# Can 100Gbps wavelengths be deployed using 10Gbps rules?

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# Introduction

- 40Gb/s market just beginning to take-off
  - Driven by OC-768 port availability on next generation IP routers
- Growth driven by converged IP networks
  - VOIP, video distribution, peer-to-peer video
- Core network growth estimated to double every 2 years through 2011*
  - Growth highest in non-Internet (IP video-to-TV) sector
- Optical transport spectral efficiency and port speed must keep pace with this growth rate

* “Global IP Traffic Growth & Methodology, 2006-2011”, Cisco public white paper, http://www.cisco.com/application/pdf/en/us/guest/netsol/ns537/c654/cdccont_0900aecd806a81aa.pdf

# Driver

# 100Gb/s optics requirements

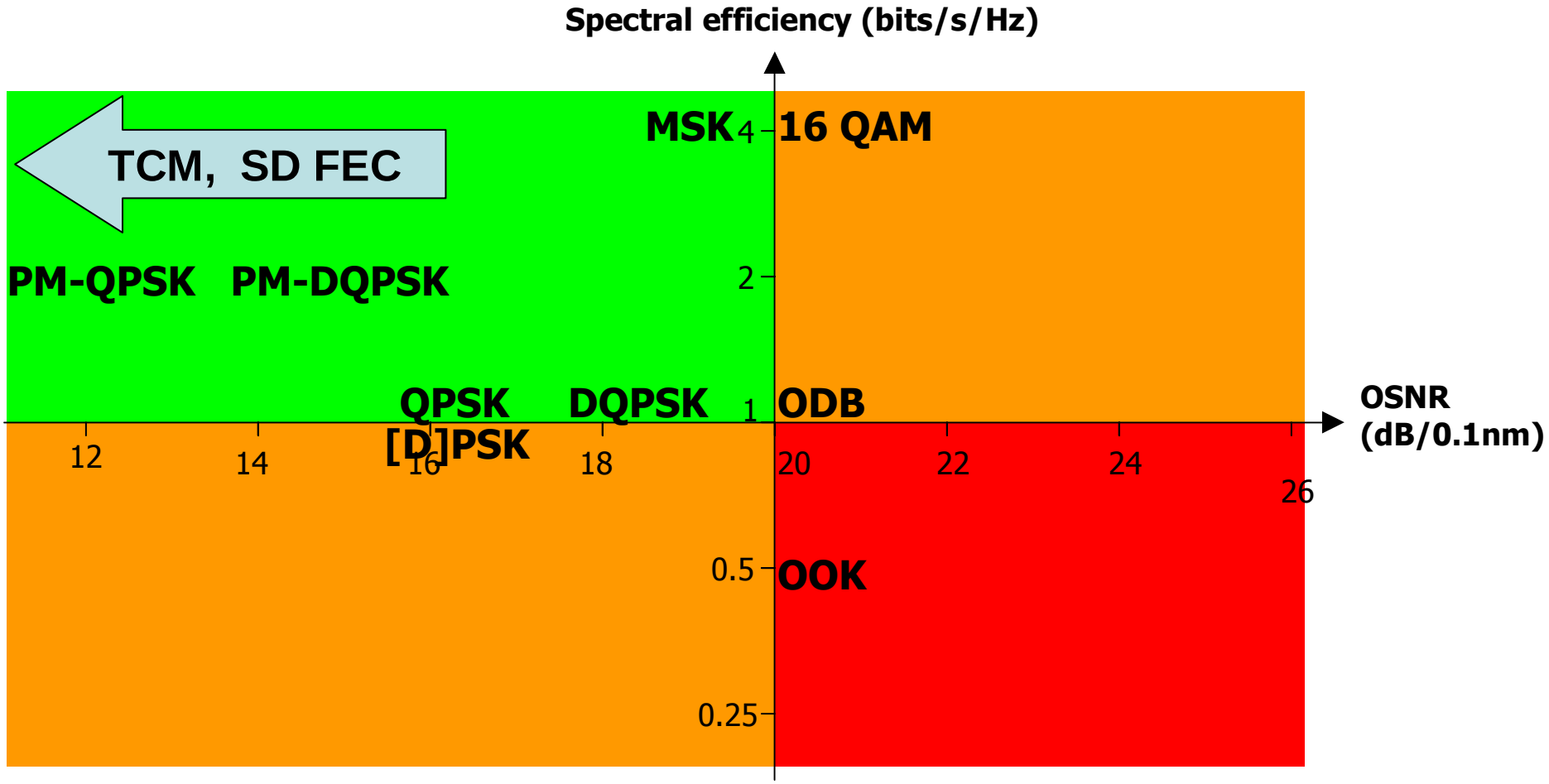
- Optical reach of ≥ 1,500km;
- Support 50GHz DWDM channel spacing;
- No change to existing DWDM common equipment;
- Non traffic-affecting upgrades
- No significant crosstalk penalty on existing DWDM channels;
- Power per channel adjustable ± 2.0dB;
- Chromatic dispersion tolerance of ±700ps/nm;
- Polarization Mode Dispersion tolerance of 10ps (mean DGD);
- Ability to express signal through ≥ 4 ROADMs at 50GHz spacing;
- Ability to express signal through ≥ 24 ROADMs at 100GHz spacing;
- Automated dispersion tuning/tracking, if applicable;
- Full band tunable lasers on 50GHz ITU grid;
- Should support Digital Wrapper (OTU4) frame structure
- Must be bit-for-bit transparent for the 100GE client interface
- Must be “plug and play” and installable by existing field technicians

**AKA – Make it work with what’s in the field (gear + humans)!**

# Optical technology considerations

- Must always tradeoff performance for complexity (i.e. cost)
- Many schemes also tradeoff spectral efficiency for reach
- Must use practical electronics speeds
- Electrical signal processing is in general lower cost than optical
- Gain insight from other industries, e.g. wireless GSM (MSK), HDTV (TCM), satellite (QPSK/QAM), WiMAX/DSL (OFDM/DMT)
- Use of DSP is immature in optical communications
- Fiber nonlinearity limits practical launch powers

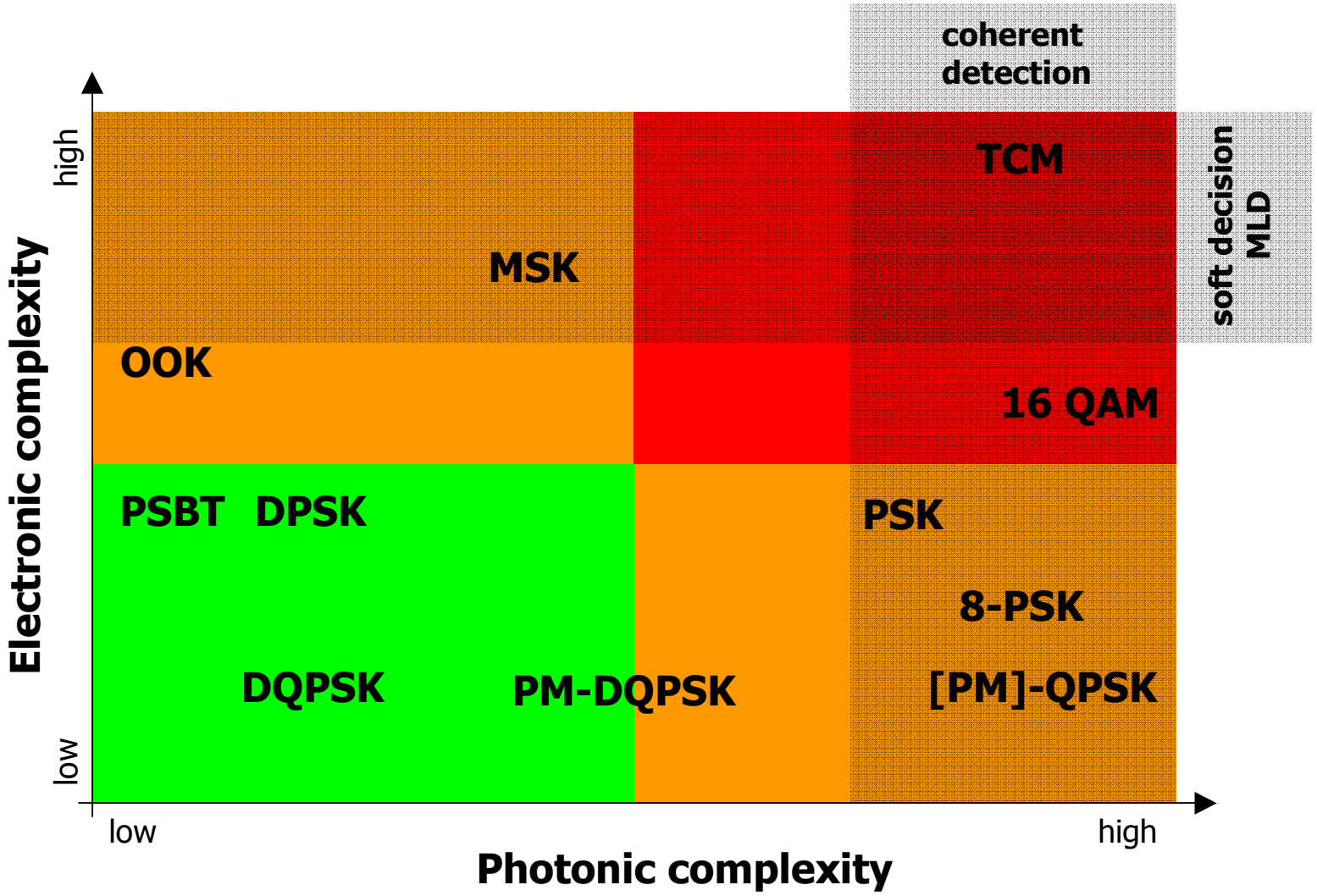
# Spectral efficiency vs. OSNR




OOK = On-Off Keying
MSK = Minimum Shift Keying
PSK = Phase-Shift Keying
QPSK = Quadrature PSK
PM-QPSK = Pol Muxed QPSK
TCM = Trellis Coded Modulation

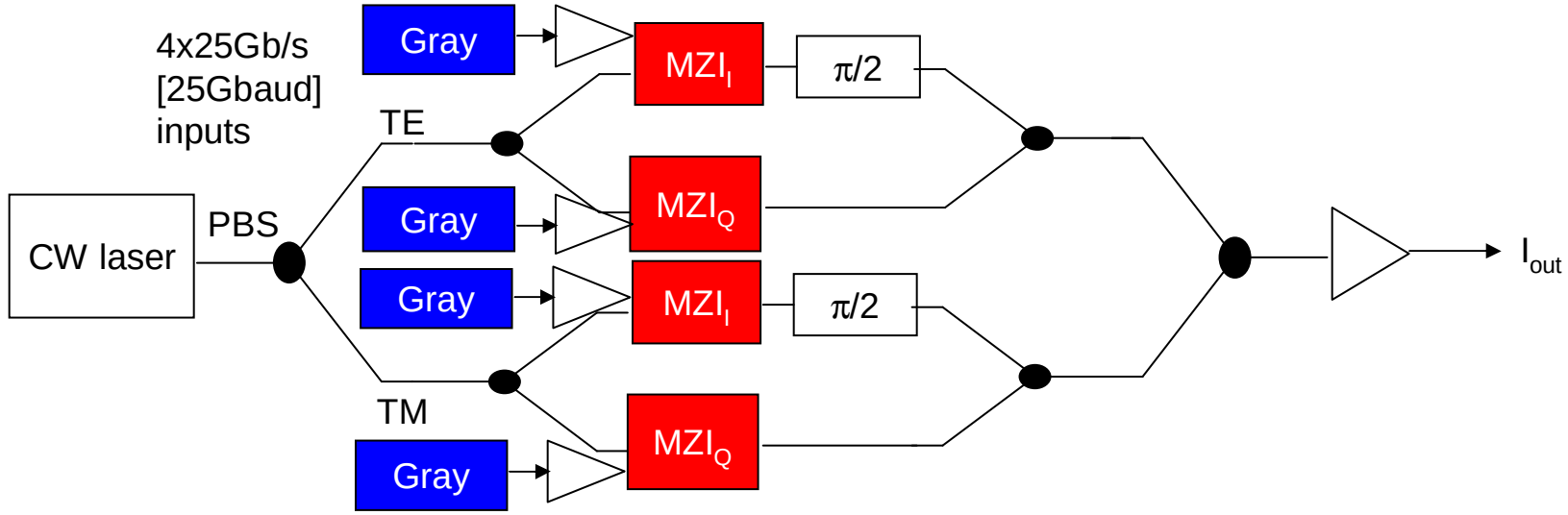
ODB = Optical Duobinary
QAM = Quadrature Amplitude Modulation
DPSK = Differential PSK
DQPSK = Differential QPSK
PM-DQPSK = Pol Muxed DQPSK
SD-FEC = Soft Decision FEC

# Implementation complexity

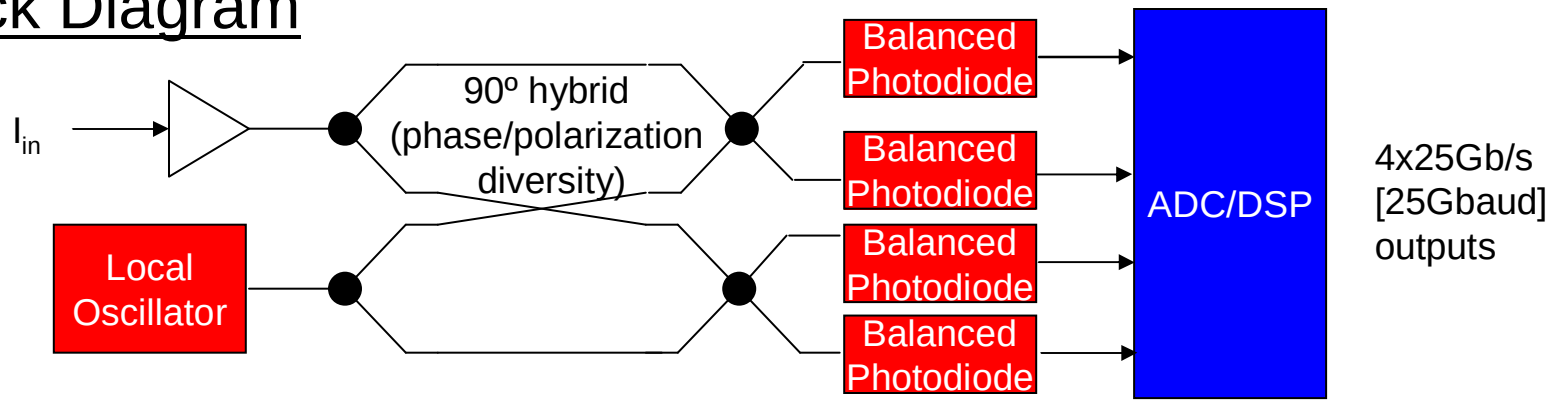


# High spectral efficiency - 100Gbps PM-QPSK

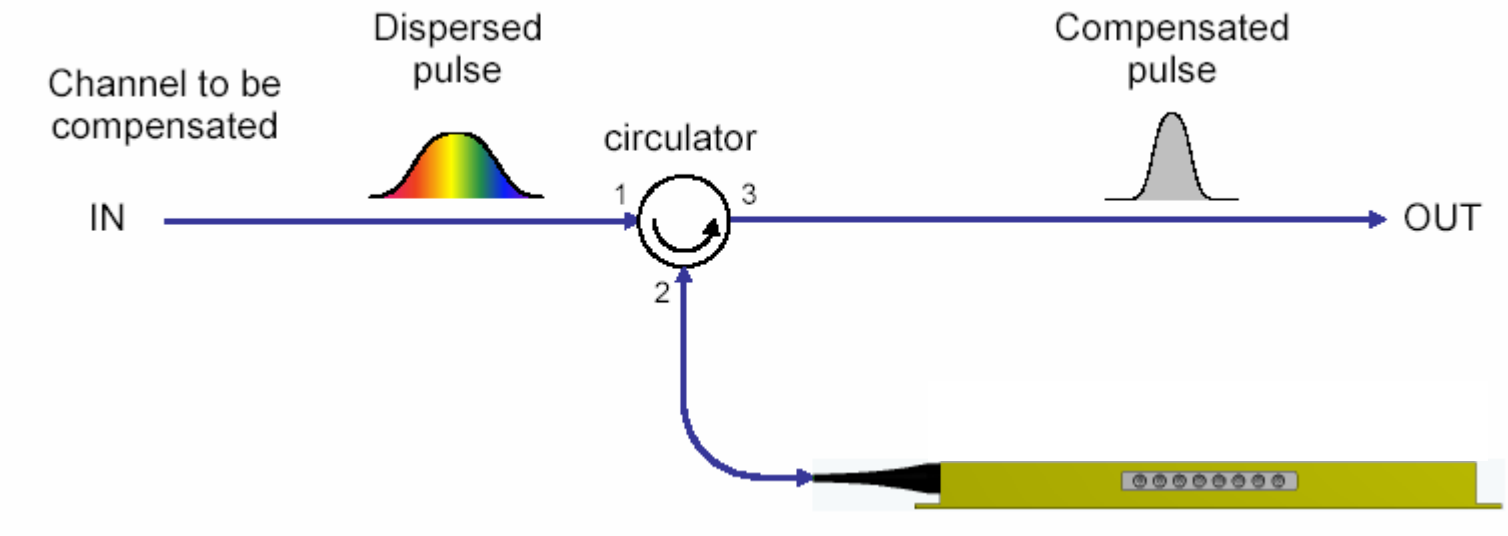
## Tx Block Diagram

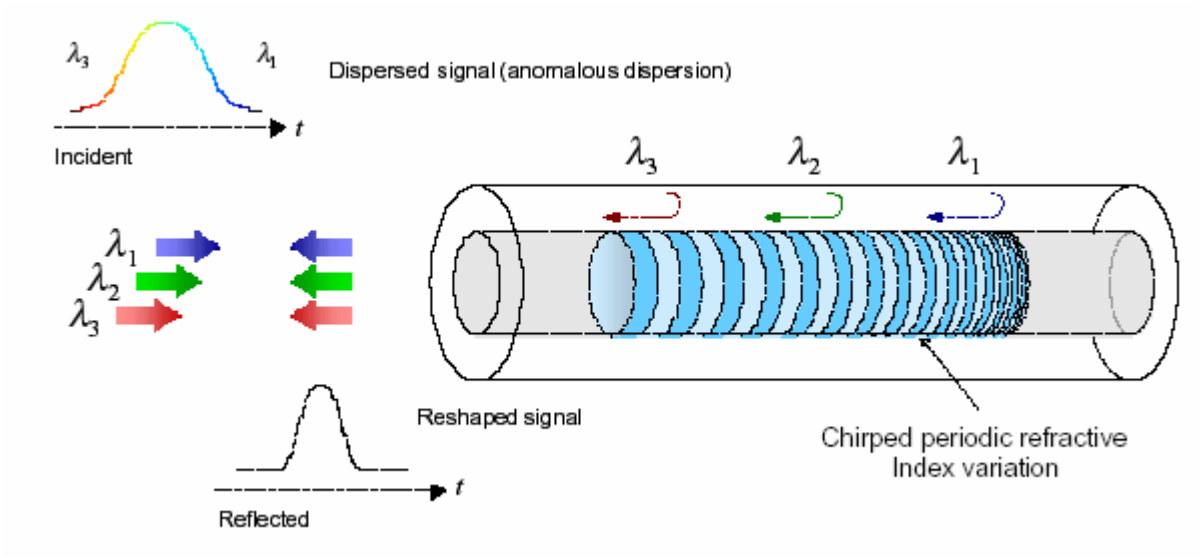



## Rx Block Diagram

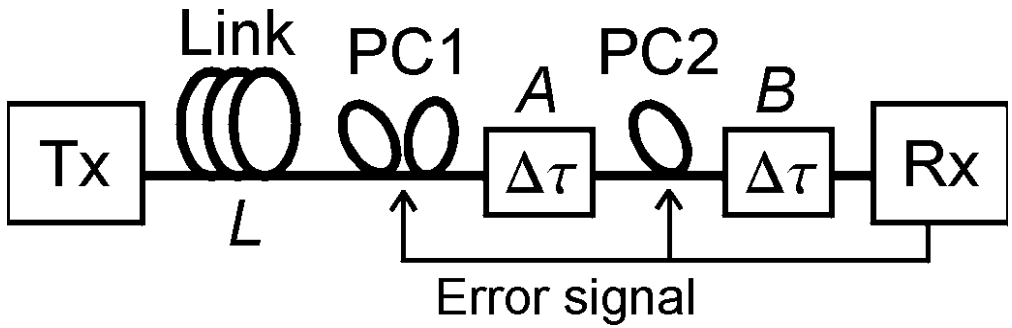


# Enabling technology - Optical Tunable Dispersion Compensator



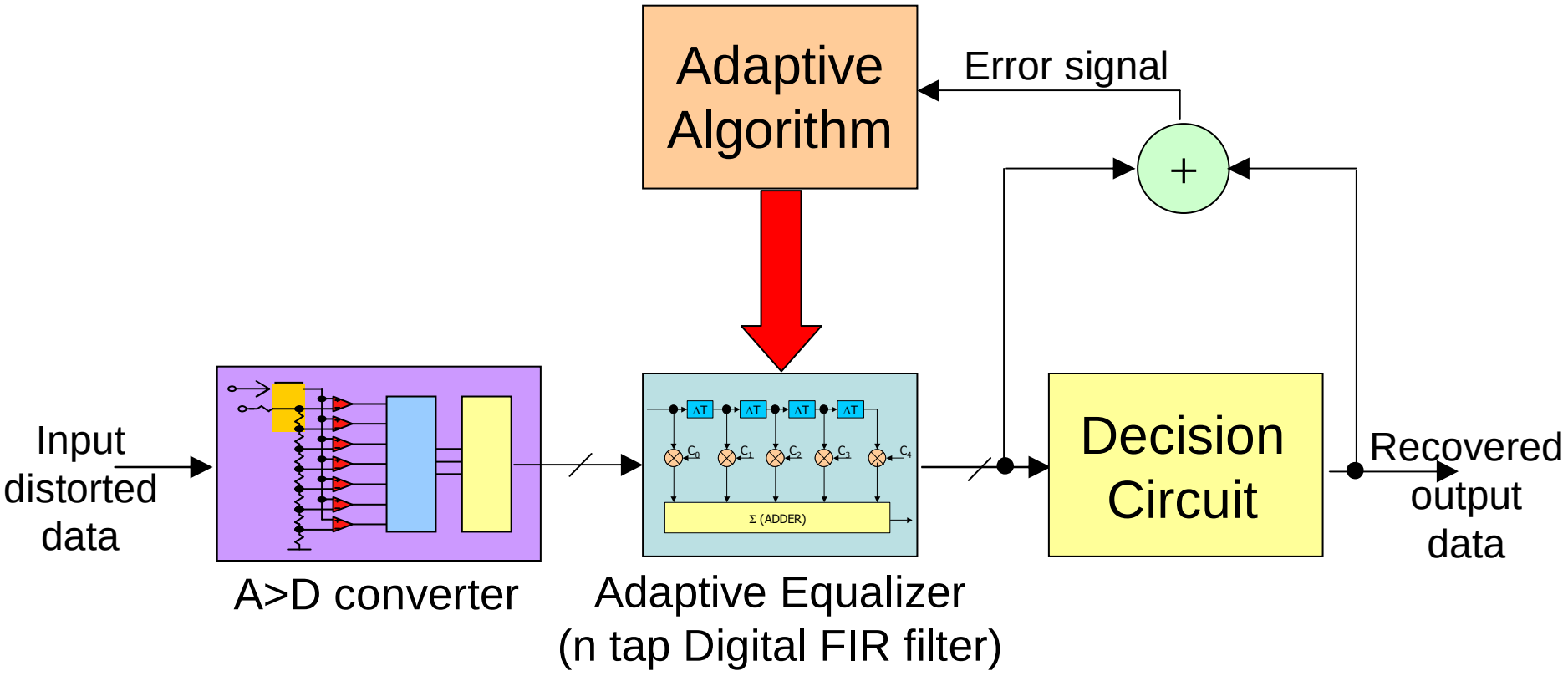



# Enabling technology - Optical Polarization Mode Dispersion Compensator




- PMDC consists of:
  - Two polarization controllers (PC1 and PC2)
  - Two fixed DGD elements
  - Error signal for feedback (DOP and pre-FEC BER)
- Reset-free control of any link SOP variation
- Partially compensates 2nd order PMD
- Increases mean PMD tolerance to 9ps
- Fast tracking speed

# Enabling technology - Electrical Polarization Mode Dispersion Compensator



# State-of-the-Art Qualified Electronics

| Technology | Speed (GHz) | Foundries |
|---|---|---|
| SiGe BiCMOS | $f_T$ = 180~200,<br>$f_{max}$ = 185~220, &<br>0.13~0.25um CMOS | IBM (8HP),<br>Jazz (SBC13),<br>IHP (SG25H1), … |
| CMOS | 90nm and 65nm | TSMC, UMC, CSM, SMIC, … |
| III-V (HEMT, HBT, etc.) | $f_T$ = 135~180,<br>$f_{max}$ = 200~350 | Velocium,<br>TriQuint,<br>Agilent, Win, … |

In about 18 months, qualified next-gen technology would become available to public, such 250~300 GHz SiGe BiCMOS & 45nm CMOS.

# 100Gbps Modulation Schemes Comparison

| | OOK | PSBT | DPSK | DQPSK | QPSK | PM-DQPSK | PM-QPSK |
|---|---|---|---|---|---|---|---|
| Spectral Efficiency | 0.4 bits/s/Hz | 1 bits/s/Hz | 0.8 bits/s/Hz | 1.6 bits/s/Hz | 1.6 bits/s/Hz | 3 bits/s/Hz | 3 bits/s/Hz |
| OSNR sensitivity | 20dB/0.1nm | 20dB/0.1nm | 17dB/0.1nm | 18dB/0.1nm | 16dB/0.1nm | 15dB/0.1nm | 13dB/0.1nm |
| PMD tolerance | 1ps | 1ps | 1ps | 2ps | 2ps | 4ps | 4ps |
| CD tolerance | 15ps/nm | 50ps/nm | 12ps/nm | 35ps/nm | 35ps/nm | 140ps/nm | 140ps/nm |
| Analogue electronics complexity | HIGH | HIGH | HIGH | MEDIUM | MEDIUM | LOW | LOW |
| Digital electronics complexity | LOW | LOW | LOW | LOW | HIGH | MEDIUM | HIGH |
| Optical complexity | LOW | MEDIUM | MEDIUM | MEDIUM | HIGH | MEDIUM | HIGH |
| Reach estimate | 400km | 400km | 800km | 700km | 1,000km | 1,200km | 1,600km |
| Cost estimate | 0% | +10% | +20% | +50% | +70% | +90% | +110% |

N.B. 1 [Q]PSK schemes assume coherent detection with Rx ADC/DSP; 2 Assumes 8.5dB NECG FEC;
3 No adaptive dispersion compensation assumed, dispersion tolerances are intrinsic per modulation scheme

# Summary

- Traffic growth being fuelled by video and IP rich media
  - Network traffic expected to double every 2 years till 2011
- Deploying 100Gbps wavelengths using 10Gbps rules is feasible
  - Requires advanced modulation techniques to achieve 2bits/s/Hz spectral efficiency
    - Code multiple bits/symbol to run 100Gb/s through 50GHz optical filters
  - Reach is a challenge
    - Coherent detection and/or next-generation FEC required
  - Optics is easy @25Gbaud, electronics is the challenge
    - Need very fast ADC/DSP mixed signal ASIC development