
# 40Gbps Modulation Schemes Comparison

**TECHNICAL DOCUMENT 3000070-00/REV3.0**

**FEATURES AND SPECIFICATIONS ARE PRELIMINARY AND SUBJECT TO CHANGE WITHOUT NOTICE**

## INTRODUCTION

As optical transport networks migrate from 2.5Gbps and 10Gbps to 40Gbps line rates, the selection of a suitable 40Gbps modulation format is an important consideration. Service providers will only consider large-scale deployment of 40Gbps technology if their performance and cost requirements are satisfied. In general, the 40Gbps transponders should be priced below 4 times existing 10Gbps equivalents, while the 40Gbps wavelength deployment rules should match the existing 10Gbps link engineering rules as close as possible. This application note considers the advantages and limitations of 3 potential 40Gbps modulation formats —Phase-Shaped Binary Transmission (PSBT), Carrier-Suppressed Return-to-Zero (CS-RZ) and Differential Phase Shift Keying (DPSK), and compares how they measure up against key service provider requirements.

## 40GBPS MODULATION SCHEMES DESCRIPTION AND COST STRUCTURE

The following paragraphs describe the high level block diagrams for each modulation format. This is useful to compare the implementation complexity, which directly translates into cost.

### 1.1 Phase-Shaped Binary Transmission (PSBT)

The PSBT block diagram is shown in Figure 1. This design only requires a single modulator/driver and a single direct-detection photodetector. As 40Gbps PSBT has a high intrinsic tolerance to Chromatic Dispersion (CD), an integrated Tunable Dispersion Compensator (TDC) is not required. The critical enabling components for PSBT are the precoder and encoder, which are implemented in the electronic domain and hence are low-cost. PSBT has the lowest cost structure of the 3 modulation formats considered.

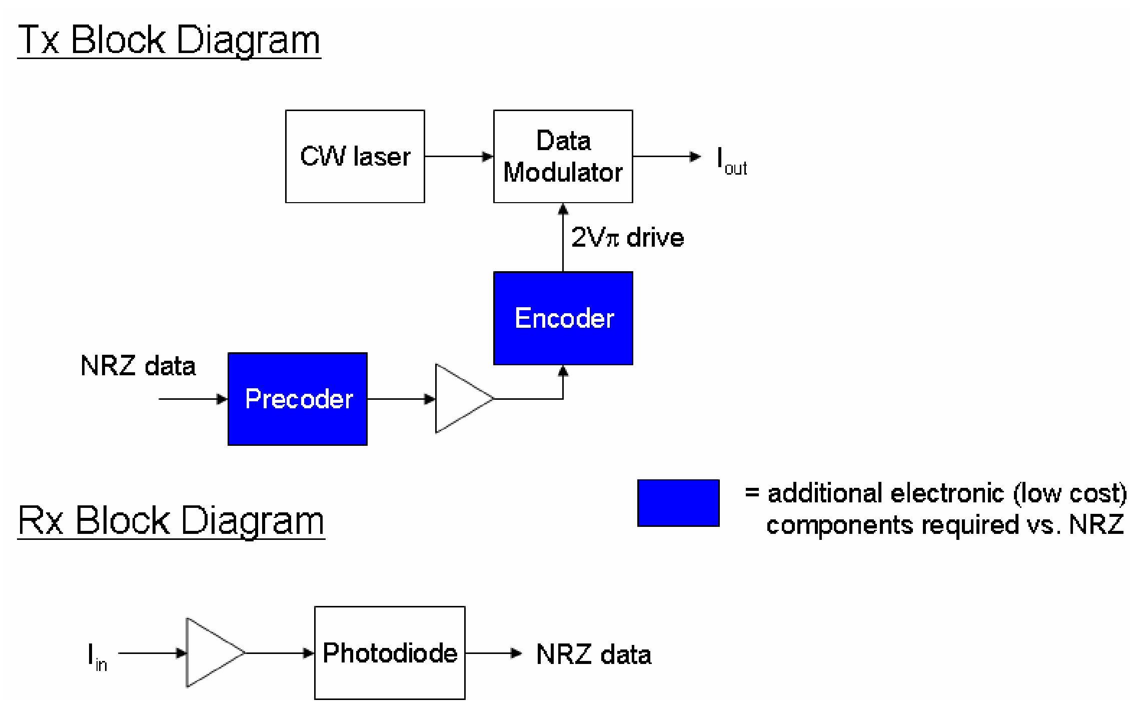


**Figure 1.** PSBT Implementation

### 1.2 Carrier-Suppressed Return-to-Zero (CS-RZ)

The block diagram for CS-RZ is shown in Figure 2. At the transmitter, CS-RZ requires two modulators and two driver amplifiers. The increased insertion loss of the two cascaded modulators (typically $LiNbO_3$ with around 8dB insertion loss each) requires an additional EDFA to provide adequate transmit output power. At the receiver, an integrated TDC is always required due to the poor chromatic dispersion tolerance of CS-RZ. The higher complexity of CS-RZ increases the cost by around 30%, compared to PSBT.

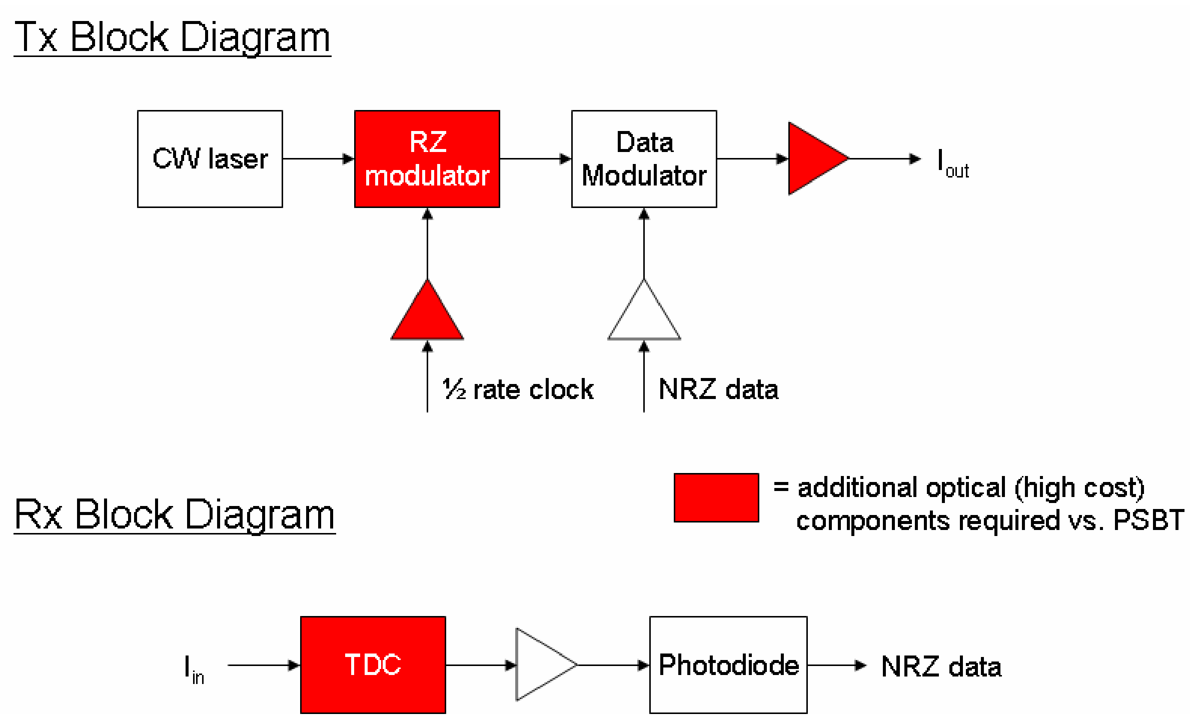


**Figure 2.** CS-RZ Implementation

### 1.3 Differential Phase Shift Keying (DPSK)

The DPSK block diagram is shown in Figure 3. The DPSK transmitter (NRZ type) is very similar to a PSBT transmitter. The precoder is identical and the modulator driver has the same drive level, bandwidth requirement and biasing. The only difference in the transmitter is that the PSBT encoder is removed. At the receiver, DPSK is more complex as a delay-and-add Mach-Zehnder Interferometer (MZI) is required to decode the DPSK signal, followed by a balanced photodetector. DPSK has a similar chromatic dispersion tolerance to CS-RZ, so an integrated TDC is also always required at the receiver.

The incremental complexity of the DPSK receiver adds around 20% to the total line card cost, as compared to PSBT. Note that DPSK (NRZ-type) is still a lower cost solution than CS-RZ. RZ-DPSK was not considered as it has a significantly higher cost structure but only a marginal performance improvement vs. (NRZ)-DPSK.

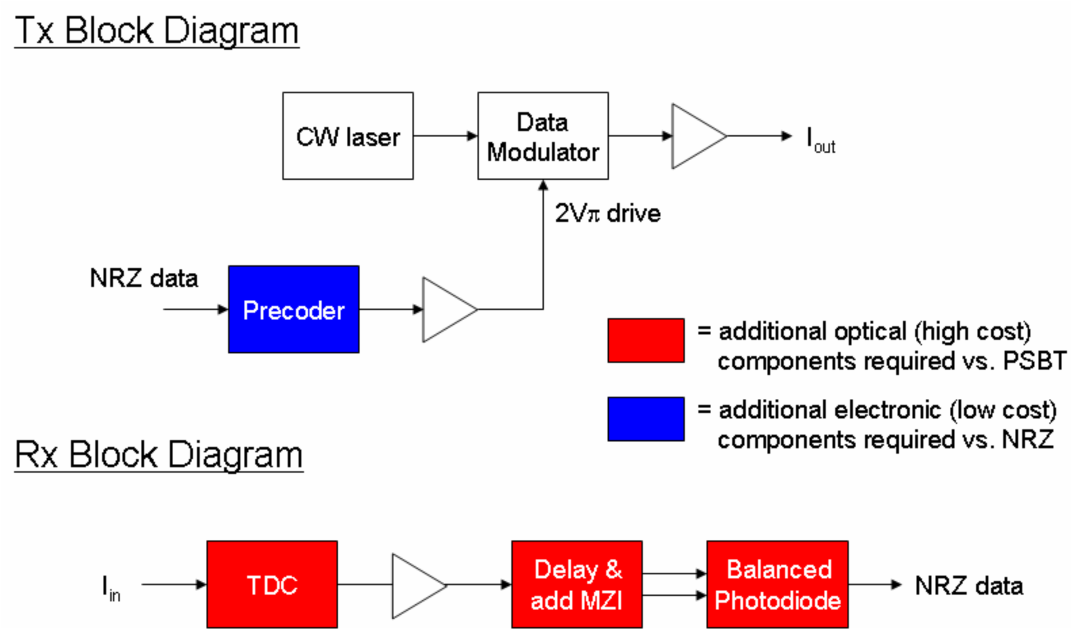


**Figure 3.** DPSK Implementation

## Optical Performance Comparison

### 1.4 Reach

As most service providers plan to introduce 40Gbps wavelengths in their networks alongside 10Gbps wavelengths on existing links, reach has become a critical design target for 40Gbps systems. This is challenging considering that increasing the bit rate by 4 conventionally means the noise bandwidth of the receiver is 6dB greater, implying a 6dB increase in OSNR is required to match the 10Gbps bit error rate (BER). The use of enhanced FEC (EFEC) is clearly a "must-have" requirement for 40Gbps, but even with EFEC it is a challenge to design 40Gbps with a reach beyond 1000km.

RZ modulation typically improves the OSNR sensitivity by around 1dB, depending on the electrical bandwidth of the receiver. RZ can also permit the launch of higher power as the Self Phase Modulation (SPM) threshold is higher than for NRZ formats.

40Gbps CS-RZ should have an OSNR sensitivity of around 16dB/0.1nm. PSBT, on the other hand, suffers from reduced eye opening versus NRZ, which decreases the OSNR sensitivity to around 20dB/0.1nm. An important consideration for PSBT is that narrowband optical filtering (e.g., due to cascaded ROADMs or 50GHz DWDM channel filters) improves the OSNR sensitivity to 17dB/0.1nm

[1]. The measured OSNR improvement for Bandwidth-Limited PSBT (BL-PSBT) using 50GHz interleavers is shown in Figure 4.

The main advantage of using DPSK is that OSNR sensitivity improves by 3dB [2,3] to 13dB/0.1nm. DPSK is also more robust to higher launch powers as the phase, rather than intensity, is modulated. The constant envelope modulation minimizes SPM and Cross Phase Modulation (XPM) distortions.

The increased reach capability of DPSK makes this modulation format a good candidate for ULH and submarine applications.

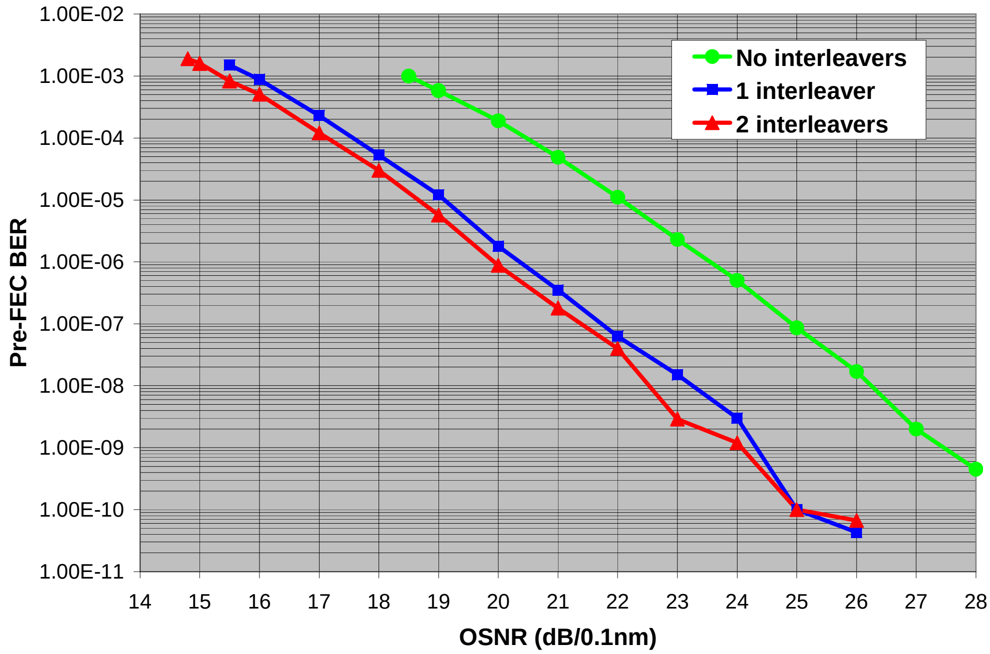


**Figure 4.** Measured BL-PSBT OSNR Performance Improvement (44GHz FWHM blue; 40GHz FWHM red)

### 1.5 Spectral Efficiency

Most 40Gbps modulation schemes will not operate at 50GHz channel spacing due to the spectral width of the signal. As many 10Gbps systems have been deployed, or designed, to work at 50GHz channel spacing, this can impact the choice for 40Gbps. PSBT has a narrow spectral width (approx. 22GHz FWHM) and supports 0.8bits/s/Hz spectral efficiency, thus supporting 40Gbps transmission on the ITU standard grid with 50GHz channel spacing. DPSK has wider spectral width than PSBT but can be designed for operation on 50GHz channel spacing by using transform-limited NRZ-DPSK modulation and de-tuning of the DPSK decoder in the receiver [4].

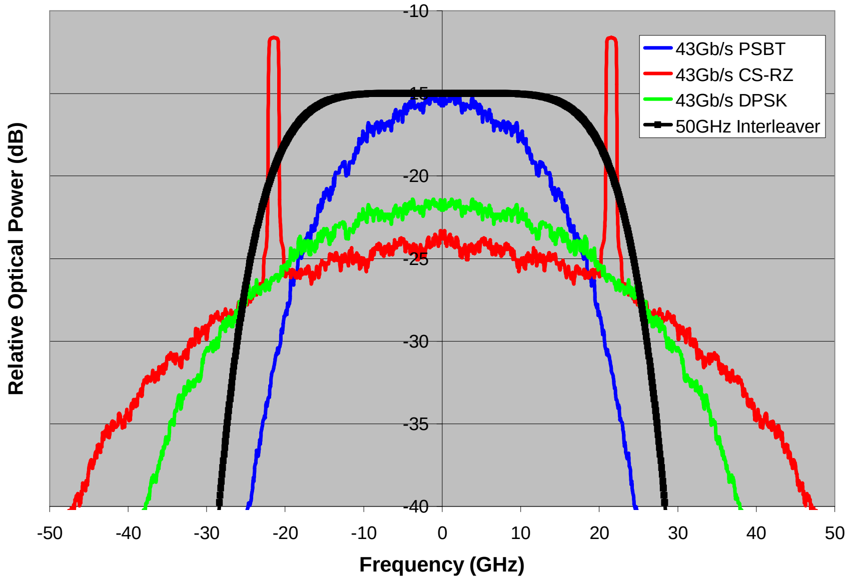


**Figure 5.** DWDM Filter Compatibility

Due to its wide spectrum, CS-RZ cannot operate at 50GHz channel spacing. Figure 5 compares 43Gbps PSBT, 43Gbps CS-RZ, 43Gbps DPSK and a typical 50GHz interleaver passband profile. The 40Gbps CS-RZ signal energy that falls outside the filter causes distortion on the signal channel and induces crosstalk on the adjacent channels. Assuming 80 channels at 50GHz spacing, 40Gbps PSBT or DPSK increases the total capacity to 3.2Tb/s per band.

### 1.6 ROADM Tolerance

The resilience of the modulation format to narrowband optical filtering is an important consideration, particularly in networks with many cascaded Reconfigurable Optical Add/Drop Multiplexers (ROADMs). ROADMS based on wavelength blockers typically have a very narrow filter width and may not support any 40Gbps other than PSBT. For other ROADM technology, e.g. PLC-based AWGs, the filters may be wider but the impact on performance when many are cascaded must still be considered. An advantage of PSBT is that OSNR performance actually improves with intermediate cascaded ROADMs, due to the bandwidth-limiting effect [1]. For CS-RZ and DPSK, ROADMs with 100GHz channel spacing will typically induce 0.1 to 0.2dB additional OSNR penalty for each ROADM pass-through. This negatively impacts the reach in a real network scenario and complicates the link engineering rules. Figure 6 illustrates the ROADM tolerance of PSBT, BL-PSBT (50GHz interleaver included at Rx end) and CS-RZ.

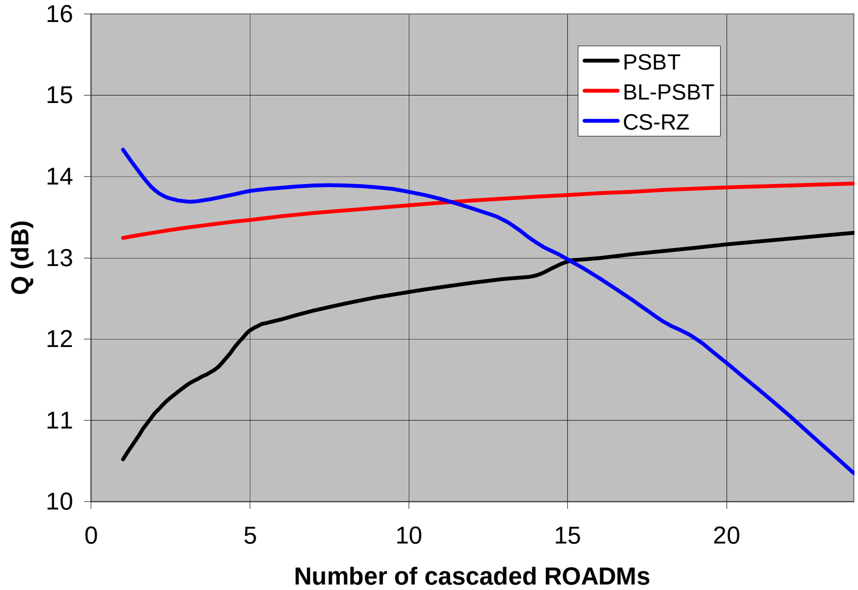


**Figure 6.** Simulated Sensitivity to Cascaded ROADMs (no filter offset, 21dB/0.1nm OSNR, ROADM FWHM = 65GHz)

For a large number of cascaded ROADMs, the Q (and hence reach) is actually larger for PSBT than CS-RZ. Another key issue is the required accuracy on ROADM filter center frequency. A simulation assuming a 6GHz offset in the ROADM center frequency is shown in Figure 7, illustrating that CS-RZ requires a higher degree of accuracy in matching the signal center frequency to the ROADM center frequency, whereas PSBT is much more robust to filter frequency offset. This is again related to the wide spectrum of CS-RZ, compared to PSBT.

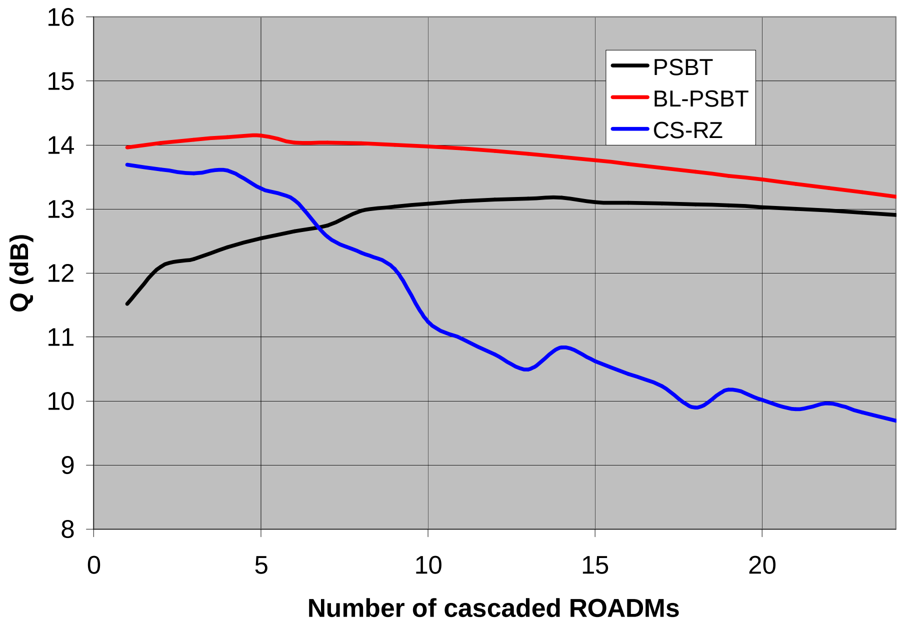


**Figure 7.** Simulated Sensitivity to Cascaded ROADMs (6GHz filter offset, 21dB/0.1nm OSNR, ROADM FWHM = 65GHz)

### 1.7 Dispersion Tolerance

Due to the narrow spectral width, PSBT has a much larger tolerance to Chromatic Dispersion (±160ps/nm) than CS-RZ or DPSK (±40ps/nm). Polarization Mode Dispersion (PMD) tolerance is very similar across the modulation formats, i.e., all between 2 and 2.5ps mean Differential Group Delay (DGD) tolerance. The penalty contour map of CD vs. DGD is shown in Figure 8. An interesting observation is that for PSBT, PMD tolerance improves when the CD is at optimum, rather than at 0. It can therefore be concluded that using a tunable dispersion compensator (TDC) with PSBT will have the added benefit of increasing the PMD tolerance. The opposite is true for CS-RZ in that any net CD offset away from 0 will decrease the PMD tolerance.

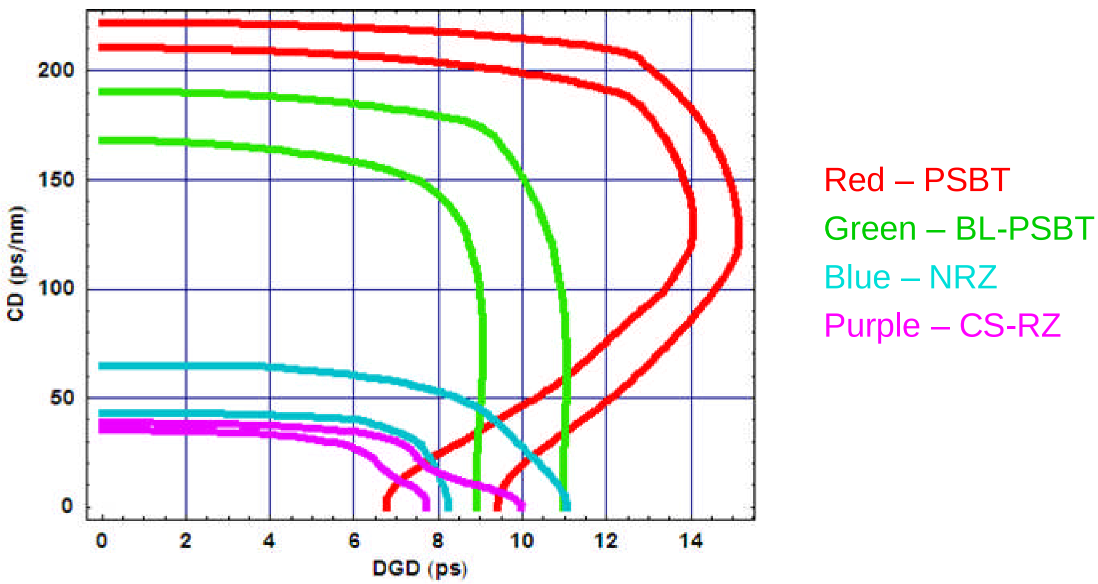


**Figure 8.** Intrinsic CD + DGD Tolerance (1dB and 2dB penalty contours shown)

Although the DGD (1st order PMD) tolerance of the different modulation formats is similar, the narrow optical spectrum of PSBT makes it more robust to 2nd order PMD effects, Polarization Dependent Chromatic Dispersion (PCD) and Polarization State Depolarization (PSD). Figure 9 shows a sensitivity analysis of the different modulation formats to PSD, the more dominant 2nd order PMD term [5]. This becomes very important when considering the use of a polarization mode dispersion compensator (PMDC) to compensate PMD in a network. To achieve a tolerance of 8-10ps mean DGD, CS-RZ or DPSK require high-order PMD compensation, whereas PSBT only needs a 1st order PMDC as PSBT effectively combats 2nd order PMD with its narrow spectral width.

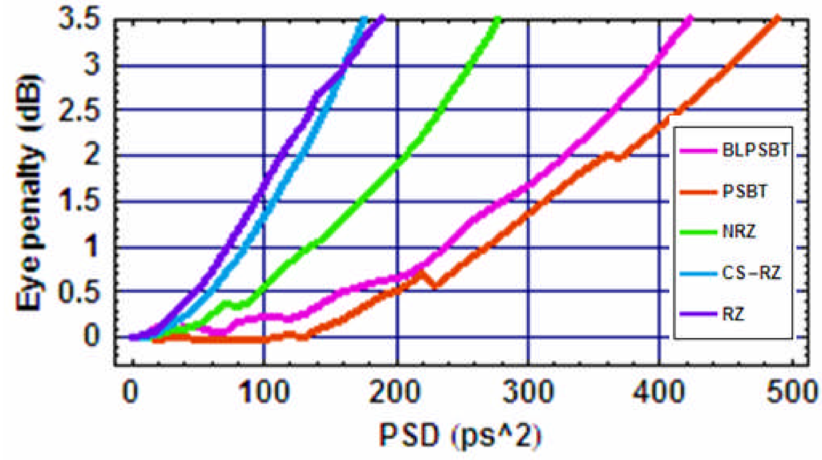


**Figure 9.** PSD Sensitivity

### COMPARISON SUMMARY

The relative advantages and limitations for PSBT vs. CS-RZ vs. DPSK at 40Gbps line rates are summarized in Table 1 below.

| | PSBT | CS-RZ | DPSK |
|---|---|---|---|
| Relative cost estimate[1] | 0% | +30% | +20% |
| Spectral efficiency | 0.8bits/Hz | 0.4bits/Hz | 0.8bits/Hz |
| CD tolerance[2] | 320ps/nm | 460ps/nm | 460ps/nm |
| PMD tolerance[3] | 2.1ps[4] | 2.8ps | 2.5ps |
| PMD tolerance with PMDC[5] | 8ps | 4ps | 4ps |
| OSNR sensitivity | 17dB[6] | 16dB | 13dB |
| Reach[7] | 1,000km | 1,125km | 1,600km |
| Penalty per ROADM[8] | negligible | 0.2dB | 0.2dB |

[1] Cost estimate increase vs. PSBT
[2] CS-RZ and DPSK include TDC; PSBT with optional TDC = 2,400ps/nm tolerance
[3] Mean PMD for 1dBQ eye penalty and 10-5 outage probability
[4] Increases to 2.5ps with BL filtering or 3ps with TDC (but without BL filtering)
[5] Assumes first-order only PMD compensator
[6] Assumes 50G interleaver included in DWDM for bandwidth-limiting
[7] Crude assumption that 1dB OSNR = 0.5dB reach increase, baseline BL-PSBT = 1,000km, no ROADMs in-line
[8] OSNR penalty, assumes 65GHz FWHM BW ROADM passband profile

**Table 1.** 40Gbps Modulation Scheme Comparison Table

The application space summary for 40Gbps line rates is shown in Figure 10. In the majority of cases PSBT offers the best combination of price and performance. For cases where extremely long reach is required (e.g. ULH express networks or submarine systems), DPSK may be a better choice. CS-RZ does not offer the right price or performance for 40Gbps deployments in any application.

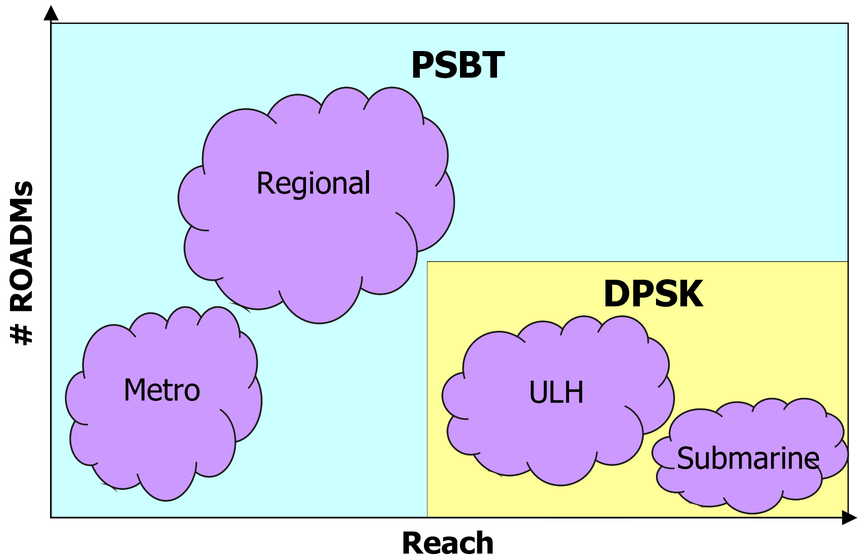


**Figure 10.** Application Space for 40Gbps Modulation Schemes

## REFERENCES

[1] Schmidt, Ted, "Application Note – Optimal Optical Filters", StrataLight Tech. Doc. #3000019-00/Rev2, June 2005.

[2] Xu, Chris, Liu, Xiang, "Differential Phase-Shift Keying for High Spectral Efficiency Optical Transmissions", IEEE J. of Quantum Electronics, Vol 10(2), March 2004.

[3] Gnauck, A.H. and Winzer, P.J., "Optical Phase-Shift-Keyed Transmission", Journal of Lightwave Technology, Vol 23(1), January 2005.

[4] Malouin, Christian et al., "DPSK Receiver Design – Optical Filtering Considerations", to be presented at OFC 2007, Anaheim, USA.

[5] Francia, Cristian et al., "PMD Second-Order Effects on Pulse Propagation in Single-Mode Optical Fiberss", IEEE Photonics Technology Letters, Vol 10(12), December 1998.



For additional information or product support please contact:
StrataLight Communications, 2105 S. Bascom Ave., Suite 300, Campbell, CA 95008, USA
Telephone: +1.408.961-6250 • FAX +1.408.626.7100 • E-mail: productinfo@stratalight.com • http://www.stratalight.com