40 Gbit/s 1.55 μm RZ Transmission over 109 km of Non-dispersion Shifted Fibre with Long Continuously Chirped Fibre Gratings

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Abstract:

We report the first demonstration of 40 Gbit/s transmission over 109 km of standard fibre at 1.55 μm with dispersion compensating linearly chirped continuous fibre gratings and a ~0.5 nm source wavelength tolerance, demonstrating the feasibility of fabricating such gratings for use at very high data rate.

Background:

Chirped fibre gratings are compact and potentially cheap and have become an attractive alternative to technologies such as dispersion-compensating fibres for the upgrade of the installed non-dispersion shifted fibres (NDSF). In particular the recent demonstration of 10 Gbit/s transmission over 700 km of NDSF [11] and 40 cm broadband (4 nm) linearly chirped gratings for much increased source wavelength and operation condition tolerance [2] confirm this potential. These long gratings have essentially flat reflectivity over their usable bandwidth with raised cosine apodisation at both ends of the spectrum. The delay characteristic can be controlled to be linear with less than 2% error in delay and with a dispersion slope as high as ~1700 ps/nm (equivalent to ~100 km of standard fibre). At the same time, the broad bandwidth available from the long linearly chirped gratings makes it possible for the first time to achieve dispersion compensation over a significant length of NDSF at several tens of Gbit/s data rates.

To date 40 Gbit/s transmission over a significant length of NDSF at 1.55 µm has only been demonstrated using dispersion compensating fibres [3,4]. The best result to our knowledge is an error-free transmission over 150 km of NDSF [4]. Without dispersion compensation, the maximum transmission distance is limited to ~4 km at this bit rate.

In this paper we report the first demonstration of 40 Gbit/s transmission over 1.09 km of NDSF at 1.55 µm by employing two continuously chirped 40 cm long, 4 nm bandwidth gratings.

Experiment:

Two linearly chirped gratings were employed in combination with a 4 port circulator. The characteristics are shown in figure 1. Grating 1 exhibits ~98% reflectivity with < ±0.1 dB amplitude deviation over 3.8 nm, dispersion slope of 837 ps/nm and maximum delay deviation from linear fit of < ±50 ps. Whilst comparable figures for grating 2 are ~98% reflectivity, < ±0.1 dB amplitude deviation over 3.5 nm, dispersion slope of 870 ps/nm with < ±40 ps delay deviation from linear fit.

A schematic of the system is shown in figure 2. A 10 GHz pulse train was generated by an actively mode-locked erbium ring laser. A 2^7-1 PRBS data pattern was imposed on the pulse train by a MZ modulator. A two stage inter-leaver was used to generate the 40 Gbitis data. The grating compensator was inserted at the beginning of the link to reduce the launched power intensity to avoid any possible nonlinear effect. Two experiments were performed. In the first grating 2 was used in conjunction with 55 km standard fibre and in the second gratings 1 and 2 (total dispersion slope of 1707 ps/nm) were used in series in conjunction with 1.09 km of fibre. The exact link length used was trimmed to get the shortest pulse. The optimised link lengths were 54.8 km and 108.9 km respectively. For the 54.8 km link the transmitter pulse was 8.9 ps and FWHM spectral width 0.405 nm centred at 1558.0 nm.

After transmission the pulse width broadened to 12.5 ps and FWHM spectral width narrowed slightly to 0.334 nm. Comparable figures for the 108.9 km link are a centre wavelength of 1557.2 nm, transmitter pulse width of 6.4 ps and FWHM spectral width of 0.424 nm, with received pulse width of 9.0 ps and FWHM spectral width of 0.311 nm.

For the single grating experiment, the pulse width after the grating was estimated to be ~350 ps, a stretching factor of ~40. It was recompressed to 1.4 times of the original pulse. In the case of the dual gratings the pulse width after the gratings was estimated to be ~720 ps, a stretching factor of ~110 but was still recompressed to 1.4 times of the original width. The transmitted and received pulses for 108.9 km transmission are shown in fig.3.

The received data was amplified before going through an electro-absorption demultiplexer to gate out a 10 Gbit/s data stream. The gate width was ~15 ps. The transmission results are shown in fig.4. There was a 3 dB penalty for the 54.8 km transmission with no detection of any noise floor. For the 108.9 km transmission, error free transmission was achieved with a penalty of 6 dB just before running out of system power margin. Source wavelength tolerance was also tested for the two systems by tuning the source wavelength and leaving the rest of the system unchanged. A ~1 nm flat region was found for the 54 km link and ~0.5 nm for the 109 km link, beyond which the transmission deteriorates.

Discussions:

Practical broad-band dispersion compensations requires continuously chirped gratings. The tunability of the current transmission is mainly limited by the local dispersion deviation from linearity. This can cause local slope to deviate by as much as ~100 ps/nm over a fraction of nanometre in the worst case (~10% in relative term). A less than 5 ps variation in the received pulse width while tuning will require the fibre and grating dispersion slope to be matched to <13 ps/nm across the spectrum of the grating, assuming a 0.4 nm FWHM for the pulse. The third order dispersion will cause a dispersion slope change of ~3.5 ps/nm^2 and ~7.0 ps/nm^2 for a 50 km and a 100 km link respectively. This will effectively give a tuning range of ~3.7 nm and ~1.8 nm for a 50 km and 100 km link respectively. The local dispersion error can also explain the imperfection in the link dispersion compensation and part of the penalty. The source laser had large wavelength jitters (can be as much as few nanometres in the worst case), and this would give much of the penalty in conjunction with the wavelength dependence. Indeed, the expected excessive noise as result of this can be seen in the eye diagram. An improved future result will come from gratings with better controlled dispersion characteristics. A broadband tuning (several nanometres) is possible if third order dispersion compensation can be written in the same grating. Nevertheless we have demonstrated for the first time transmission over 27 times the dispersion limit using chirped fibre gratings.

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References:

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Figure 1 Characteristics of the two gratings used in the transmission test.

Figure 2 Experimental set-up for the transmission test.

Figure 3 (a) transmitted and (b) received pulses for the 109 km link.

Figure 4 (a) BER performance and (b) wavelength tolerance of the transmission.

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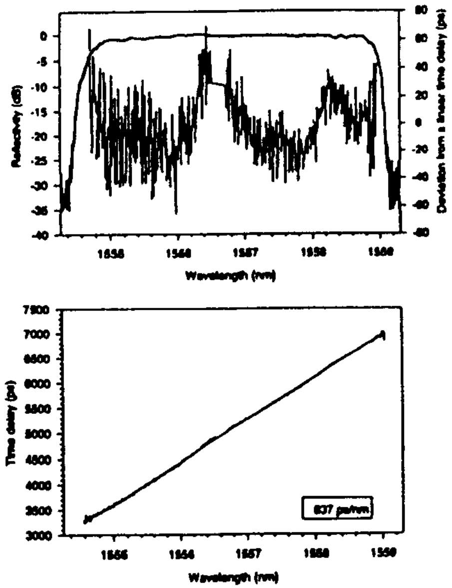
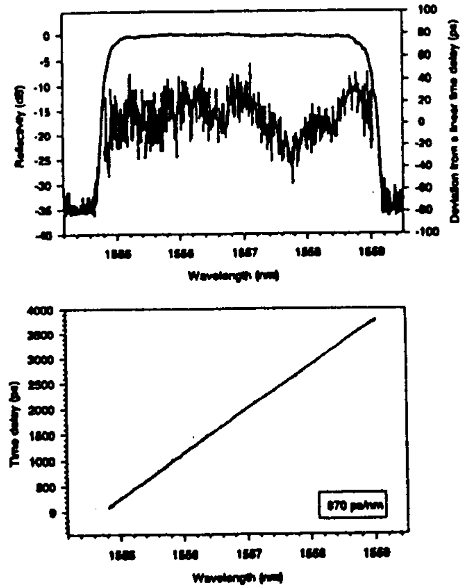
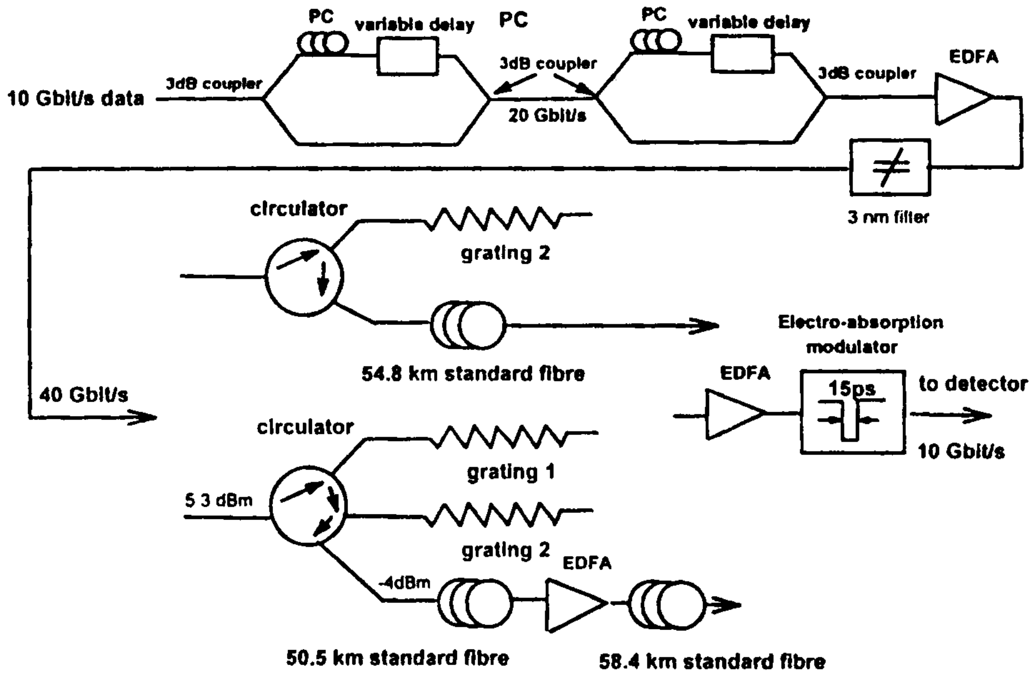


#002 40Gbit/s system trial (4nm)




PC
variable delay
PC
3dB coupler
PC
variable delay
3dB coupler
10 Gbit/s data
3dB coupler
20 Gbit/s
EDFA
3 nm filter
circulator
grating 2
54.8 km standard fibre
40 Gbit/s
circulator
grating 1
5 3 dBm
grating 2
-4dBm
EDFA
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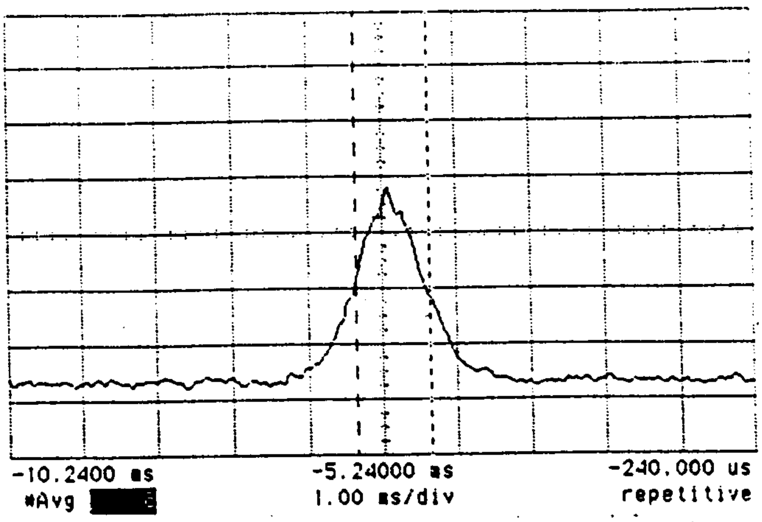
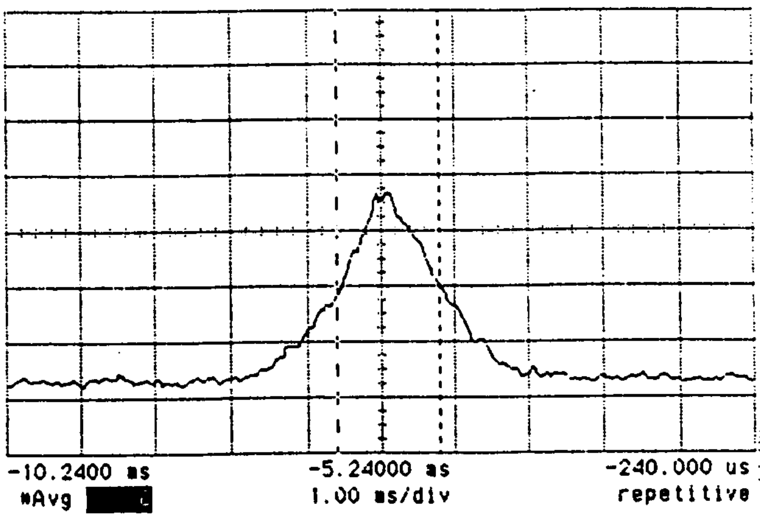
58.4 km standard fibre
Electro-absorption
modulator
EDFA
15ps
to detector
10 Gbit/s

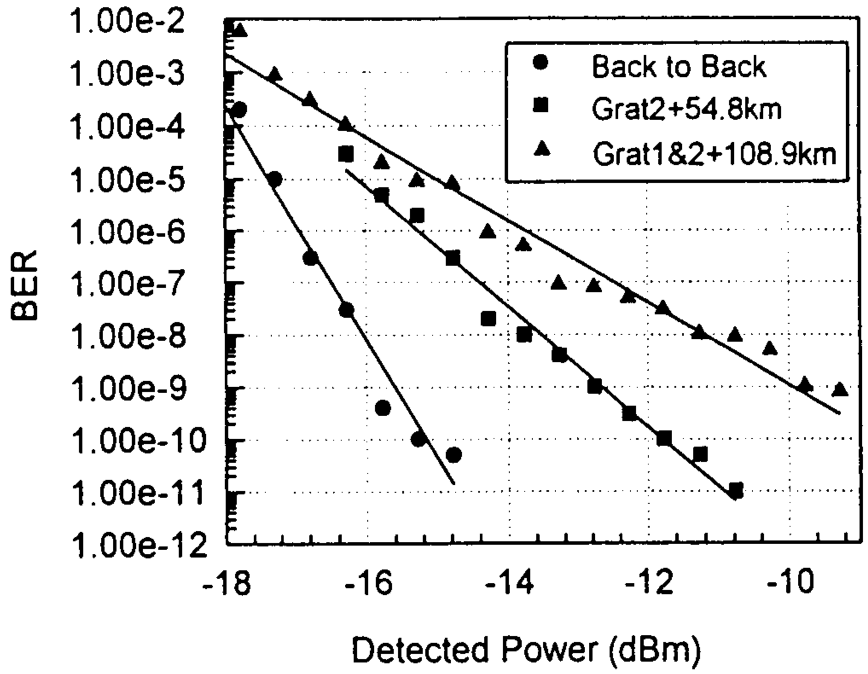


(a) FWHM = 6.4 ps



(b) FWHM = 9.0 ps

(a)



Back to Back
Grat2+54.8km
Grat1&2+108.9km
BER
1.00e-2
1.00e-3
1.00e-4
1.00e-5
1.00e-6
1.00e-7
1.00e-8
1.00e-9
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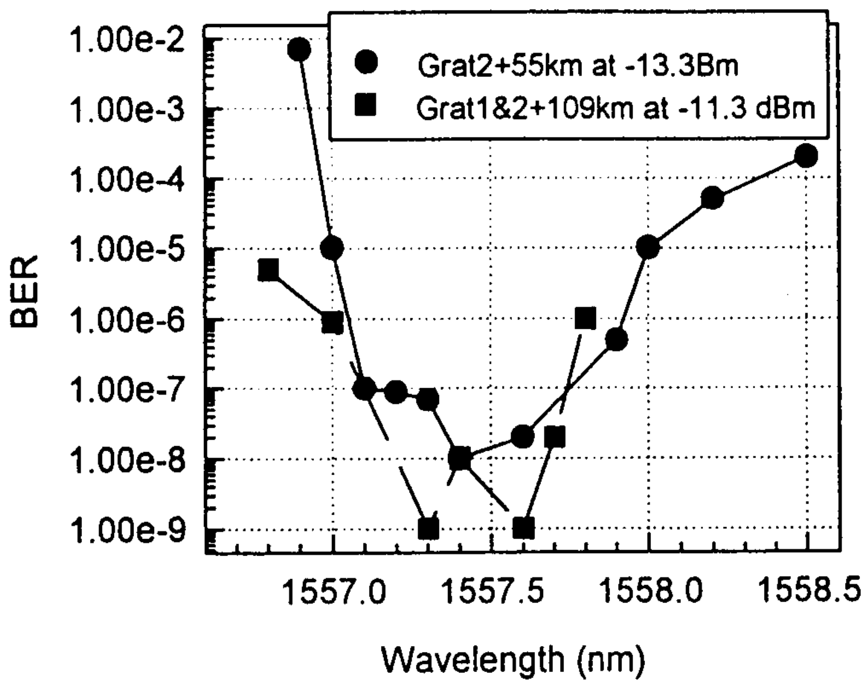
-12
-10
Detected Power (dBm)

(b)



Grat2+55km at -13.3Bm
Grat1&2+109km at -11.3 dBm
BER
1.00e-2
1.00e-3
1.00e-4
1.00e-5
1.00e-6
1.00e-7
1.00e-8
1.00e-9
1557.0
1557.5
1558.0
1558.5
Wavelength (nm)