subm to IEEE PTL. 1094

A dispersion tunable grating in a 10Gbit/s 100-220km step index fibre link

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Abstract

A dispersion tunable 40mm fibre grating has been employed in a 10Gbit/s, step- index fibre link. Dispersion is effectively compensated for span lengths in the range 103-216km. However, at the longer spans the increased dispersion of the grating results in a reduced bandwidth and therefore its centre wavelength is found to be critical ($\pm$0.005nm).

Introduction

Dispersion compensation is a powerful technique which potentially allows the upgrade of currently installed step-index (SI) fibre links to high bit-rate operation at 1.55μm where the fibre exhibits high ($\sim$17ps/nm.km) dispersion. Several techniques have been demonstrated including laser pre-chirping, mid-span spectral inversion, the addition of highly-dispersive compensating fibre and chirped fibre gratings[1-5]. Chirped fibre gratings are of particular interest since they are compact, low-loss, polarisation-insensitive and offer high negative-dispersion of arbitrary and tunable profile. In previous work a 5cm chirped fibre grating has been employed to effectively compensate for the dispersion of 160km of standard fibre in a 10Gbit/s externally modulated transmitter experiment[4]. Whilst more recently in a similar experiment, 270km of fibre was compensated by a 12.5cm chirped grating, however in this case, with an $\sim$2dB penalty[5].

In this paper we present a detailed investigation of the bandwidth-dispersion trade-off for a fixed (40mm) length tunable linearly-chirped fibre grating. In addition we demonstrate that using such a grating we can precisely compensate the dispersion in a 10Gbit/s transmission experiment for standard step-index (SI) fibre lengths anywhere in the range 103-216km. For the longest span and, thus, narrowest bandwidth compensator its centre wavelength is found to be critical ($\pm$5pm) but well within the tolerance of possible active stabilisation. These results demonstrate that by carefully matching the grating wavelength and bandwidth to those of the transmitter long spans can be compensated with a single, compact compensator.

Experiment

The basic link is shown schematically in Figure 1 and was established such that compensation of linear dispersion for total span lengths up to 216km could be investigated. A 10Gbit/s externally modulated transmitter was employed. This exhibited negative chirp ($\alpha = 1$) to maximise transmission distance over step index fibre. This was followed by power-, line- and pre-amplifiers as well as a receiver. Attenuators were included in each section such that, when adding fibre or the dispersion compensator, power levels in the link were maintained constant to eliminate penalty variations due to amplifier noise variations. Receiver sensitivity was measured by varying the input to the commercial preamplifier with integral narrow band ($\Delta\nu = 50$GHz) tracking ASE filter. At all times power levels in the link were such that operation in the linear regime was insured.

Dispersion compensation of the link was provided by incorporating a chirped fibre grating between the transmitter and power amplifier. Since the grating operates in reflection, an optical circulator was included to convert it to a transmissive device. The linear fibre grating was written with a frequency-doubled excimer laser and scanning interferometer in hydrogenated standard telecommunications fibre. The grating was approximately 40mm in length with flat top profile and slight apodising at the edges. Peak reflectivity of the unchirped grating was $\sim 80\%$. The grating was mounted such that its centre wavelength could be mechanically tuned to match that of the transmitter whilst a linear chirp could be applied via a linear temperature gradient as indicated in Figure 1.

Figure 2(a,b) show typical reflection spectra and time delay characteristics measured using an interferometric set up[6] for a temperature differential of 15°C (15°C/45mm). A 3dB reflection bandwidth of 0.159nm is observed, however modulation in the spectra is present despite the small degree of apodisation. Nevertheless, a near linear time delay against wavelength characteristic is observed across the reflection band, in this case, with a slope of -1401ps/nm. No polarisation sensitivity to this slope was observed. Figure 3 shows the measured and predicted bandwidth-dispersion characteristic for the grating. The dispersion is roughly inversely proportional to the 3dB grating bandwidth and, as anticipated, results in a near constant bandwidth-dispersion product which is proportional to twice the grating length. Once chirped, the grating reflectivity reduced and thus, for a typical bandwidth of 0.287nm the circulator-grating combination exhibited an insertion loss of ~8.5dB, but owing to its location this had negligible effect on the link power budget. The polarisation dependent loss of the grating-circulator combination was measured to be ~0.1dB.

Figure 4 plots the receiver penalty, compared to the back-to-back sensitivity of -27dBm and measured for a 2^{31}-1 data pattern and a 10^{-11}BER, for varying span lengths . Results are compared with and without the grating. Without the grating the receiver sensitivity is observed to improve (-ve penalty) for short span lengths and exhibit a minimum around 50km due to the negative-chirped transmitter. For increasing span lengths, the penalty increased sharply with 0 and 3.5 dB penalties being observed for 80km and 102.6km spans, respectively. In the case of the dispersion compensated link, by variation of the grating dispersion and hence bandwidth as indicated (see fig. 3), a large span variation, 102.6-185.3km, is observed where a receiver improvement of 4.5-5dB is obtained. Optimisation of the grating dispersion was investigated for each span length as shown in figure 5 where the BER penalty as a function of temperature differential is plotted. From this figure and Figure 3 we infer that for a <X10 BER penalty the dispersion must be compensated to within ~±150ps/nm.

For the increased span of 216.8km a reduction in the dispersion compensation is observed. In the case of the 185.3 and 216.8km spans the grating 3dB-bandwidth of 0.144nm corresponded to the transmitter 11.5dB-bandwidth and thus setting of the grating centre wavelength was critical. This wavelength sensitivity was reduced by increasing the grating bandwidth which decreases the dispersion and thus incurs a slight penalty. In this case the 0.166nm 3dB grating bandwidth corresponded to the 14dB transmitter bandwidth. Figure 6 shows BER penalty as a function of detuning the grating centre wavelength via temperature. In the case of the 0.144nm bandwidth grating an inferred wavelength accuracy of ±0.005nm is required. Increasing the bandwidth to 0.166nm, although reducing the dispersion compensation (see Figures 3&4), reduced the wavelength tolerance to ±0.01nm. These wavelength tolerances, although tight, are not unreasonable as long as wavelength tracking of the grating/ transmitter is provided. If developed such a filter could be employed in the pre-amplifier to provide noise filtering in addition to dispersion compensation. In this case the flat-top spectral response of a chirped filter may be advantageous compared to the response of Fabry-Perot type filters.

Figure 7 plots the required grating length to achieve a given dispersion and bandwidth. For a 4cm, 0.15nm bandwidth grating the predictions are in good agreement with the experiments. Further, it is observed that with a single 10cm, 0.15nm bandwidth chirped fibre grating it should be possible to compensate for the dispersion of around 400km of SI fibre providing that the grating centre wavelength is locked to that of the transmitter.

Conclusions

The bandwidth-dispersion trade-off of a fixed length (40mm) length tunable chirped fibre grating has been investigated in detail. As anticipated the grating bandwidth-dispersion product is near constant and thus the grating can be accurately tuned to compensate the dispersion of a 100-220km SI fibre link. However for the longer links the grating centre wavelength is found to be critical (±0.005nm) owing to its reduced bandwidth.

Acknowledgements

The authors acknowledge D.N. Payne, G. Grasso and Shoa-Kai Liu for encouragement whilst the technical assistance of their colleague G. Dempster is much appreciated. R.I. Laming acknowledges the Royal Society for provision of a Research Fellowship. The ORC is an EPSRC funded Interdisciplinary Research Centre.

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Figure captions

Figure 1: Experimental setup.

Figure 2(a,b): Typical reflection spectra and time delay characteristics measured using an interferometric test rig[6], in this case for a temperature differential of 15°C/45mm.

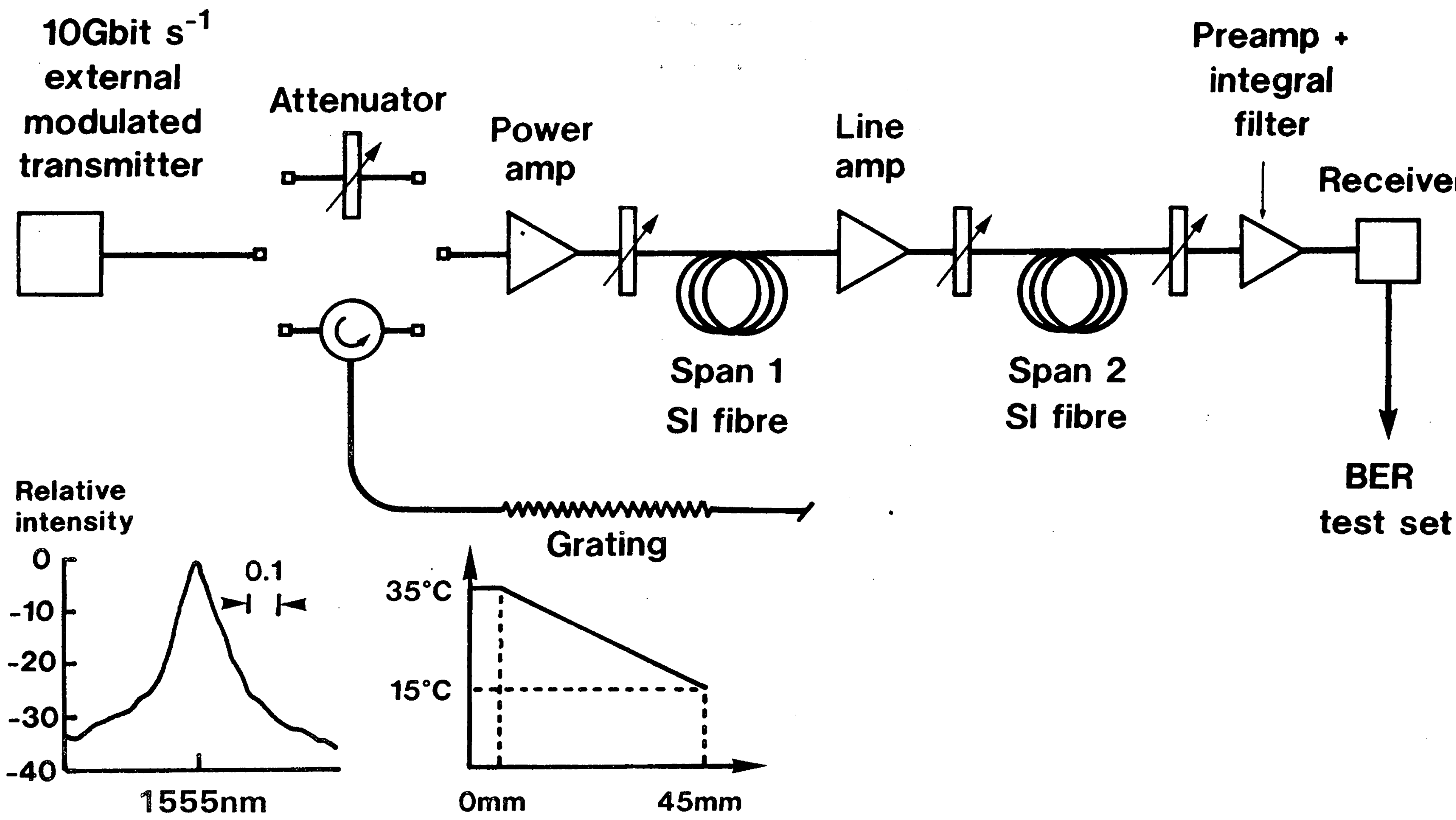
Figure 3: Measured and predicted bandwidth-dispersion characteristic for the tunable grating.

Figure 4: Receiver penalty compared to the back-to-back sensitivity of -27dBm at a 10^{-11} BER for varying span lengths.

Figure 5: BER penalty as a function of temperature differential for span lengths in the range 102.6-185.3km. Results indicate the degree of dispersion tuning.

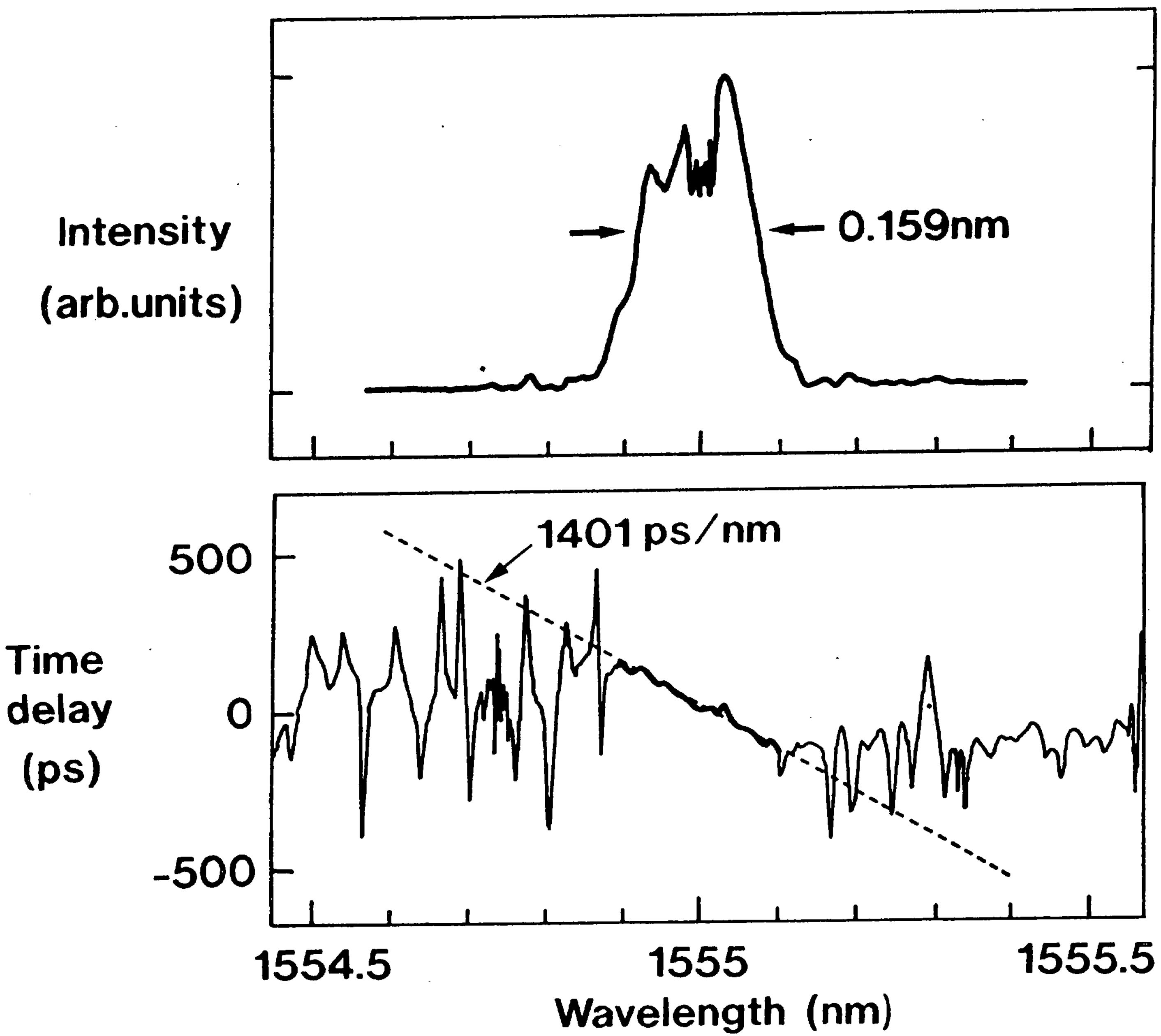
Figure 6: BER penalty as a function of detuning the grating centre wavelength via temperature.

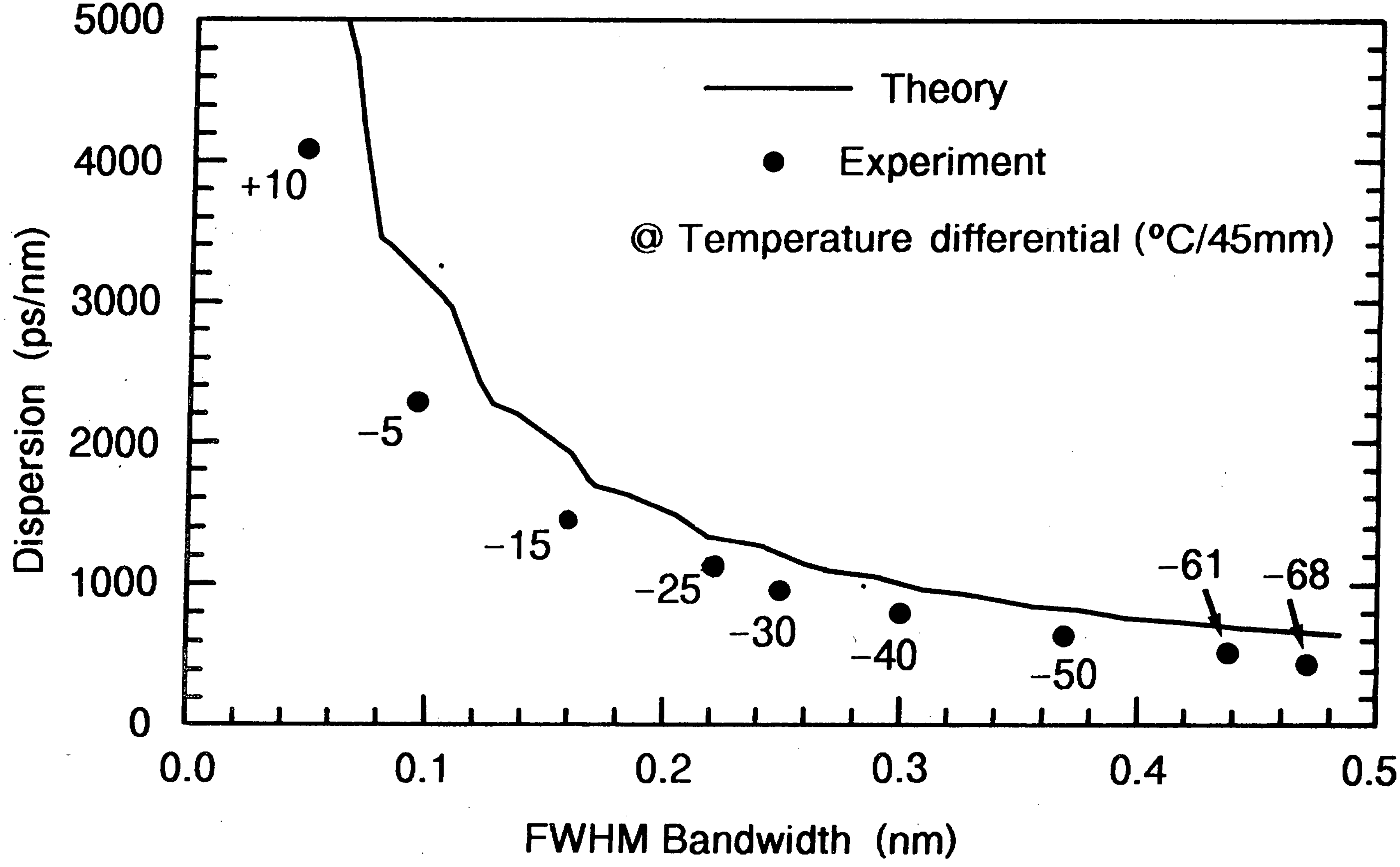
Figure 7: Mean dispersion as a function of the grating length for different 3dB bandwidths.



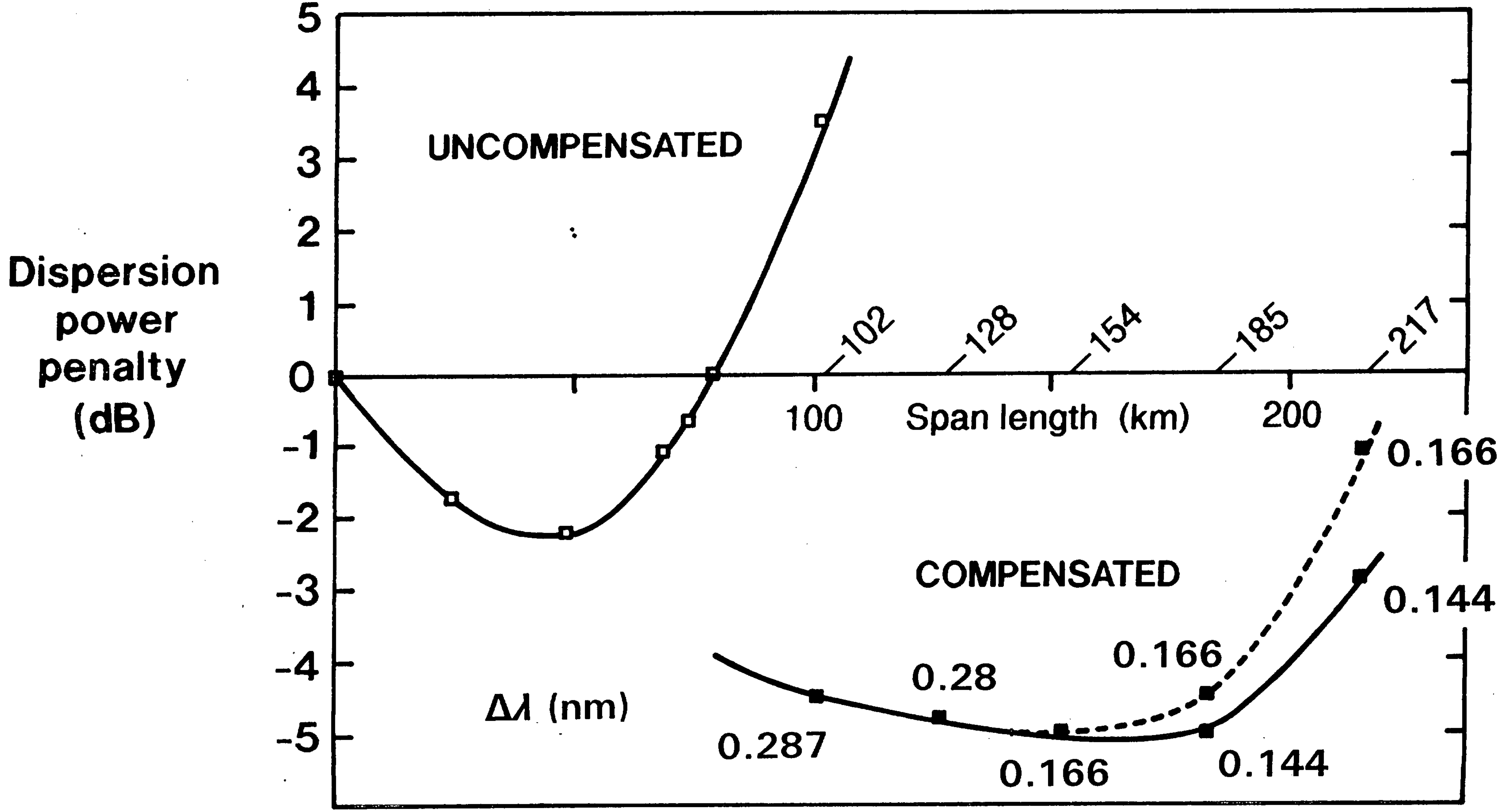
10Gbit s-1
external
modulated
transmitter
Attenuator
Power
amp
Line
amp
Preamp +
integral
filter
Receiver
Span 1
SI fibre
Span 2
SI fibre
BER
test set
Grating
Relative
intensity
0
-10
-20
-30
-40
0.1
1555nm
35°C
15°C
0mm
45mm

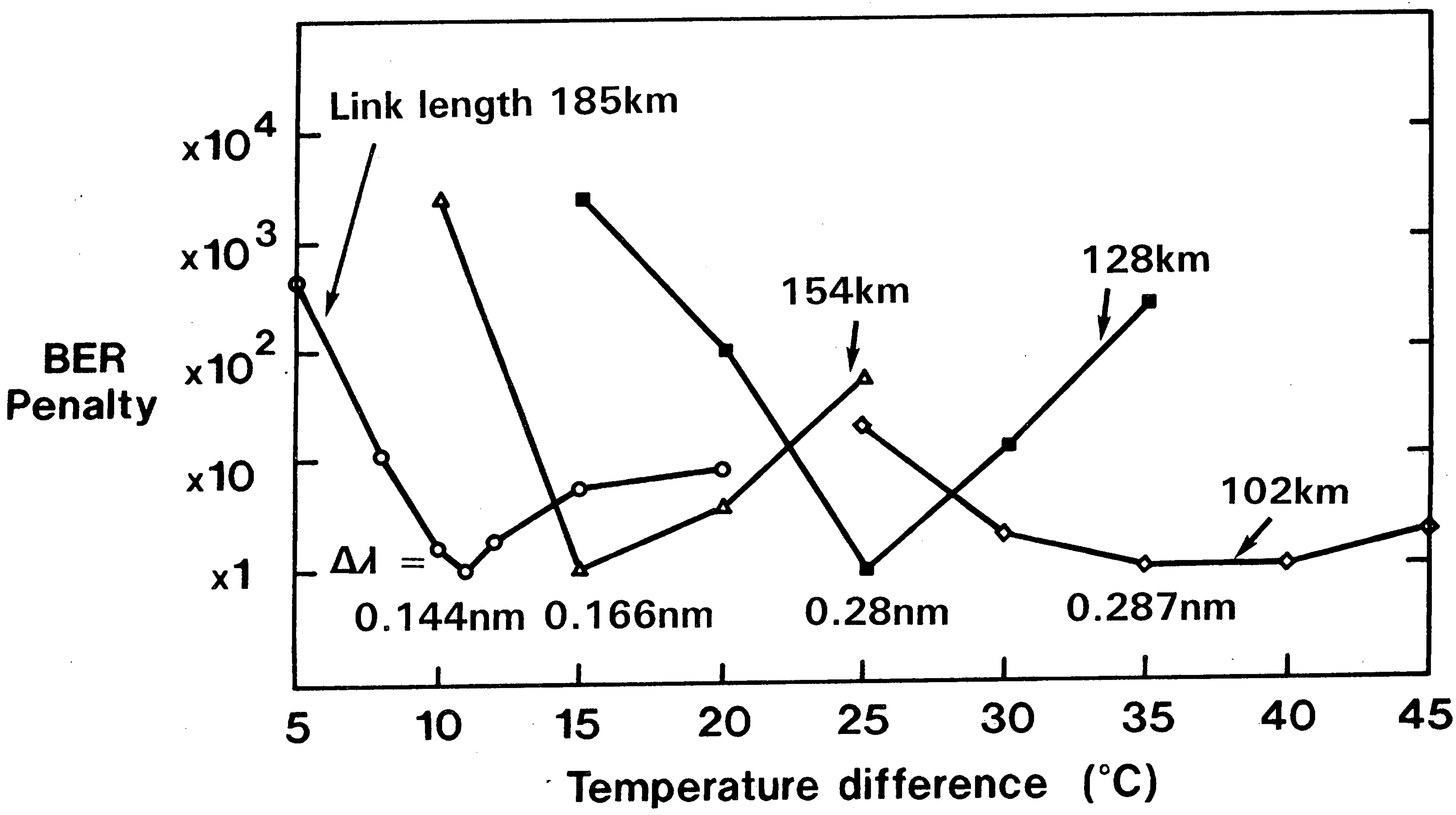
Lanning et al, fig 6

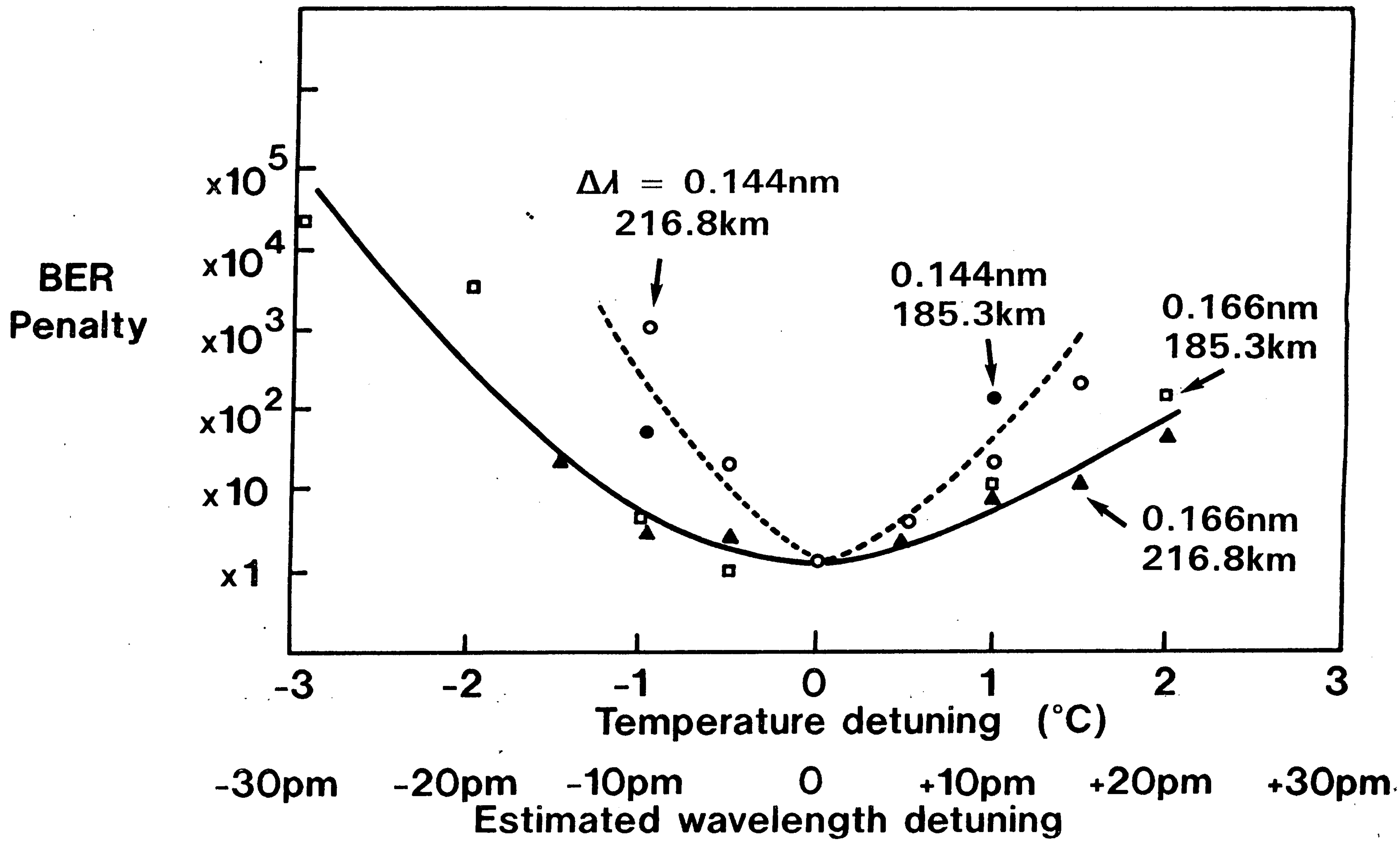




Theory
Experiment
@ Temperature differential (°C/45mm)
+10
−5
−15
−25
−30
−40
−50
−61
−68
5000
4000
3000
2000
1000
0
Dispersion (ps/nm)
0.0
0.1
0.2
0.3
0.4
0.5
FWHM Bandwidth (nm)


Dispersion power penalty (dB)
5
4
3
2
1
0
-1
-2
-3
-4
-5
UNCOMPENSATED
COMPENSATED
100
200
Span length (km)
102
128
154
185
217
Δλ (nm)
0.287
0.28
0.166
0.166
0.144
0.166
0.144


Link length 185km
x10^4
x10^3
x10^2
x10
x1
BER Penalty
154km
128km
102km
Δλ =
0.144nm 0.166nm
0.28nm
0.287nm
5
10
15
20
25
30
35
40
45
Temperature difference (°C)


BER
Penalty
x10^5
x10^4
x10^3
x10^2
x10
x1
Δλ = 0.144nm
216.8km
0.144nm
185.3km
0.166nm
185.3km
0.166nm
216.8km
-3
-2
-1
0
1
2
3
Temperature detuning (°C)
-30pm
-20pm
-10pm
0
+10pm
+20pm
+30pm
Estimated wavelength detuning

Laming et al, Fig. 1