengths penetrate deep into the grating and thus generate many stray reflections which interfere with the design reflection giving rise to interferometric type noise. The longer wavelengths which do not penetrate very deep into the grating do not suffer from this effect since the weak stray reflections do not get chance to build up. Figure 5 shows measurements by Jose Roman of the US Naval Research Laboratories which show that the high frequency time delay noise measured for a long, central and short wavelength. Indeed the long wavelength shows the lowest noise.

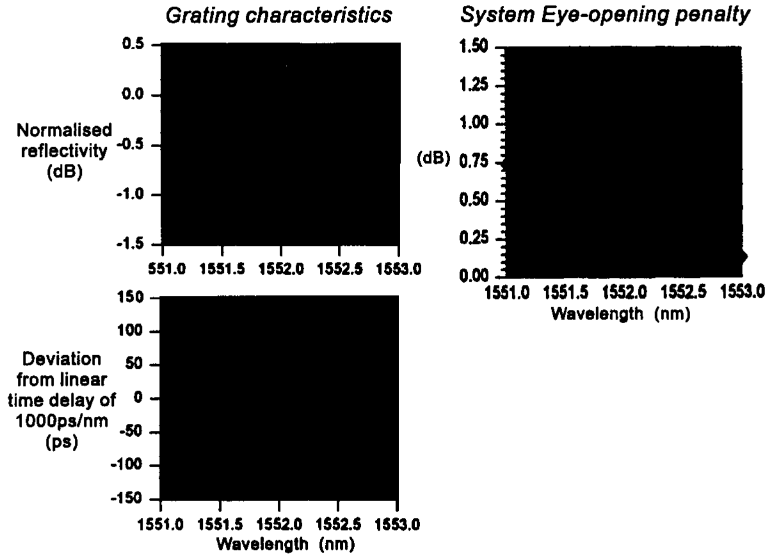


Figure 6: Effect of measured non-ideal group delay and reflection characteristics of a 1 metre grating on a 10 Gbit/s dispersion compensated transmission system (the eye-opening penalty is calculated using the measured grating data).

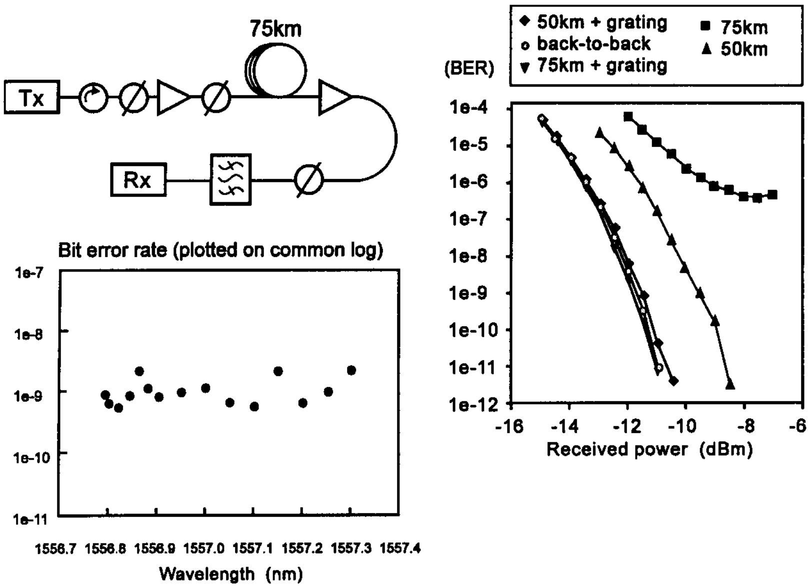


Figure 7: System performance of broadband 1 metre dispersion compensating grating

Continuing improvements in grating fabrication are likely to reduce this noise however it has already been demonstrated not to be a major limitation. This is because the 'period' of the noise is significantly shorter than the data bandwidth and thus a significant degree of averaging occurs. Figure 6 shows real reflection and time delay data from a 1 metre chirped grating with average time delay slope of 1000 ps/nm. The right hand graph shows eye-opening penalty for a standard fibre dispersion compensated link calculated over the wavelength range shown [3]. The eye-opening penalty is found to be acceptable across the band. Figure 7 shows measured BER data for a similar 1 metre grating compensating for 10Gbit/s data transmitted over 75 km of standard fibre. Compared to the back-to-back receiver sensitivity no penalty is incurred due to transmission (right graph). In addition when varying the transmitter wavelength over part of the grating bandwidth (limited by transmitter tunability) with a constant received power the BER varies only by a factor of 5 corresponding to a power penalty fluctuation less than 0.5 dB.

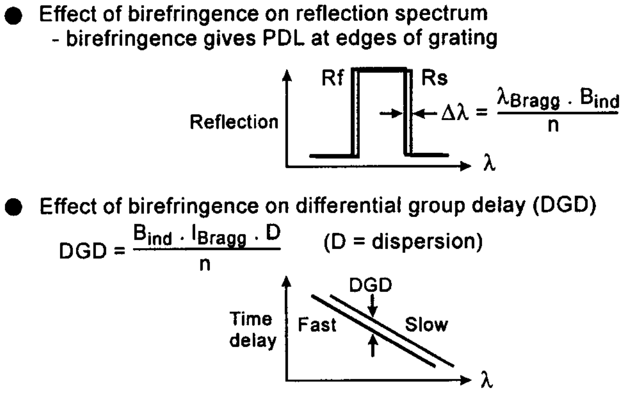


Figure 8: Differential group delay in dispersion compensating gratings

Polarisation dependent loss (PDL) has been observed to be insignificant (<0.1dB) in our gratings. However differential group delay (DGD) arises due to the host fibre birefringence as summarised in figure 8. Fibre birefringence, B can arise due to core ellipticity and stresses as well as being UV induced. The former is minimised via careful manufacture whilst the latter can be minimised by carefully aligning the UV polarisation relative to the fibre longitudinal axis [4]. Typically for a grating with D=1000 ps/nm the birefringence, B must be less than 10^{-6} to ensure that the DGD is less than 1 ps. Unlike fibre PMD, which is a time varying statistical phenomena, the DGD of the grating is fixed and thus it is believed higher values can be tolerated.

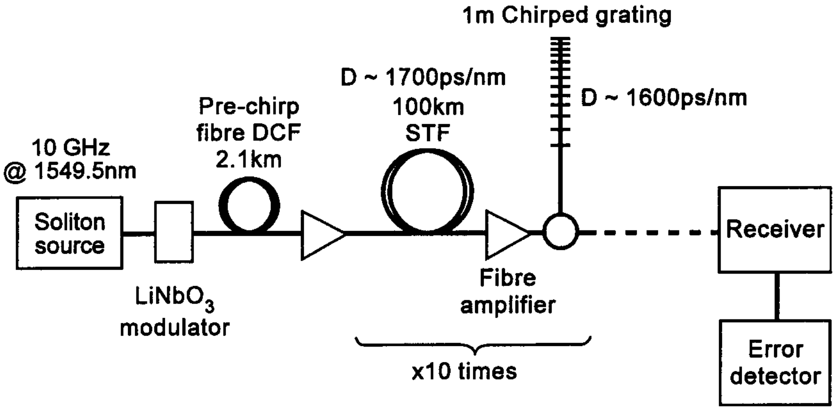


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Figure 9: Partial dispersion compensated 10 Gbit/s soliton transmission over 1000 km

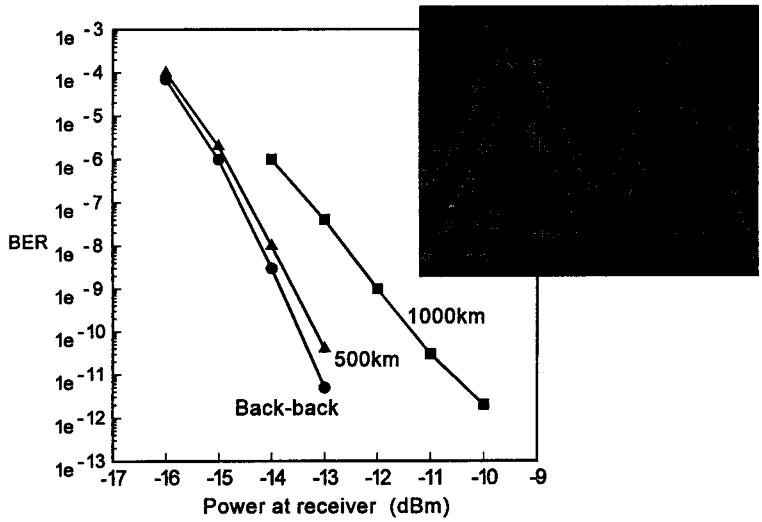

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Figure 10: Results of partial dispersion compensated 10 Gbit/s soliton transmisson over 1000 km

Recent experiments have demonstrated partial dispersion compensated 10 Gbit/s soliton transmission over 1000 km of standard fibre [5]. The experiment is shown schematically in figure 9 with the results in figure 10. Penalty free transmission was observed upto 500 km whilst a penalty less than 2 dB was observed after 1000 km.

A notable feature of this experiment was its resilience to DGD in the gratings which averaged ~7 ps per grating. This is believed to be an attractive feature of the soliton transmission, an advantage which is the focus of further studies.

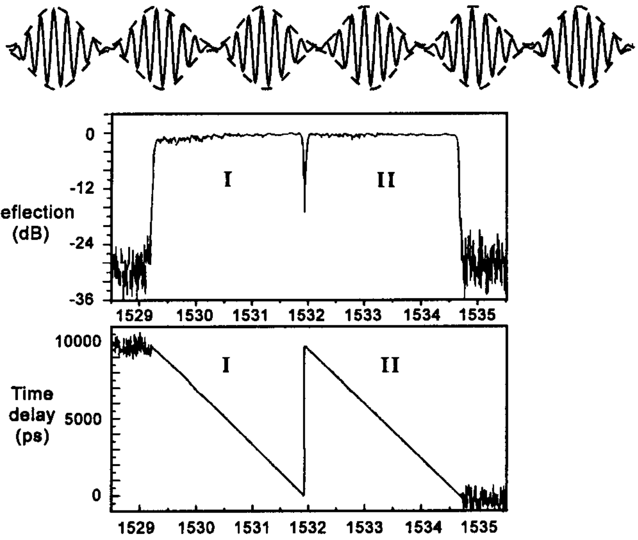

Figure 11: Dual channel Moiré chirped grating

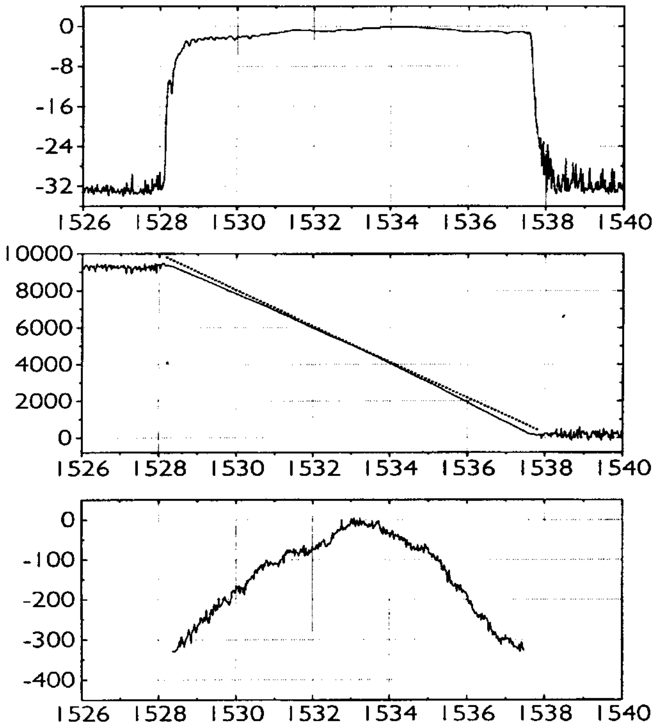

Figure 12: 1 metre, 10 nm bandwidth chirped grating designed to compensate for both linear and higher-order dispersion

By periodically modulating the strength of the grating 'sampling' creates multiple reflection gratings for WDM applications. A two channel Moiré 1 metre grating is shown in figure 11. In this case the sampling is observed to double the useful bandwidth [6]. In addition the gratings can be designed to compensate for both linear and higher-order dispersion as shown in figure 12 [7].

Narrow band gratings @ 10 Gbit/s			
100 km		CRC, Canada/NTT	`94
160 km (20Gbit/s, 80 km)		Nortel	`94
220 km		Southampton/Pirelli/MCI	`95
240 km WDM (2 channels)		OFTC/TELSTRA	`95
270 km		OFTC	`95
540 km		Southampton/Pirelli/MCI/BT	`95
700 km (duobinary transmitter)		Southampton/BT/UCL	`97
Broadband gratings			
100 km	10 Gbit/s	Southampton/Pirelli	`96
100 km	40 Gbit/s	Southampton/BT	`97
220 km	4 x 10 Gbit/s field trial	MCI/Pirelli	`97
1000 km	10 Gbit/s soliton experiment	Southampton/Pirelli/ Fondazione Ugo Bordoni	`97
315 km	8 x 20Gbit/s	AT&T/Pirelli	`98
450 km	4 x SONET OC-192 field trial	MCI/Pirelli	‘98

Figure 13: Table of dispersion compensating grating system results

In summary, chirped gratings have been shown to be ideal for upgrading the installed standard fibre network to the 1.55μm wavelength window and high bit-rate operation. Recent progress in system experiments employing fibre gratings is indicated in figure 13 and confirms their advantages.

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