NORTEL NETWORKS™

Adaptive Optical Transport

London Communications Symposium 2001

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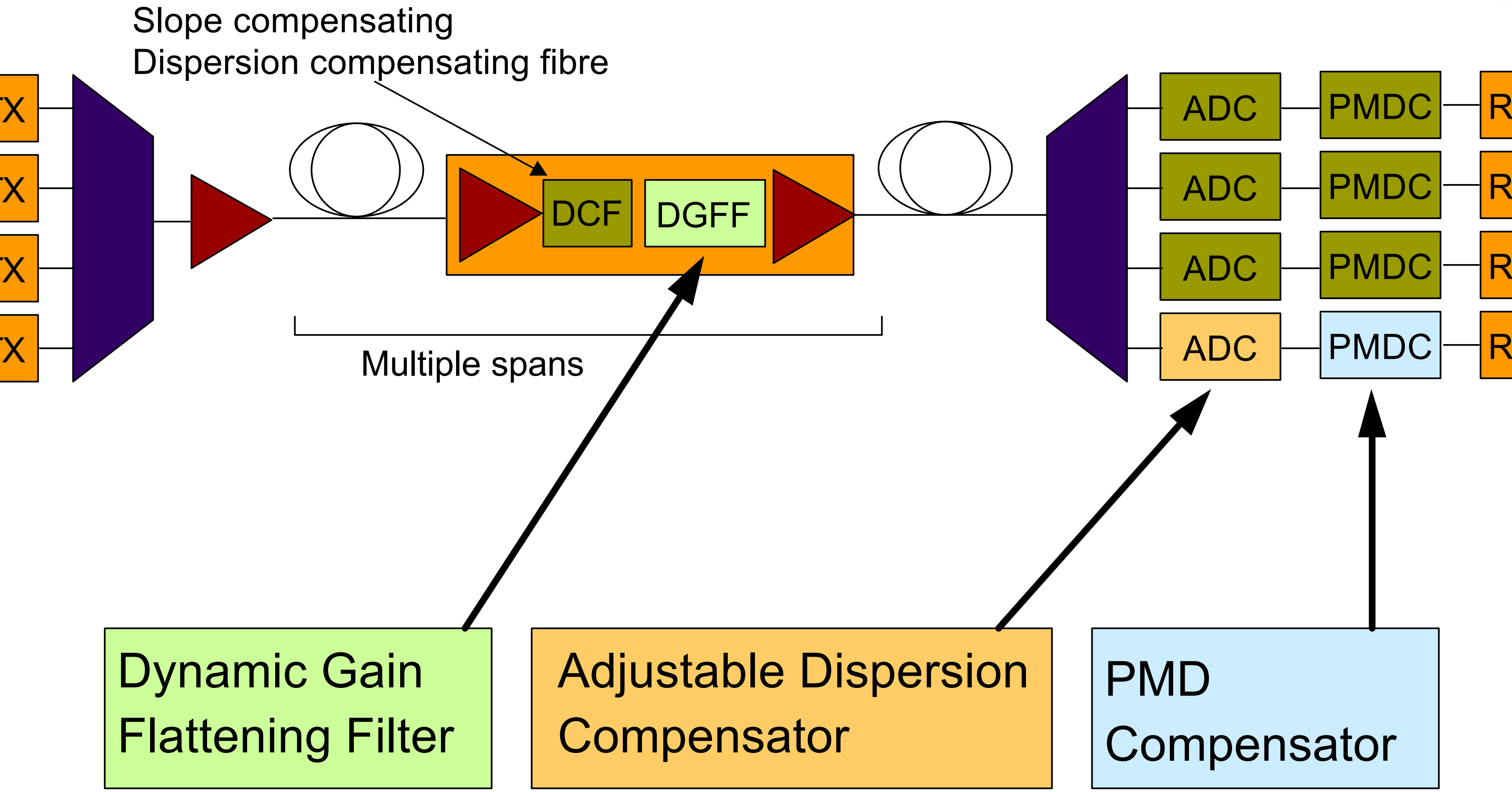
Outline

- **Introduction to adaptive systems**
- **Adaptive Gain Flattening**
- **Adaptive Dispersion Compensation**
  - Adjustable dispersion compensation technologies
  - Control schemes for adaptive compensation
- **Adaptive PMD Compensation**
- **Conclusions**

– **Acknowledgements to Simon Parry (DGFFs) and Dan Watley (PMD Compensation)**

daptive optical transport



Dynamic Gain Flattening Filter

Adjustable Dispersion Compensator

PMD Compensator

hy Dynamic Gain Flattening ?

ixed flattening filters cannot remove:

1. Static errors.

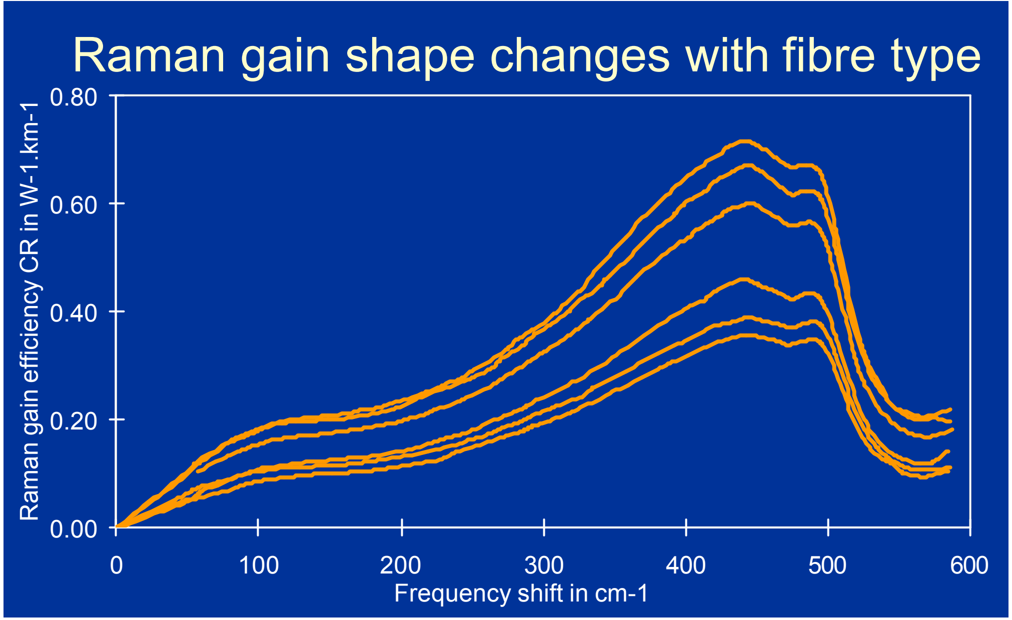
- Component tolerances
- Manufacturing tolerances
- Erbium fibre doping variations
- Raman transmission fibre

2. Dynamic errors

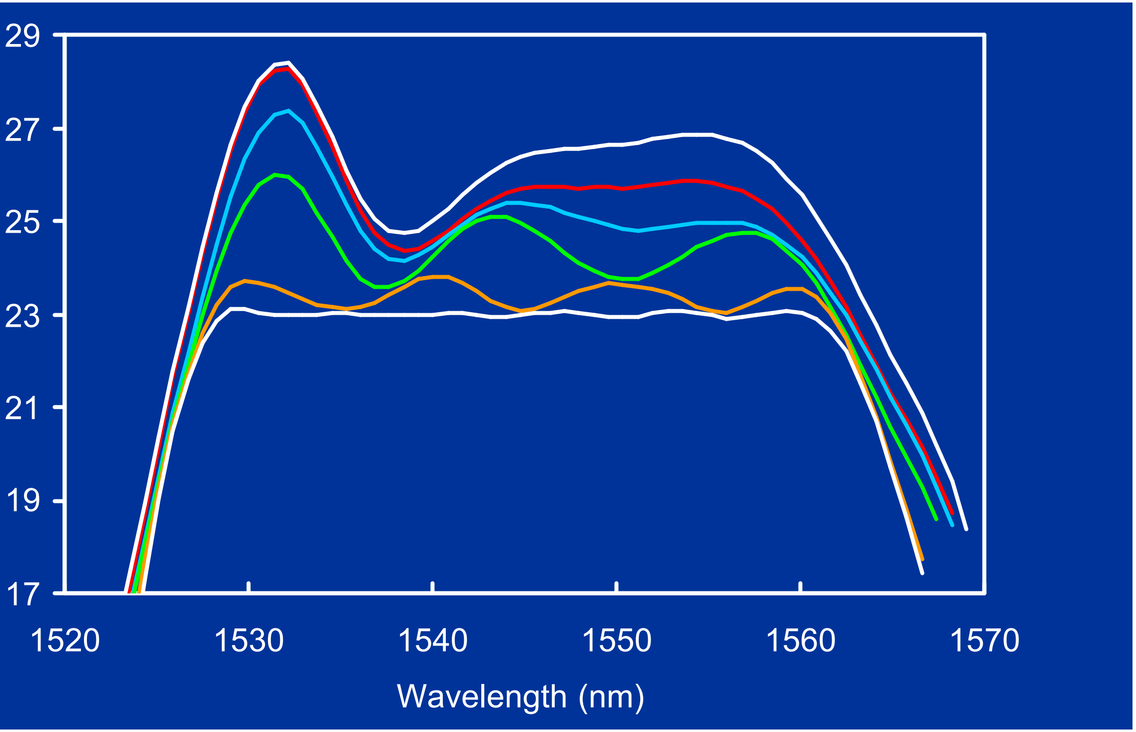
- Gain tilt
- Non-linear effects
- Thermal variations
- Dynamic add/drop

Dynamic range of i/p powers lower

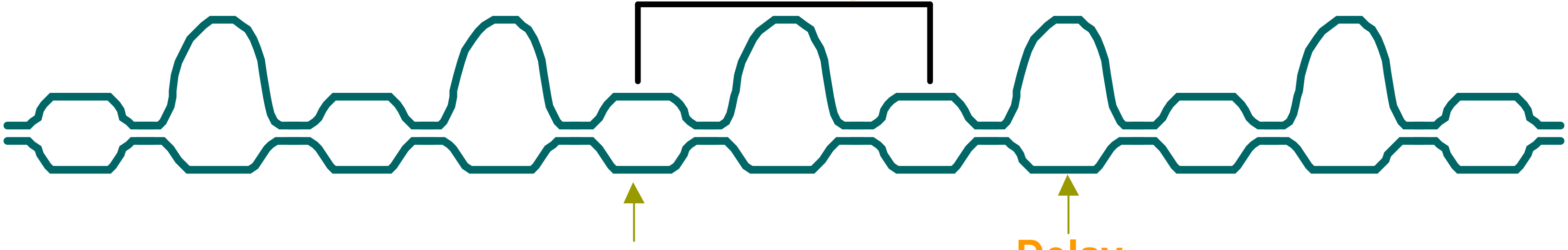
At higher bit rates


Raman gain shape changes with fibre type

GFF Lattice Filter



- 5 stage sinusoidal filter



One stage

Variable coupler

Delay line

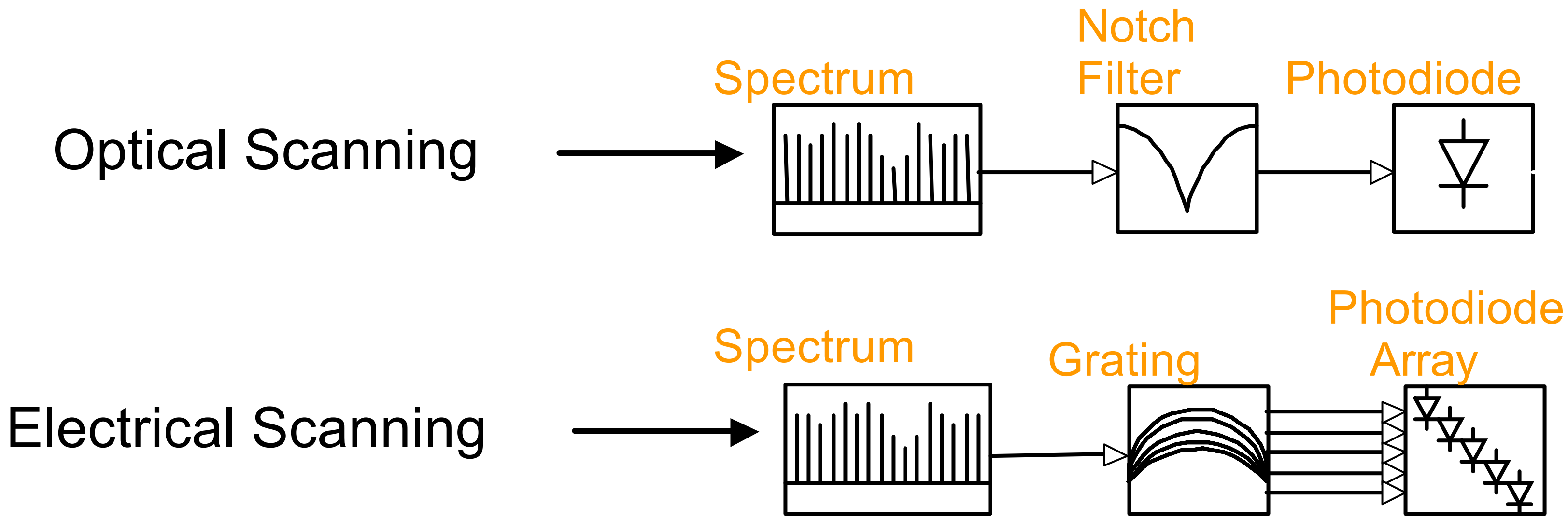
GFF adaptive control

Spectral Feedback

- Optical Spectrum Analysers – Optical SNR
- Optical Channel Monitors – Optical power

Control Algorithm

- Response time limited by spectral feedback
- Accuracy limited by spectral feedback



Optical Scanning

Spectrum

Notch Filter

Photodiode

Electrical Scanning

Spectrum

Grating

Photodiode Array

Why adjustable dispersion?

ncreased margin

- Operate in ‘sweet spot’ of dispersion curve

Track changes in dispersion

- Temperature shift of λ_0, fibre re-patching,

Optical protection switching

- Transmission path, thus dispersion changes

All-optical routing

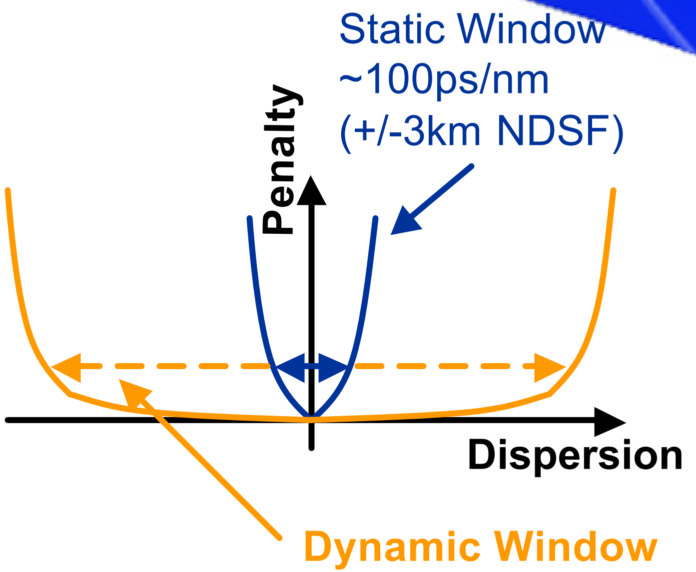
- Different channels have different dispersion

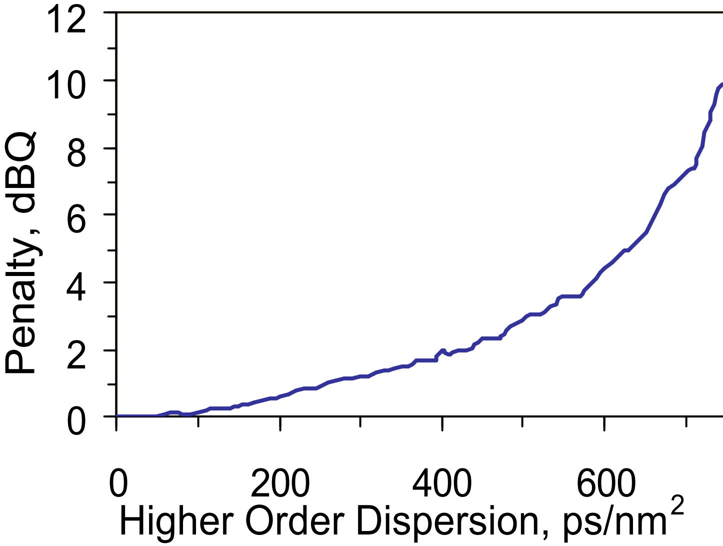
Balance nonlinearity

- Tailor dispersion to match channel power

Static provisioning of system

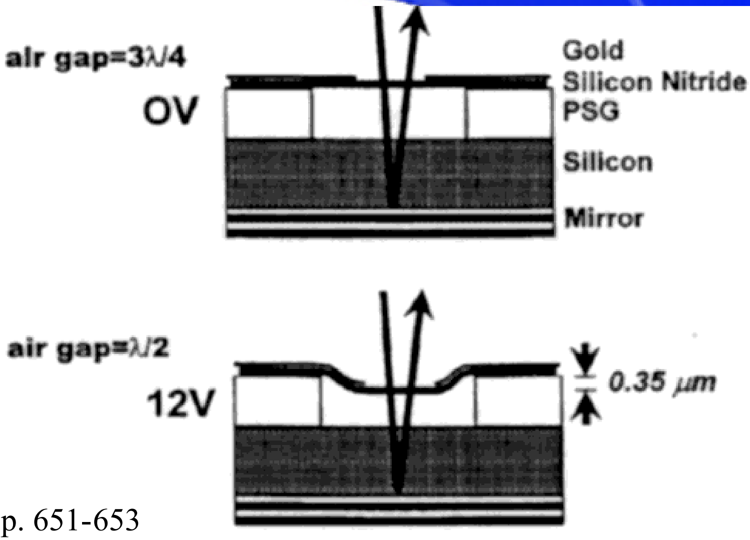
- Residual slope mismatch between DCF and transmission fibre



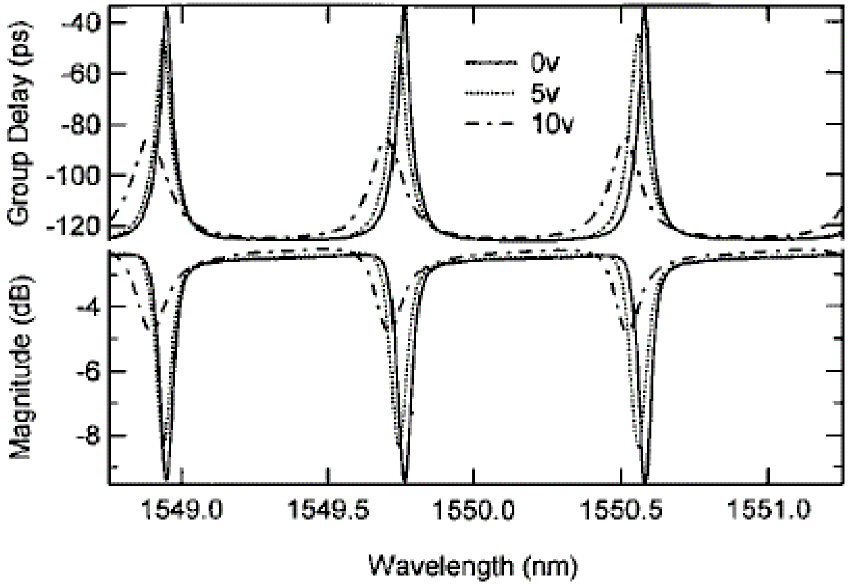


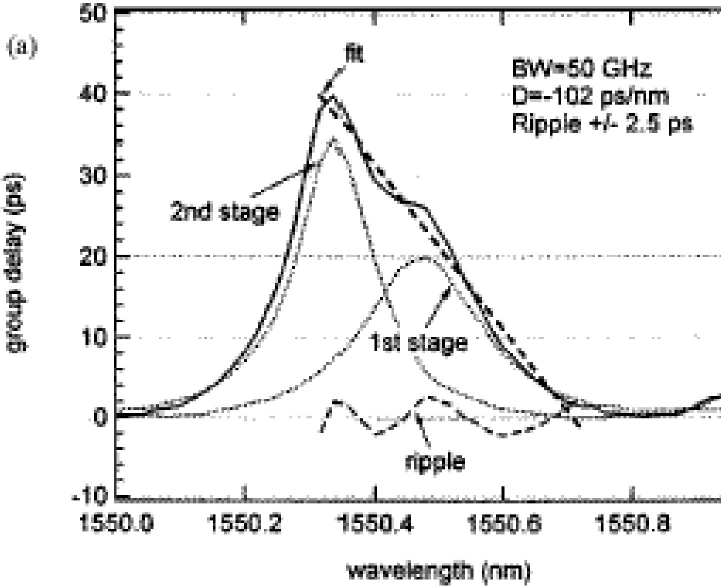
MEMS etalon

- **Asymmetric Fabry-Perot**
- **¼ wave stack on bottom**
- **MEMS variable reflector on top**
  - Actually micro-cavity F-P etalon
- **Vary top reflectivity to change finesse**
  - This alters dispersion



Madsen, C. K., IEEE Photonic Technology Letters, Vol. 12, No. 6, June 2000, pp. 651-653





ing resonator

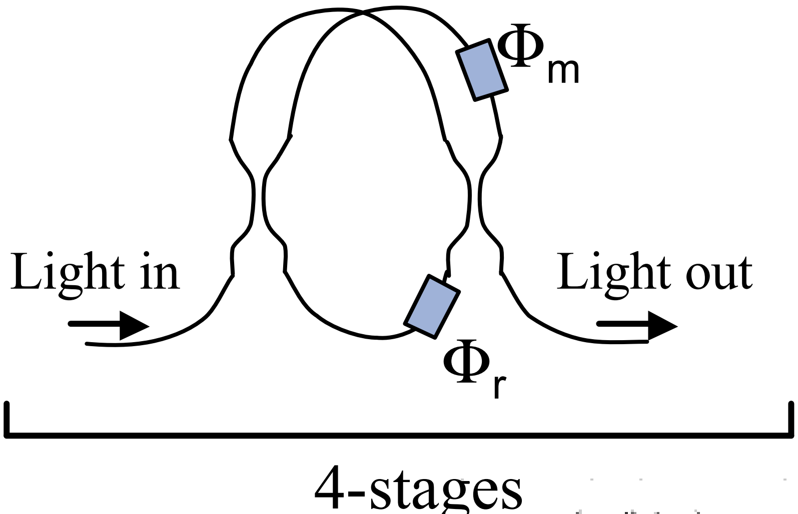
4 stage ring-resonator in silica waveguide

- 3940 ps/nm tuning range, 13.8 GHz bandwidth, periodic response, compact
- 4.4 dB fiber-fiber loss (0.8 dB per facet, 0.7 dB per ring)
- 0.5 dB penalty at 10Gbit/s, 4 channels measured

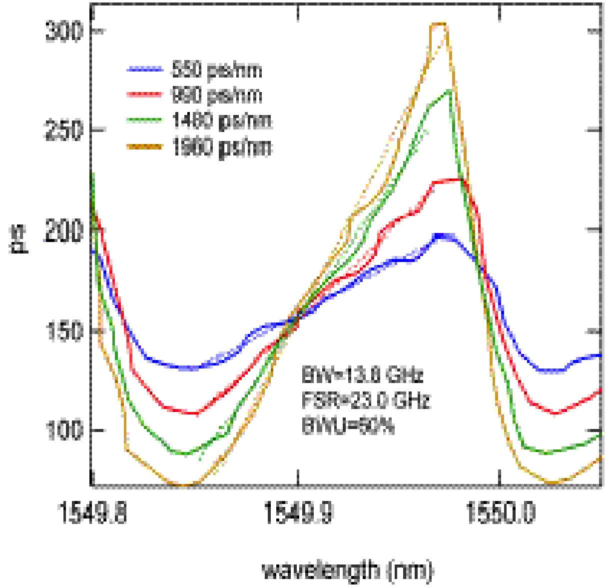
Disadvantages

Madsen, OFC'01 PD9 (Lucent)

- Polarisation dependence
- 8 control elements
- 6 dB loss variation over passband
- FSR limited (index contrast/bend radius)

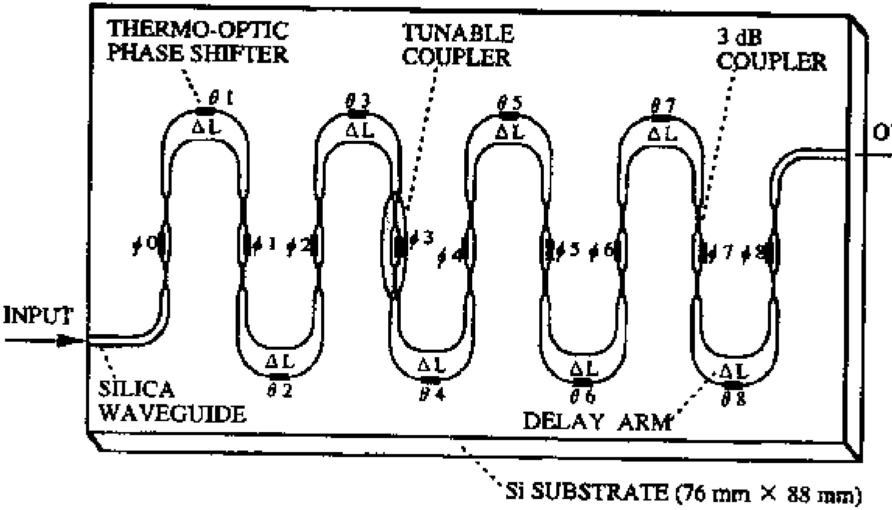


wavelength (nm)



ascaded Mach-Zehnder

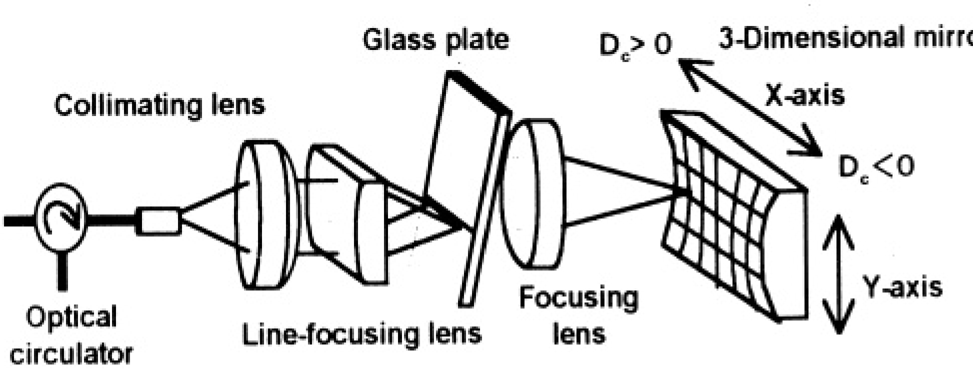
- ntegrated structure incorporating a series of tunable couplers, asymmetric and symmetric MZ interferometers
- Dispersion is induced by the different frequency components travelling through the variable length paths
- Net outcome is a variable dispersion equaliser with a periodic structure in the wavelength domain.
- Tuning range 1500 ps/nm
- Compromises between pass bandwidth and tuning range
- Quite a complex device to control

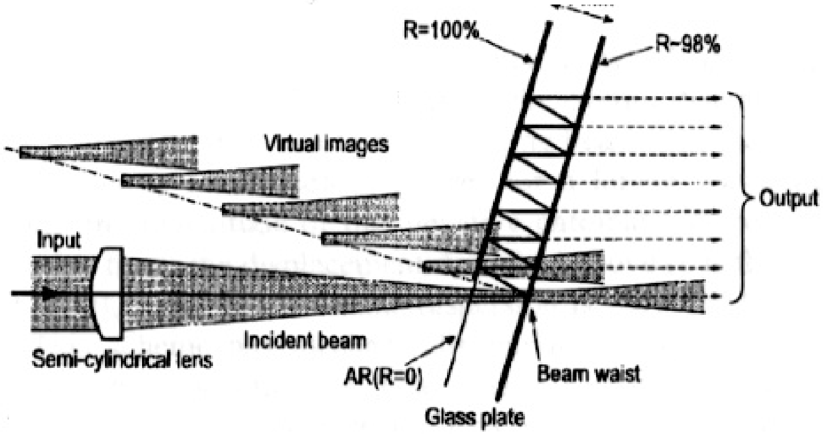


Takiguchi, K., IEEE J. Selected Topics in Quantum Electronics, Vol. 2, No. 2, June 1996, pp. 270-276

irtually imaged phased array /IPA)

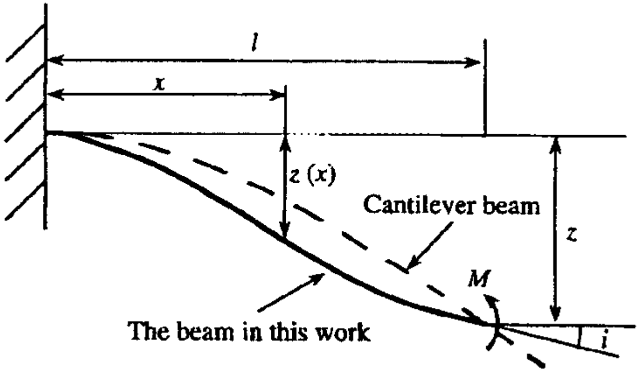
- Vavelength determines point at vhich the i/p light passes through lass plate
- istance travelled by a spectral omponent determined by no of eflections within plate
- nduced chromatic dispersion aried by changing the angle of ne plate
- eriodic response





Shiraski, M., IEEE Photonics Technology Letters, Vol. 9, No. 12, December 1997, pp. 1598 - 1600

onlinearly strained FBG



(a)

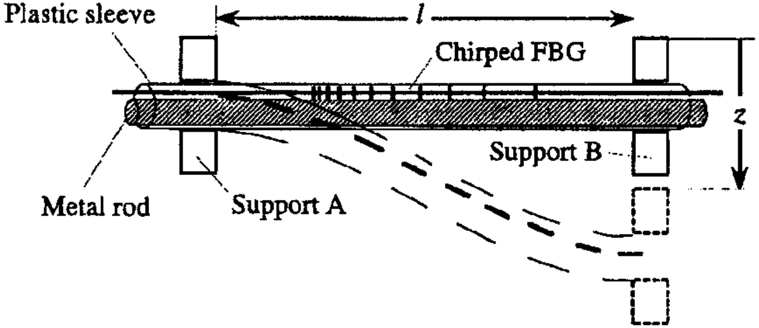
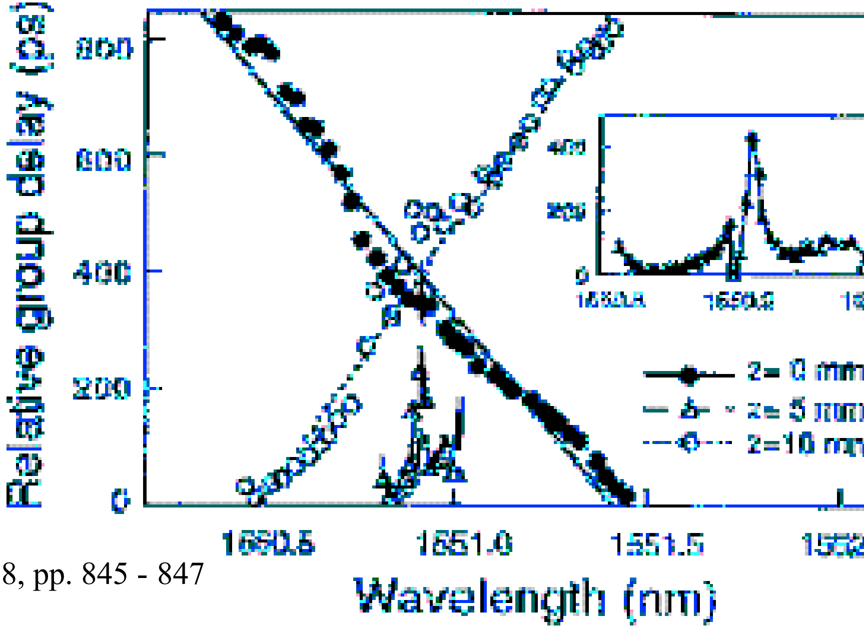


Fig.
grad

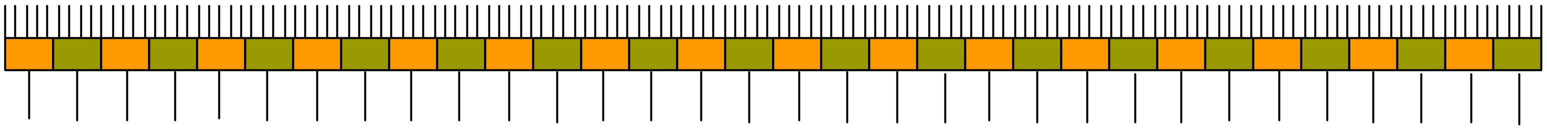
- onlinear strain changes dispersion
- ouble bend avoids wavelength shift
- ifficult to keep fibre bonded to antilever



Imai, T., IEEE Photonic Technology Letters, Vol. 10, No. 6, June 1998, pp. 845 - 847

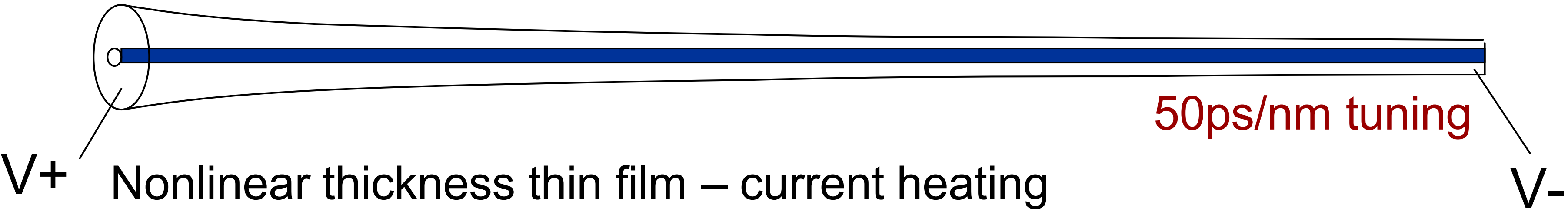
emperature gradient tuned FBG

Matsumoto, OFC'01 TuS4 (Mitsubishi)



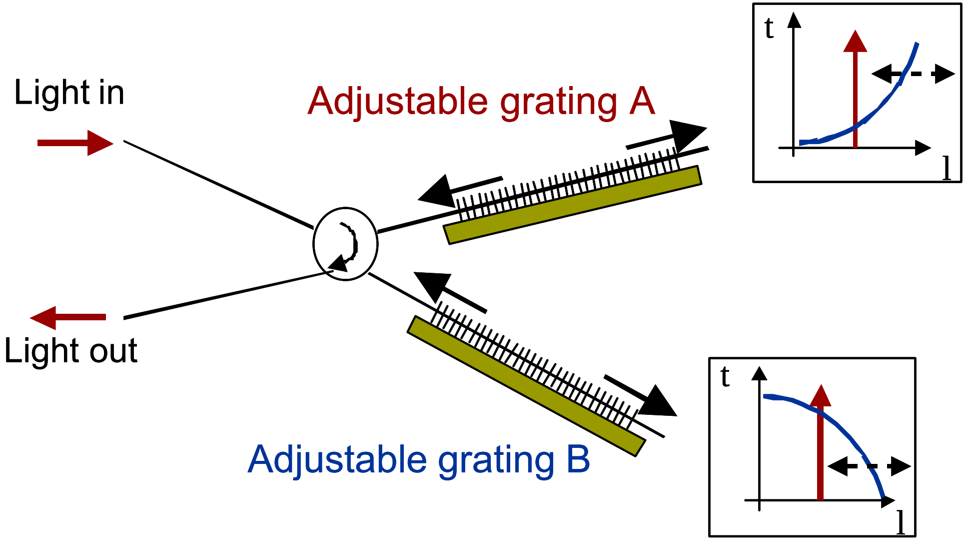
32 individual heaters – arbitrary chirp profile, inc. disp. slope
6 element Peltier across whole device to avoid wavelength shift
108 ps/nm tuning range, ~1 nm bandwidth, 3 W power
4 dB loss variation over passband, 50 ps delay ripple

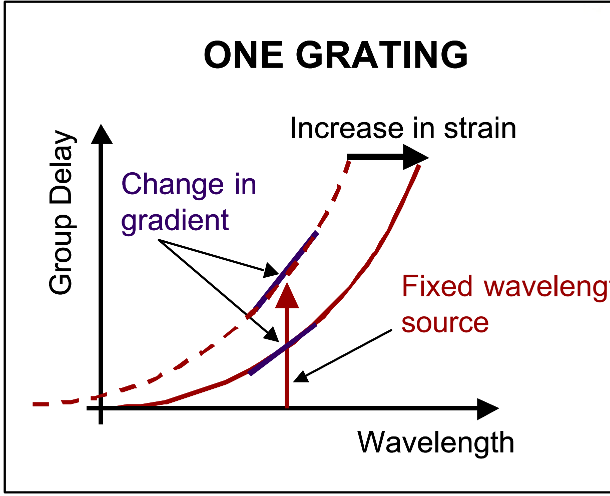
Eggleton, (PTL-12, p. 1022, 2000)

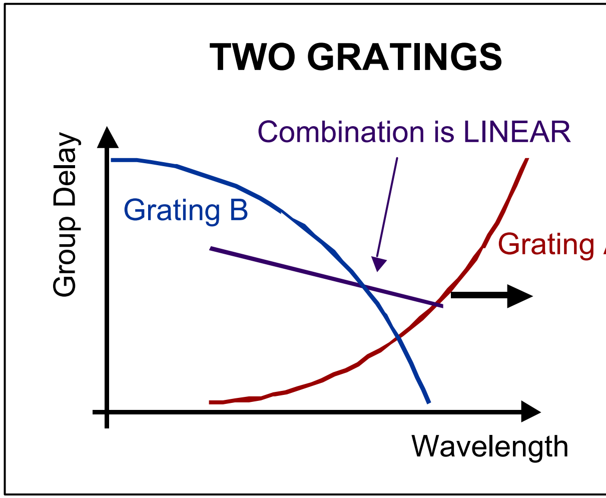


Nonlinear thickness thin film – current heating
Proposed thermally isolated DC heater to avoid wavelength shift
Rogers, Opt. Lett, 24(19), p. 1328, 1999. Not yet demonstrated

win Fibre Grating Compensator





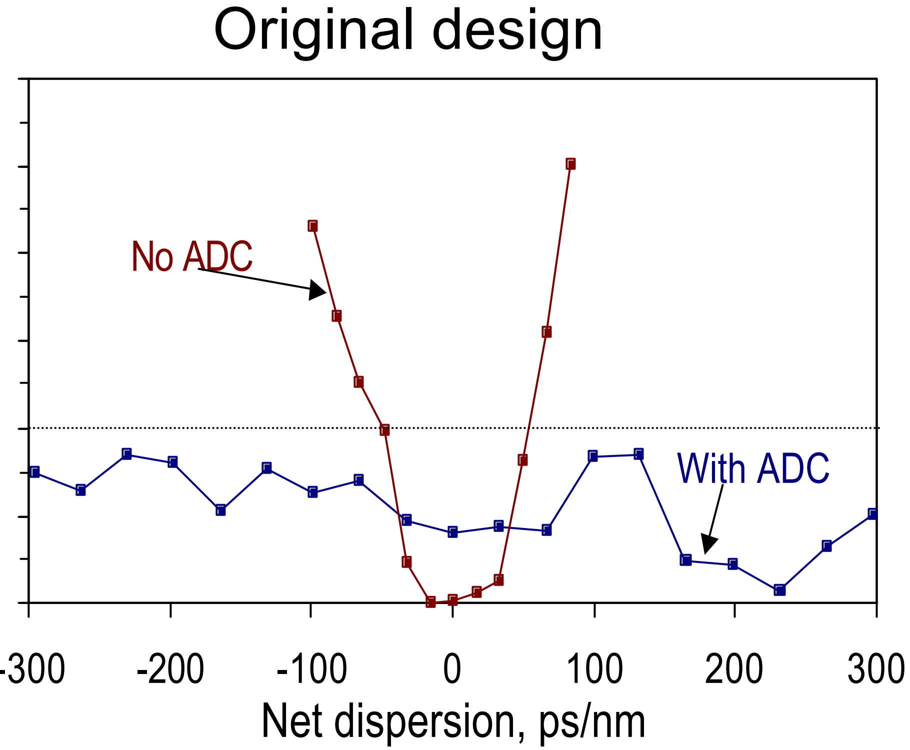


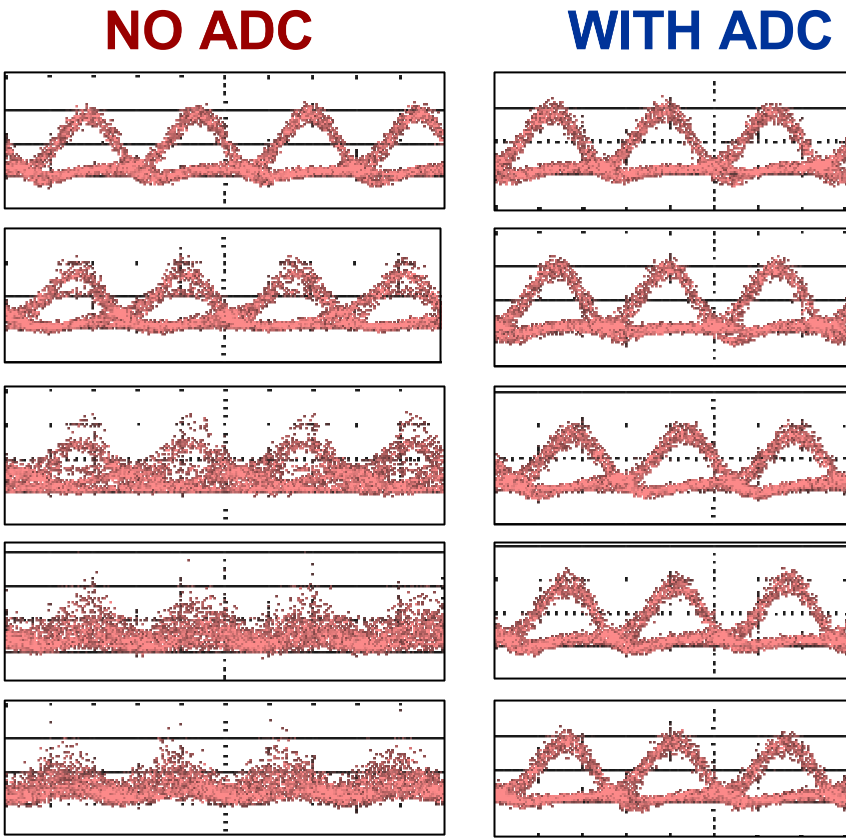
Operated by increasing the strain in grating A whilst reducing the strain in grating B, and vice versa

Simple linear strain tuning mechanism

Fells, J. A. J., Proc. ECOC 2000, September 2000, PD 2.4

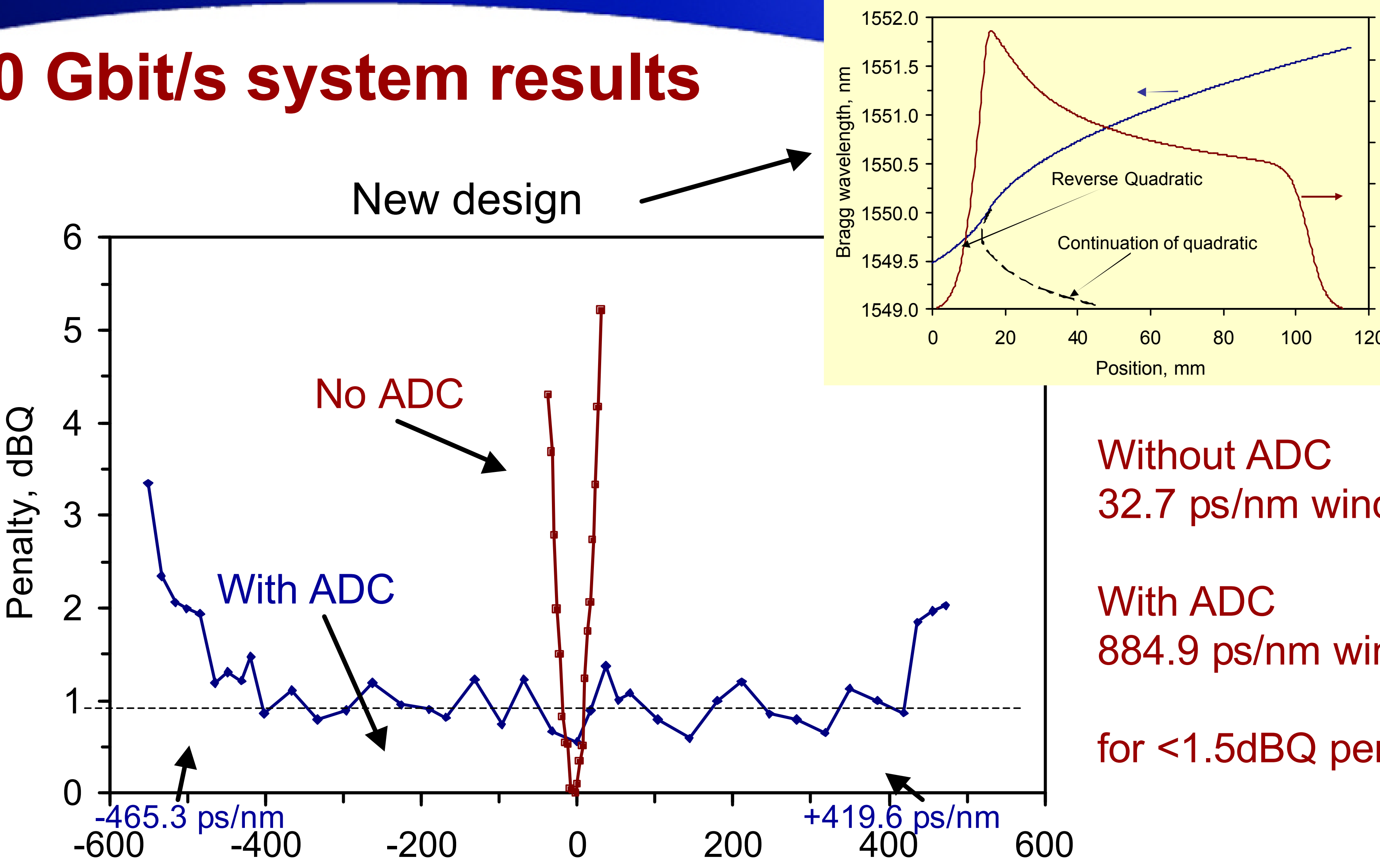
leasured results of twin FBG
ystem measurements at 40GBit/s





Fells, J. A. J., Proc. ECOC 2000, September 2000, PD 2.4

0 Gbit/s system results



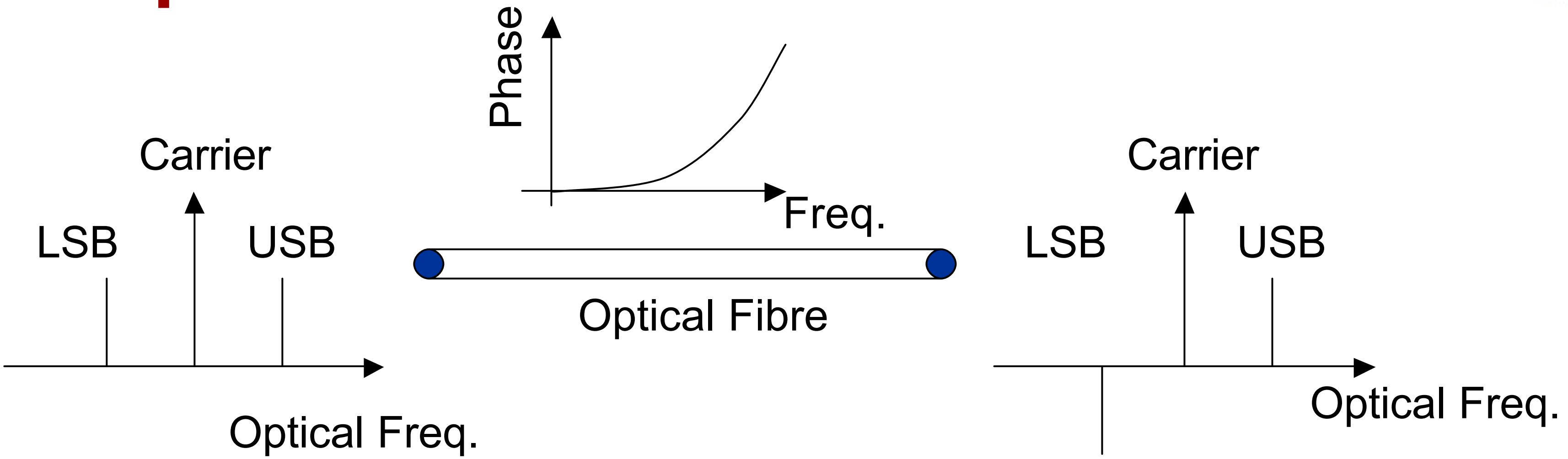
Without ADC
32.7 ps/nm win

With ADC
884.9 ps/nm wi

for <1.5dBQ pe

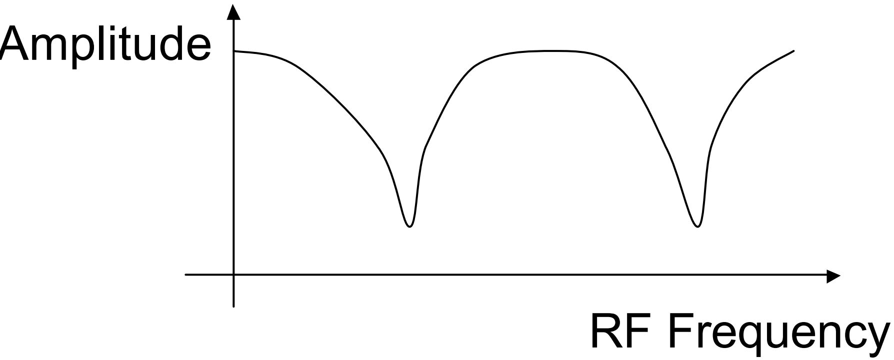
J.A.J. Fells et al. OFC'2001 Postdeadline

ignal fading CD detection echniques

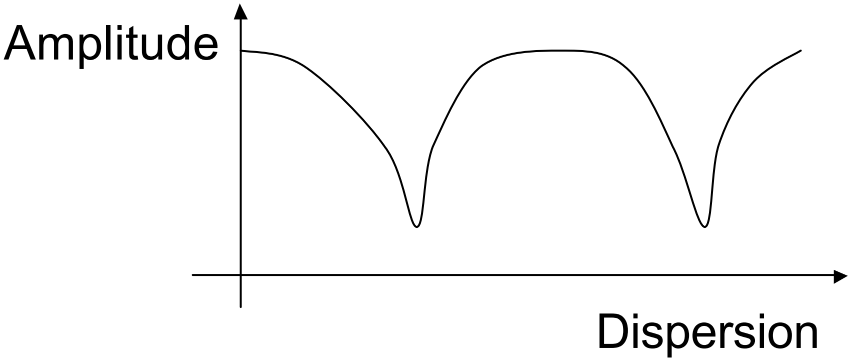


Pure sinusiodal tone

Tone is nulled



Fixed Disperison



Fixed Frequency

Adaptive dispersion control

Petersen, OFC’01 WH4 (USC-LA)

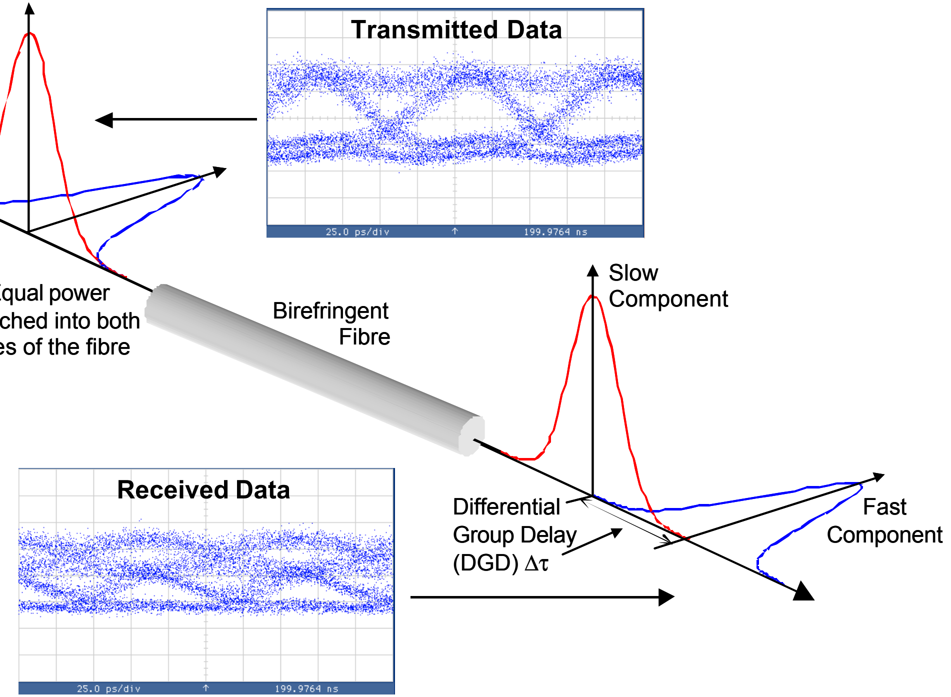
- **Add AM tone at 8 GHz to 10 Gbit/s tx signal**
  - 15 % modulation depth, 0.5 dB power penalty as a result
  - Monitor fading of AM tone, 975 ps/nm capture range
  - Manual adaptive compensation using nonlinearly chirped FBG

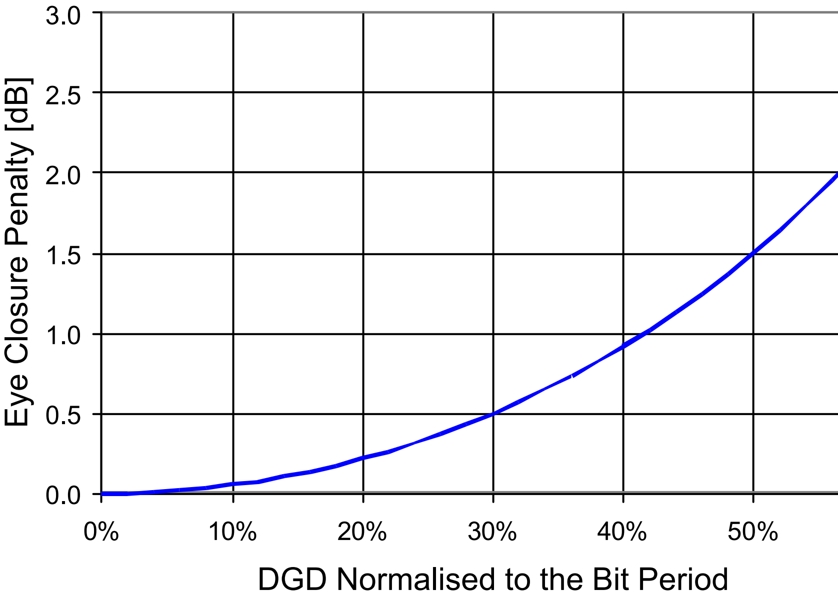
Pan, OFC’01 WH5 (USC-LA)

- **Monitor clock fading in 10 Gbit/s RZ system**
  - ±600 ps/nm capture range at 10 Gbit/s
- **Monitor clock regeneration in 10 Gbit/s RZ system**
  - ±640 ps/nm capture range at 10 Gbit/s
- **Only ±60 ps/nm at 40 Gbit/s for both schemes**

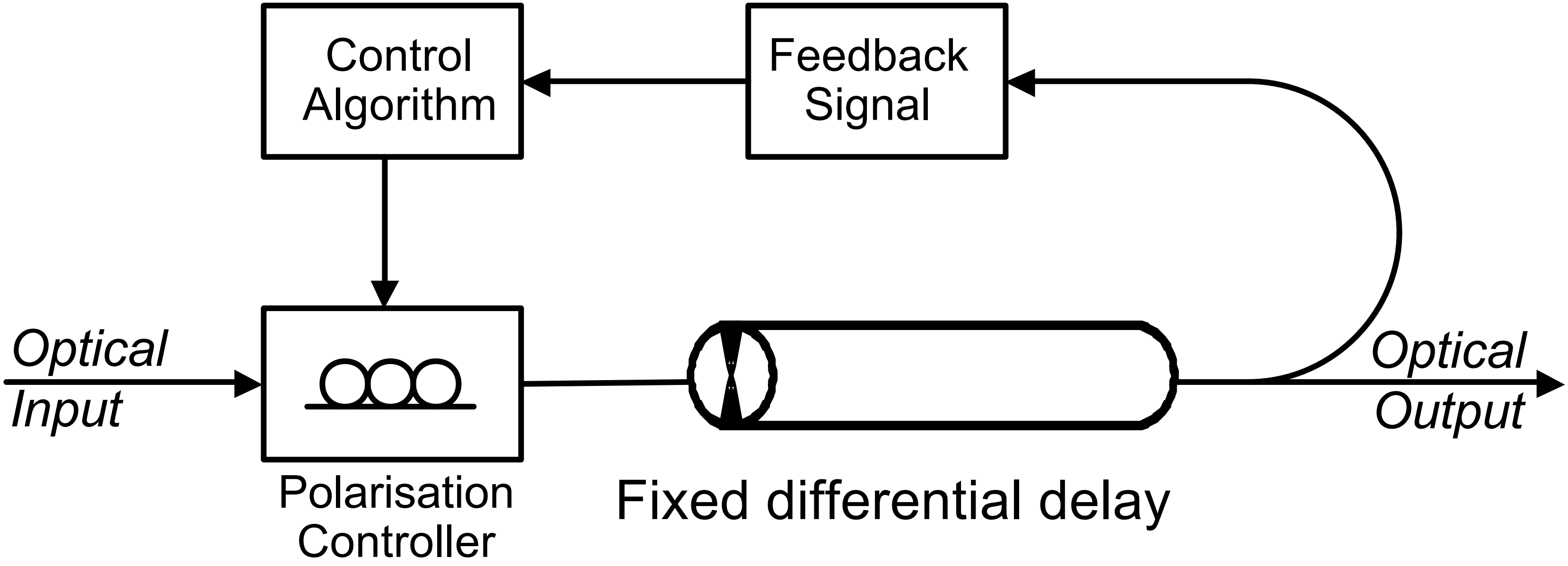
hy Adaptive PMD compensation?

- mpact of PMD increases linearly with bit-rate
- nstantaneous DGD of the system for a particular channel wi randomly vary so an adaptive compensation is required





daptive PMD compensator



Control Algorithm

Feedback Signal

Optical Input

Polarisation Controller

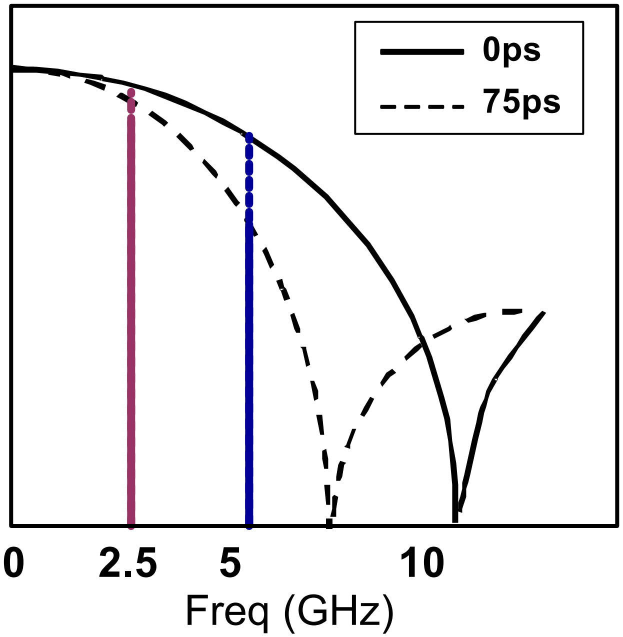
Fixed differential delay

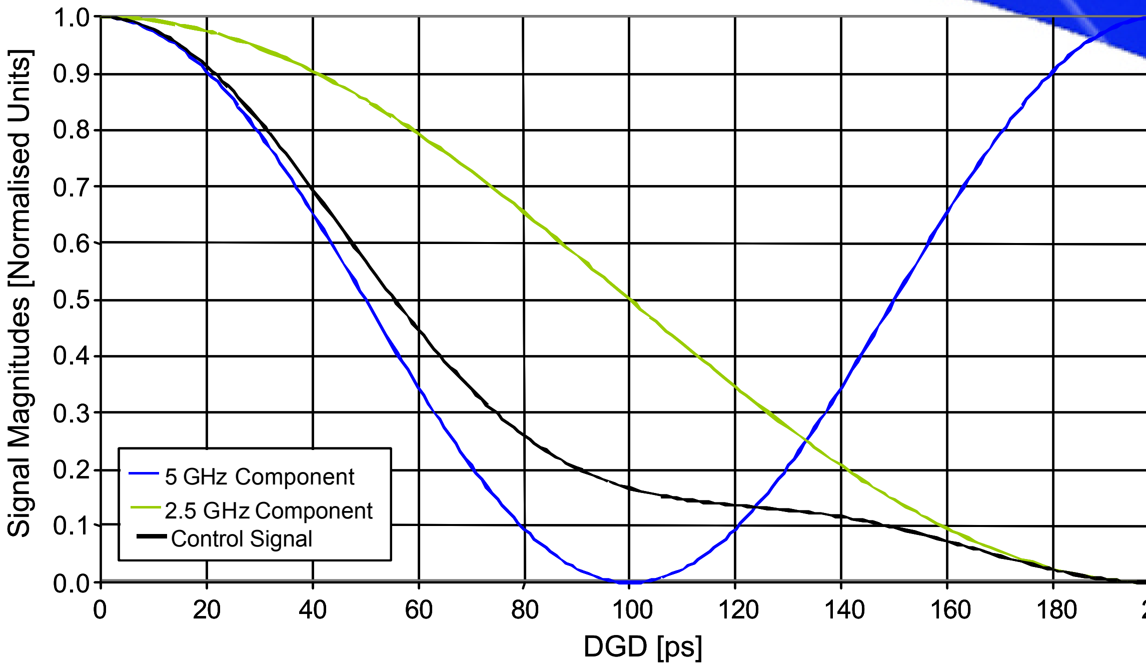
Optical Output

- Also possible to use variable DGD element

ontrol signals for 10GBit/s NRZ

Baseband electrical spectrum





Power spectral density ➡ **Eye opening**

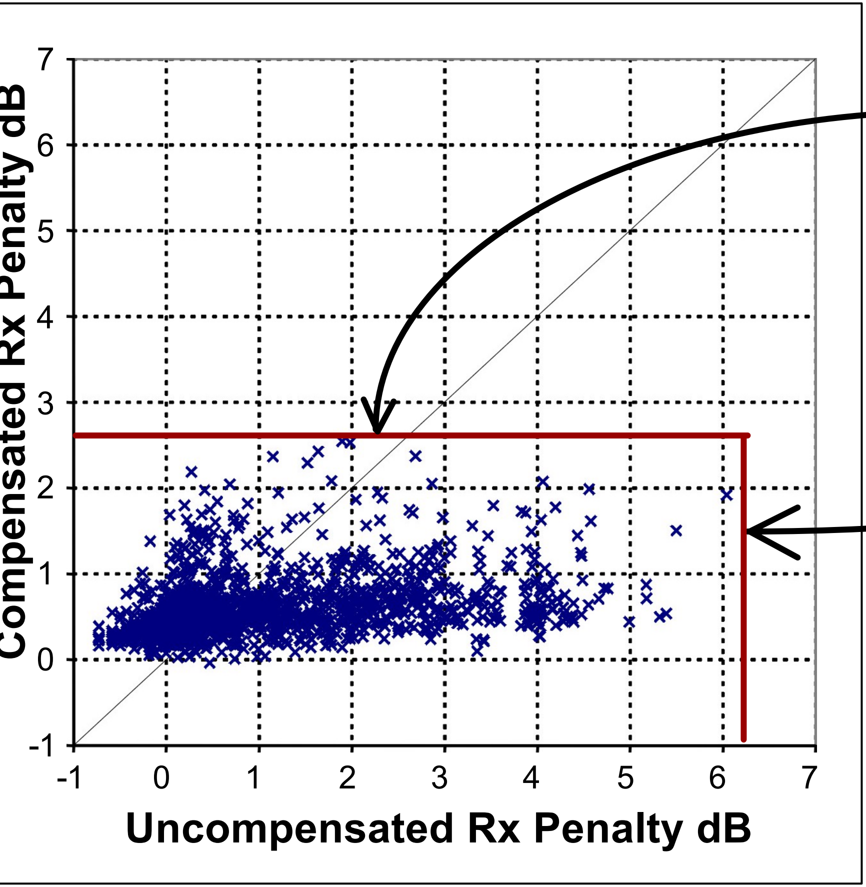
- **5 GHz very sensitive**
- **2.5 GHz unambiguous up to 200 ps**

} ***Use combination***

Similar approach can be used for any bit-rate

leasured results

Includes all orders of PMD, typical of real installed fibre with a mean PMD of 36ps



Compensated System Bounded below 2.5 dB Rx Penalty

Uncompensated System Exceeds 6dB Rx Penalty

- **125 hours of continuous tracking demonstrates the clear benefit of the PMD compensator**

Watley, D. A., Proc. OFC 2000, March 2000, Paper ThB6, pp. 37-39

onclusions

- **Dynamic gain flattening**
  - Necessary to equalise channel powers
  - Sinusoidal lattice filter implementation
- **Adjustable dispersion compensation technologies**
  - Interferometer devices: Etalon, Ring Resonator, Cascaded MZ
  - VIPA: Virtually imaged phase array
  - FBG devices: nonlinear strain, nonlinear chirp, temp. gradient
- **Adaptive dispersion control schemes**
  - Clock fading/regen detection method
- **Adaptive PMD compensation**
  - Fixed delay architecture shown
  - RF spectral analysis control scheme
  - Field measurements show >3.5dB penalty reduction