Influence of non-ideal chirped fibre grating characteristics on dispersion cancellation

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ABSTRACT

The effect of non-ideal dispersion and reflection characteristics of chirped fibre gratings on the performance of 10Gb/s NRZ-transmission systems operating over standard fibre is investigated. The effect of different amplitudes and periods of the imperfections are thoroughly quantified. Analyses of an experimental grating confirm that fabrication technology can meet the requirements for <1dB-penalty operation.

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I. INTRODUCTION

Chirped fibre gratings have been demonstrated as effective dispersion compensators to overcome the limitation of long-haul and high-bit-rate transmission over non-dispersion shifted fibre. They provide a simple and attractive optical fibre delay, which is polarisation-insensitive, inherently fibre compatible, relatively easy to produce, passive and low-loss [1]. However fibre gratings are reflective, resonant devices. Uniform strength, chirped fibre gratings have side lobes in the reflection spectra and nonlinear dispersion characteristics, which are undesirable for optical communications. Fortunately these can be significantly suppressed by apodising the grating [2]. An optimised apodisation profile improves the compensator performance in the system [3], however, there still remains slight nonlinear group-delay characteristics (ripples). The period of these depends on the length of the grating and has roughly a range of 1pm to 10pm. In addition, the fabrication process introduces stochastic variations in the time delay and reflectivity response.

In this paper, we investigate the effect of these group delay and reflectivity ripples on the grating performance in high-speed optical communication systems. The modulation is represented by a periodic function, with period in the picometer range. The effect of the modulation is found to depend on both the amplitude in reflectivity and the product of period and amplitude in the time delay. Their impact on the performance of a 10Gb/s linear transmission system is quantified by calculating the resulting eye-opening (EO) penalty.

II. MODEL DESCRIPTION

An ideal grating would exhibit a constant reflectivity and linear time delay characteristics with wavelength. Imperfections in the grating are investigated by adding a periodic function to the reflectivity and time delay equations. The grating response is a complex value $R = |R| \cdot e^{-j\theta}$, where the reflectivity and the associated time delay as function of the wavelength λ are expressed as:

$$|R(\lambda)| = (1 - r_1) + r_1 \cdot sin\left(\frac{2\pi}{p} \cdot \lambda\right)$$

$$\tau(\lambda) = a_1 \cdot \lambda + a_2 + b_1 \cdot sin\left(\frac{2\pi}{p} \cdot \lambda\right)$$

r_1 and b_1 are the amplitude of the modulations and p is the period. The coefficients a_1 and a_2 depend on the total fibre dispersion in the link. By integrating the time delay, the phase is given as:

$$\begin{aligned}\theta(\lambda) &= \frac{-2\pi\, c}{\lambda^2} \int \tau(\lambda) d\lambda \\ &= \frac{-2\pi\, c}{\lambda^2} \left(\frac{a_1}{2} \cdot \lambda^2 + a_2 \cdot \lambda - \frac{b_1 p}{2\pi} \cdot \cos(\frac{2\pi}{p} \cdot \lambda) \right) + c_0\end{aligned}$$

where c_0 is the initial constant of the integration.

The linearly chirped grating is modelled to compensate the group-velocity dispersion of 100km of standard fibre with a dispersion of 1700ps/nm at 1.55µm. The source is externally modulated by a push-pull Mach-Zehnder. To focus on the system impact of the ripples, fibre nonlinearities were ignored. NRZ pseudo-random data consisting of 2^7 -1 bits was investigated. Longer word lengths (PRBS 2^{10}-1) were investigated but only caused a 2% system penalty variation.

The grating losses are corrected by an optical amplifier, with gain set to give a constant average power launched into the fibre. At the receiver, the signal is optically filtered by a third order Bessel filter having a 3dB bandwidth of 40GHz, before being detected and electrically filtered by 7GHz bandwidth tenth order Bessel filter.

III. RESULTS AND DISCUSSION

Fig 1 shows the effect of the modulation in the reflection spectra for a peak-to-peak amplitude of ~1dB. The time delay is linear. For periods less than ~100pm (12.5GHz), the maximum penalty is ~0.3dB, whilst for periods larger than the data bandwidth the imperfections have no effect. The magnitude of the EO-penalty is observed to depend on the phase (θ) of the modulation relative to the signal wavelength (λ_0). The minimum penalty (best case) occurs for $\theta = n \cdot \pi$ ($n = 0,1,2...$) whilst the maximum (worst case) occurs for $\theta = n \cdot \pi + \pi /2$. Transmission of 40Gb/s data was also investigated and as expected, the transmission performance for a given modulation period at 40Gb/s is equivalent to four times the period at 10Gb/s. That means for 40Gb/s data periods over 400pm have a negligible impact.

Fig 2 illustrates the effect of the amplitude of the reflectivity ripples. In this case, the period of the modulation is fixed at 10pm. For less than 0.5dB EO-penalty, the peak-to-peak amplitude of the modulation should be less than ~0.32 (~1.67dB).

To study the effect of the time delay imperfections, a constant reflectivity is considered. The maximum and minimum EO-penalties for ±60ps of time delay deviation (b_l) against the period (p) of the modulation are plotted in Fig 3. The EO-penalty is worst for periods comparable to the bit rate whilst for shorter periods the data effectively averages the modulations. For periods less than the bit rate the intensity of the effect is found to depend on the product $b_l \cdot p$. Therefore, a similar eye-opening penalty is found for $b_l = 30$ps and $p = 15$pm as for $b_l = 60$ps and $p = 7.5$pm. Analogously to the effects of modulation in the reflectivity, the long period oscillation does not cause significant distortions in the compensated signal and the transmission bit rate can be scaled.

Fig 4 shows the effect of the modulation amplitude in the time delay on the EO-penalty for a fixed period of 10pm. For less than 0.5dB EO-penalty, the peak-to-peak amplitude of the modulation should be less than 170ps. Thus digital data is extremely tolerant to grating imperfections and well within the tolerances that can be manufactured [4].

Experimental data from a 70cm, 7nm bandwidth, 1000ps/nm dispersion chirped grating (see Fig. 5) has been analysed. The grating data was obtained with a wavelength resolution of 1pm and time resolution of ~1ps. Transmission over 60km is evaluated and EO-penalty over the grating bandwidth plotted in Fig. 6. The EO-penalties are typically less than 0.5dB and always less than 1.25dB. At present the imperfections are not fundamental to the grating but dominated by the fabrication process. Thus it is likely that these results will be improved with further refinements in grating fabrication.

IV. CONCLUSION

The effect of non-ideal dispersion and reflection characteristics of chirped fibre grating dispersion compensators on 10Gb/s NRZ linear fibre transmission systems has been investigated. The system degradation depends on the period and amplitude of modulation in both the reflectivity and time delay spectra. However, for high frequency (10pm period) modulations 10Gb/s NRZ data is extremely tolerant and peak-to-peak amplitudes up to 1.67dB in reflectivity and 170ps in time delay can be tolerated for less than 1dB EO-penalty. Analysis of an experimental grating confirm that chirped gratings can now be fabricated meeting these requirements.

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REFERENCES

[1] F. Ouellette, "Dispersion cancellation using linearly chirped Bragg grating filters in optical waveguides", *Opt. Lett.*, vol. 12, no. 10, pp. 847-849, 1987.

[2] P.S. Cross and H. Kogelnik, "Sidelobe suppression in corrugated-waveguide filters", *Opt. Lett.*, vol. 1, no. 1, pp. 43-45, 1977.

[3] M.N. Zervas, K. Ennser and R.I. Laming, "Design of apodised linearly-chirped fibre gratings of optical communications", in *Proc. European Conf. on Optical Commun.*, pp. 3.233-3.236, paper WeP.06., 1996.

[4] M.J. Cole, H. Geiger, R.I. Laming, S.Y. Set, M.N. Zervas, W.H. Loh and V. Gusmeroli, "Continuously chirped, broadband dispersion-compensating fibre gratings in a 10Gbit/s 110km standard fibre link", in *Proc. European Conf. on Optical Commun.*, pp. 5.19-22, post-deadline paper Th.3.5, 1996.

LIST OF CAPTIONS

Fig. 1: Maximum and minimum EO-penalty as a function of the period of modulation in the reflection spectra. Peak-to-peak amplitude of modulation is ~1dB.

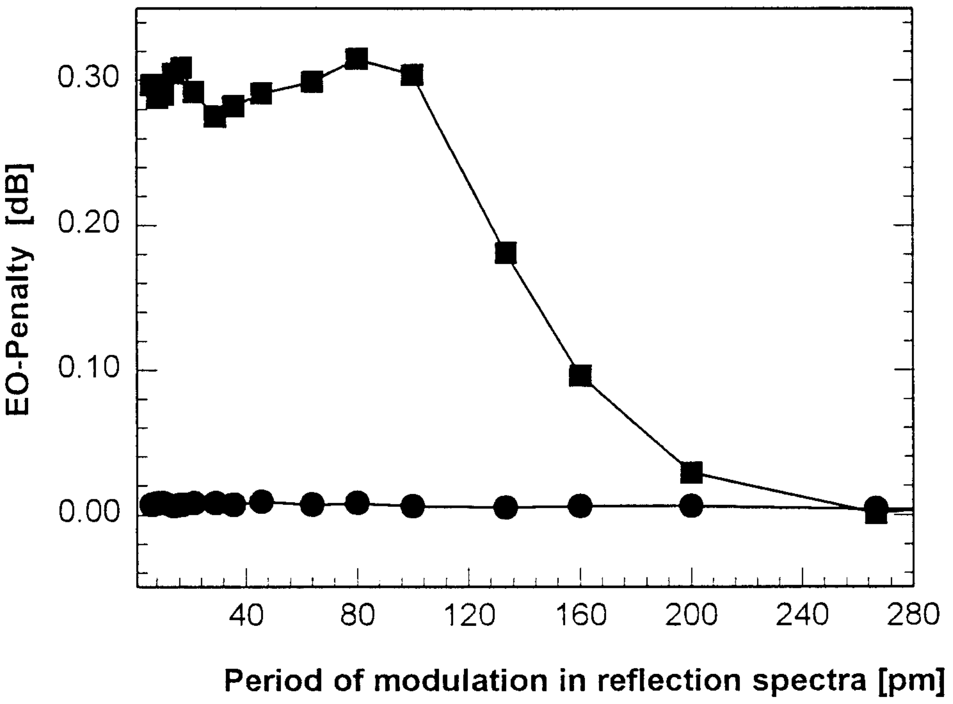
Fig. 2: Maximum and minimum EO-penalty as a function of the peak-to-peak amplitude of modulation in the reflection spectra. The period of the modulation is 10pm.

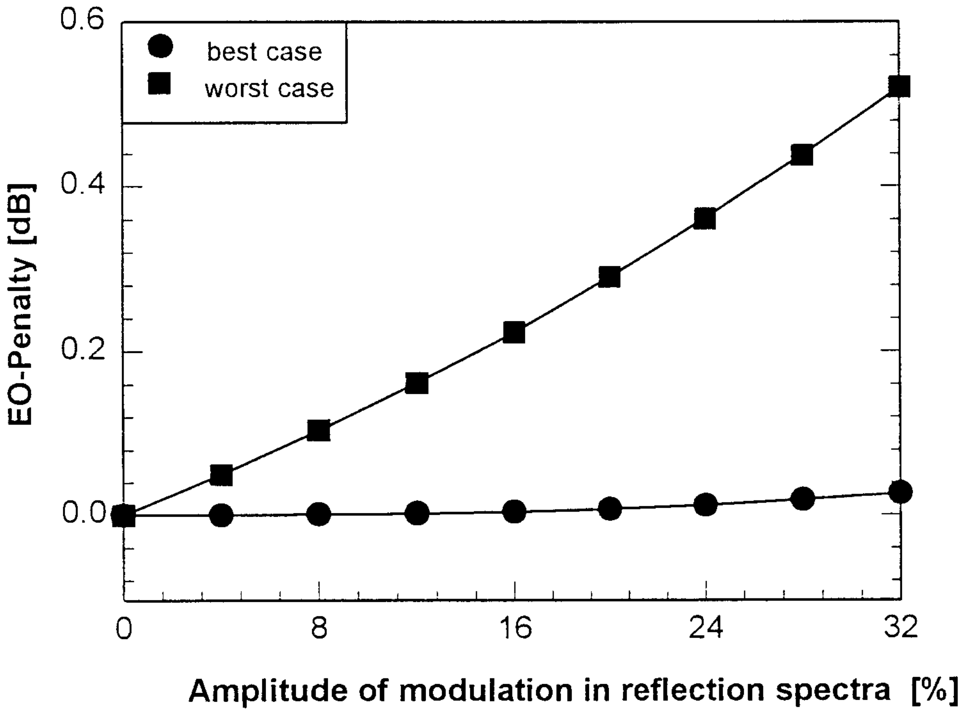
Fig. 3: Maximum and minimum EO-penalty as a function of the period of modulation in the time delay. The maximum time delay deviation is about ±60ps. The insert is a blow-up of the data for small periods.

Fig. 4: Maximum and minimum EO-penalty as a function of the peak-to-peak amplitude of modulation in the time delay. The period of the modulation is 10pm.

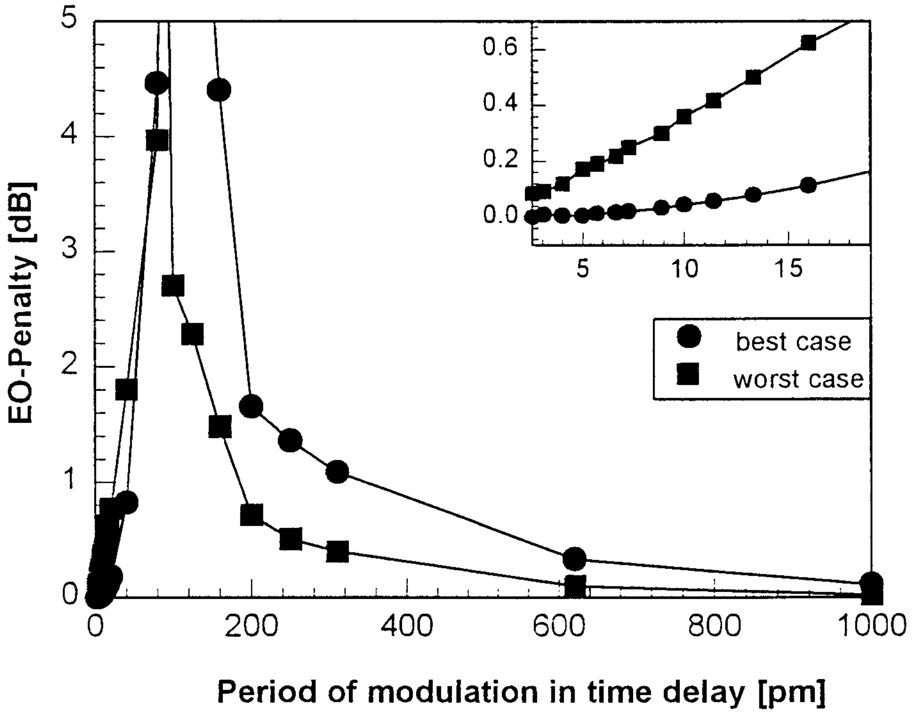
Fig. 5: Reflectivity and deviation from linear time delay of 1000ps/nm for the measured grating.

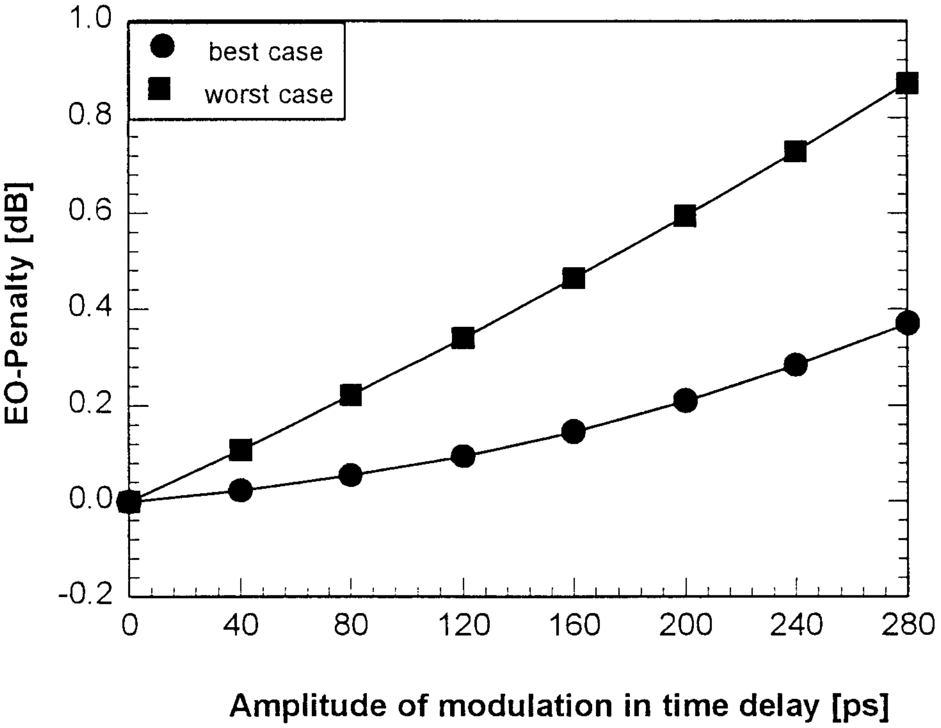
Fig. 6: System EO-penalty of the experimental grating data as a function of the transmitter wavelength.


0.30
0.20
0.10
0.00
EO-Penalty [dB]
40
80
120
160
200
240
280
Period of modulation in reflection spectra [pm]

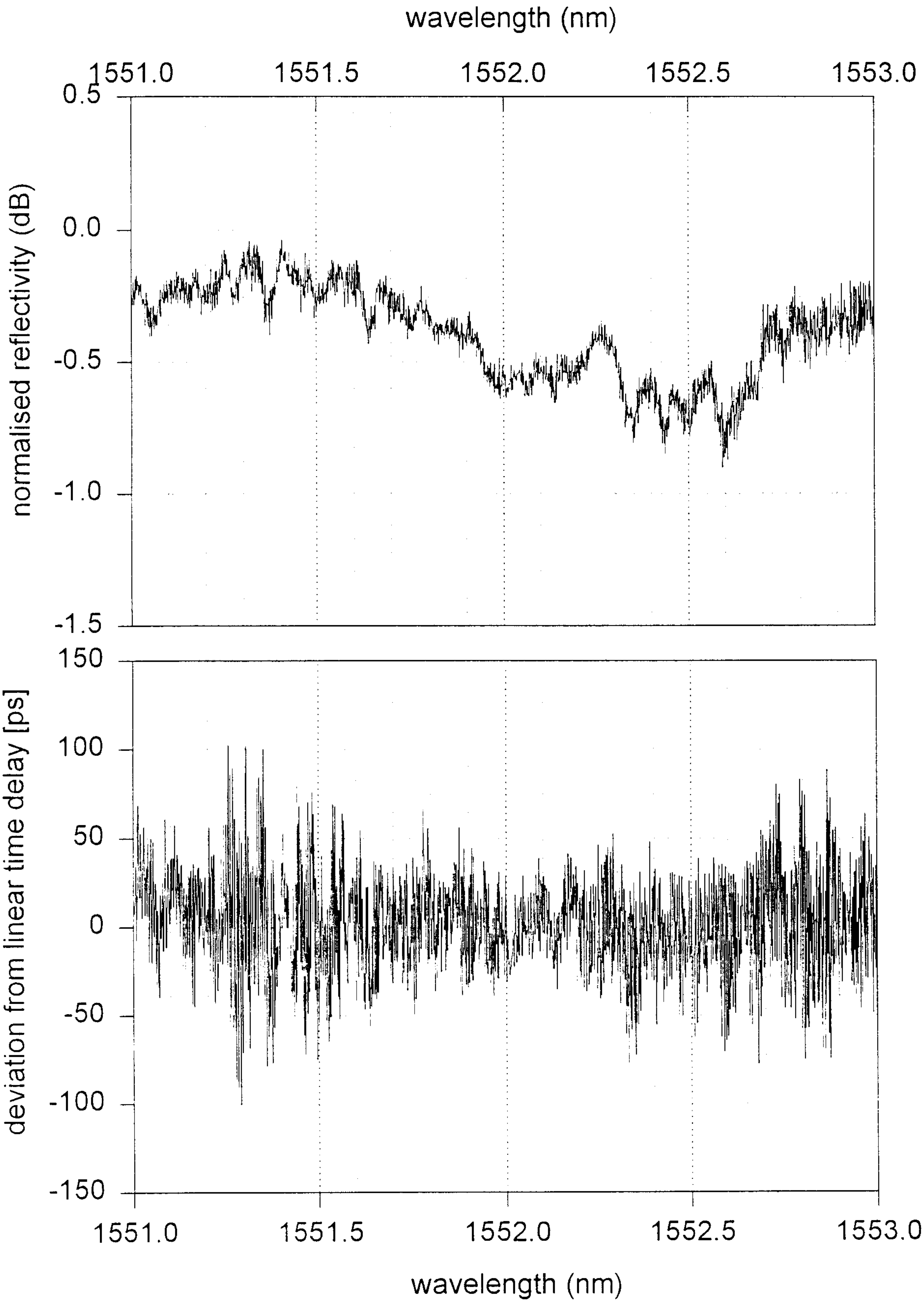


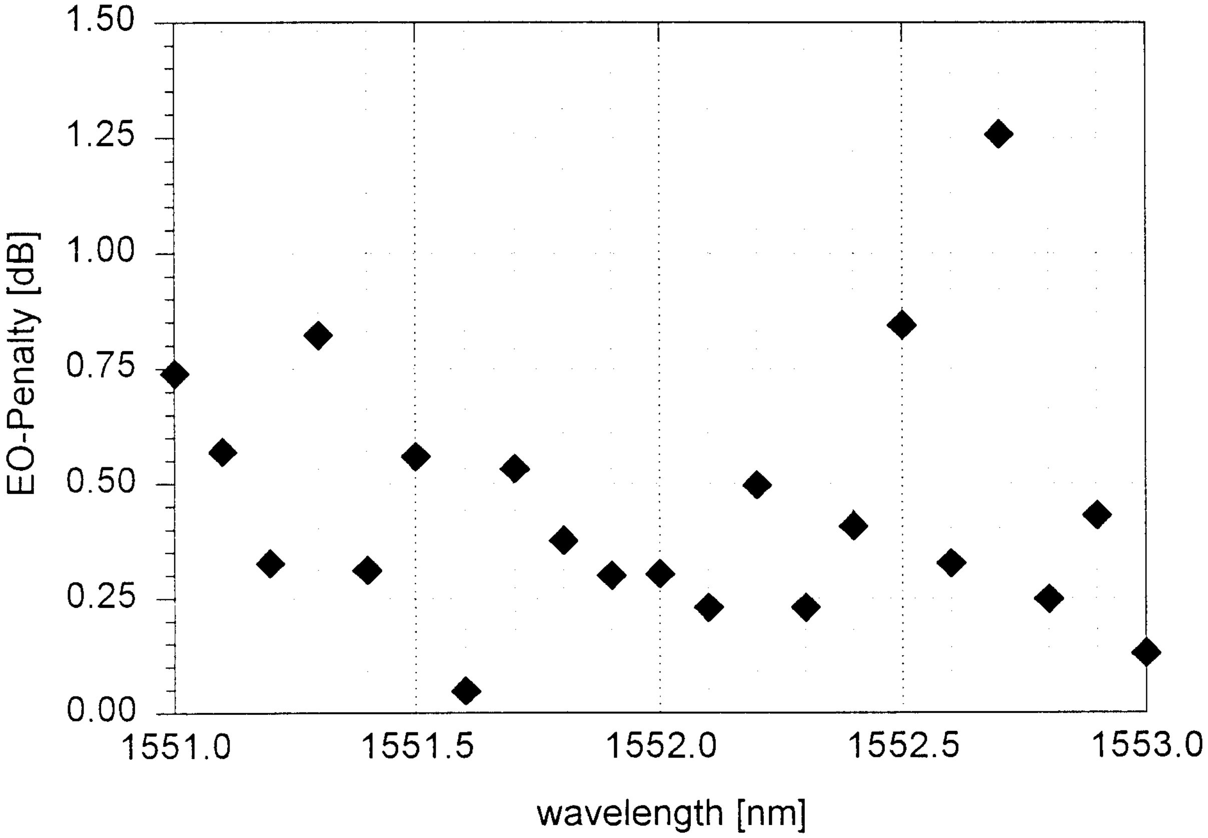
best case
worst case
EO-Penalty [dB]
0.6
0.4
0.2
0.0
0
8
16
24
32
Amplitude of modulation in reflection spectra [%]


EO-Penalty [dB]
Period of modulation in time delay [pm]
0
1
2
3
4
5
0
200
400
600
800
1000
0.0
0.2
0.4
0.6
5
10
15
● best case
■ worst case



1.0
0.8
0.6
0.4
0.2
0.0
-0.2
EO-Penalty [dB]
● best case
■ worst case
0
40
80
120
160
200
240
280
Amplitude of modulation in time delay [ps]


wavelength (nm)
1551.0
1551.5
1552.0
1552.5
1553.0
normalised reflectivity (dB)
0.5
0.0
-0.5
-1.0
-1.5
deviation from linear time delay [ps]
150
100
50
0
-50
-100
-150
1551.0
1551.5
1552.0
1552.5
1553.0
wavelength (nm)



EO-Penalty [dB]
1.50
1.25
1.00
0.75
0.50
0.25
0.00
1551.0
1551.5
1552.0
1552.5
1553.0
wavelength [nm]