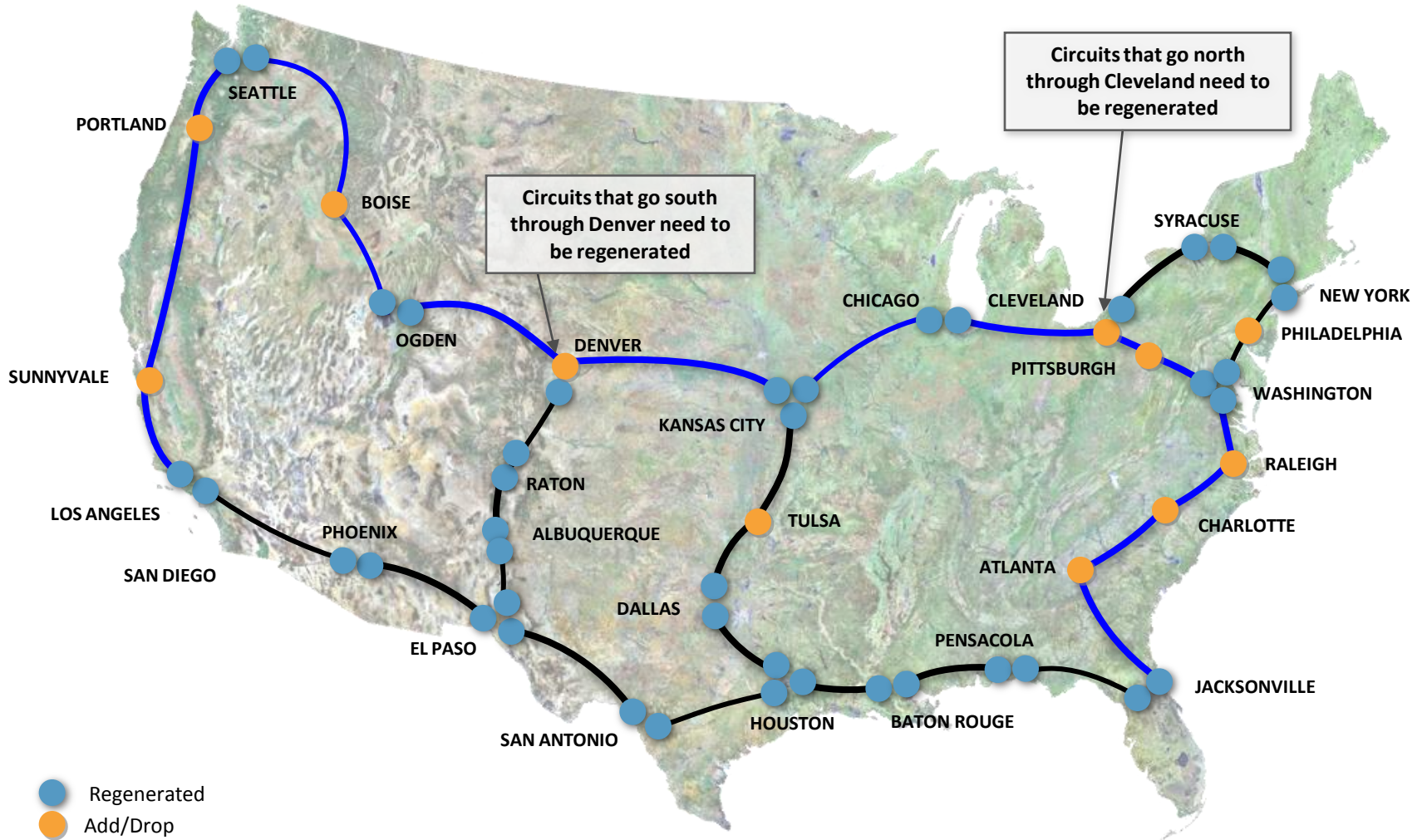


NLR Beyond 10Gb

The Path to 40G and 100G



Present 10Gig Regeneration Footprint





Existing NLR System

- Low Dispersion E-Leaf Fiber
- Cisco 15454 Core Optics with Dispersion Compensation
 - Optimized for 10Gig NRZ Signal
 - Minimal Changes to support higher speeds
 - Supports Alien Signals
- Phase 3
 - 40 Channel System at 100Ghz Spacing
 - ROADM & Raman
 - Unregenerated distances up to 2164km
- Phase 2
 - 32 Channel System at 100Ghz Spacing
 - Unregenerated distances < 1000km
- Capable of 80 Channels at 50Ghz Spacing

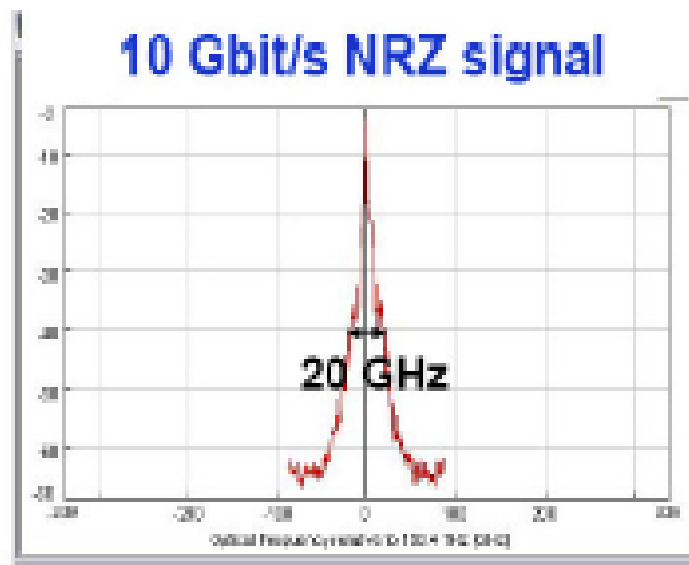
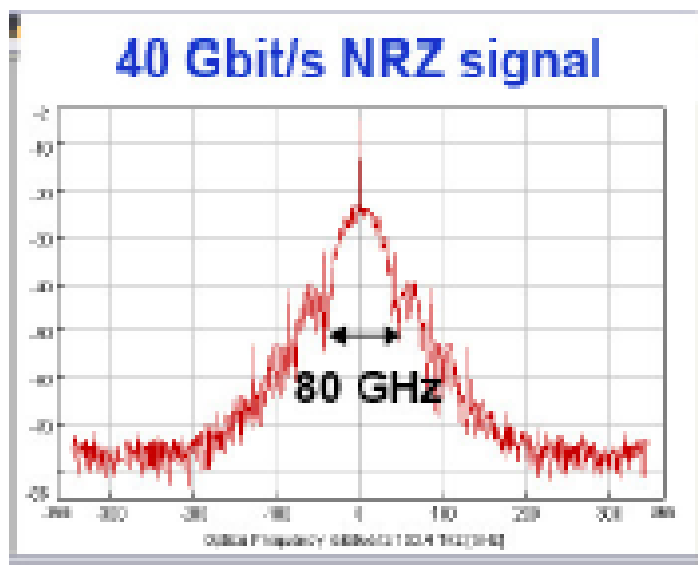


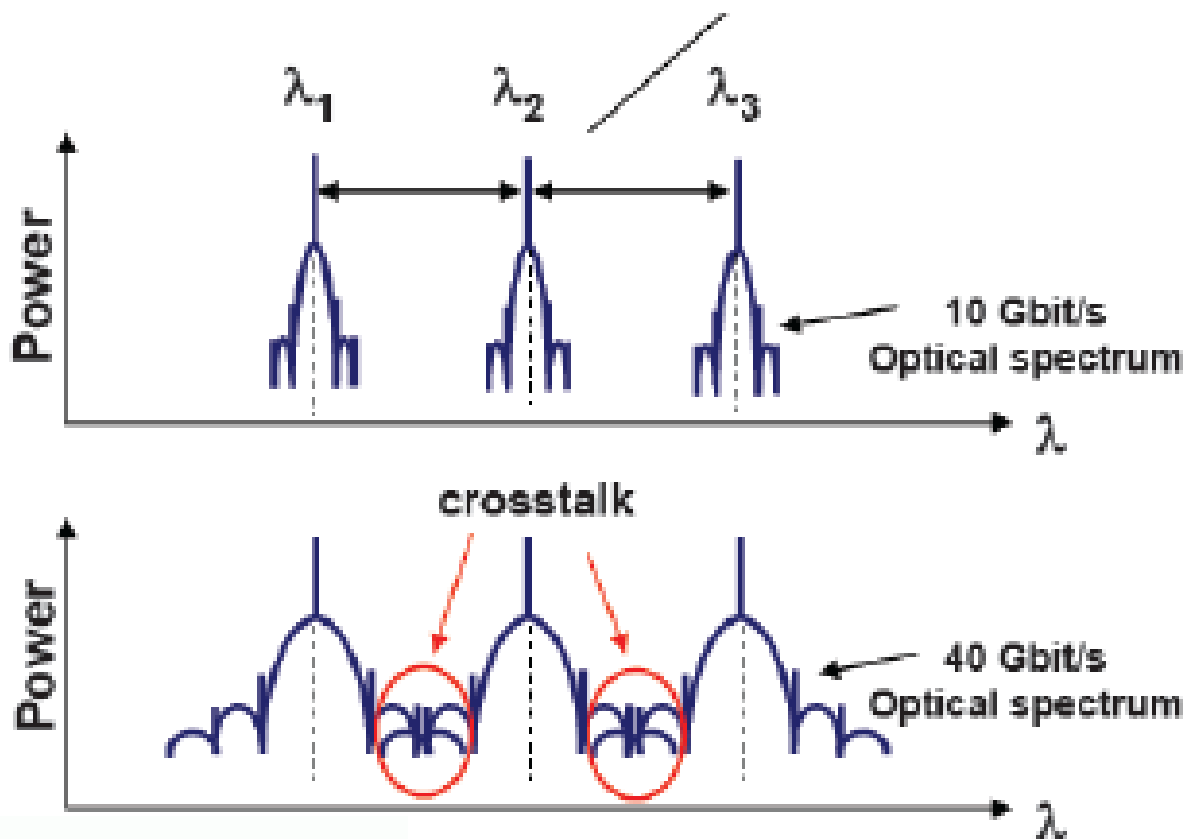
Benefits of 40 or 100 Gig on NLR

- 40G or 100G wavelengths not 4 or 10 wavelengths at 10Gig each.
 - Solves Large Flow Problem
- 40G or 100G Muxponders Expand 10G Capacity
 - Multiple 10GE or OC192 circuits per wavelength.
 - Up to 320 10G with 40G MXP
 - Up to 800 10G with 100G MXP
- Extends life of existing core system 10+ years
- Reduce Power and Space Footprint at OADM and Terminal sites.

Challenges of 40G & 100G

- 10G Signal format does not scale to 40G & 100G
 - Bit interval reduced from 100 to 25 to 10 ps
 - Electrical bandwidth increases from 10 to 40 to 100 GHz
 - Optical spectrum spreads from 0.1 to 0.8 to 2 nm (RZ)
 - Tolerance to dispersion divided by 16 & 100
 - Tolerance to PMD divided by 4 & 10
 - Rise-times sharpen, causing optical nonlinearities
 - 6 dB loss in noise margin = $\frac{1}{4}$ of the reach at 40G
 - 10 dB loss in noise margin = $\frac{1}{10}$ of the reach at 100G



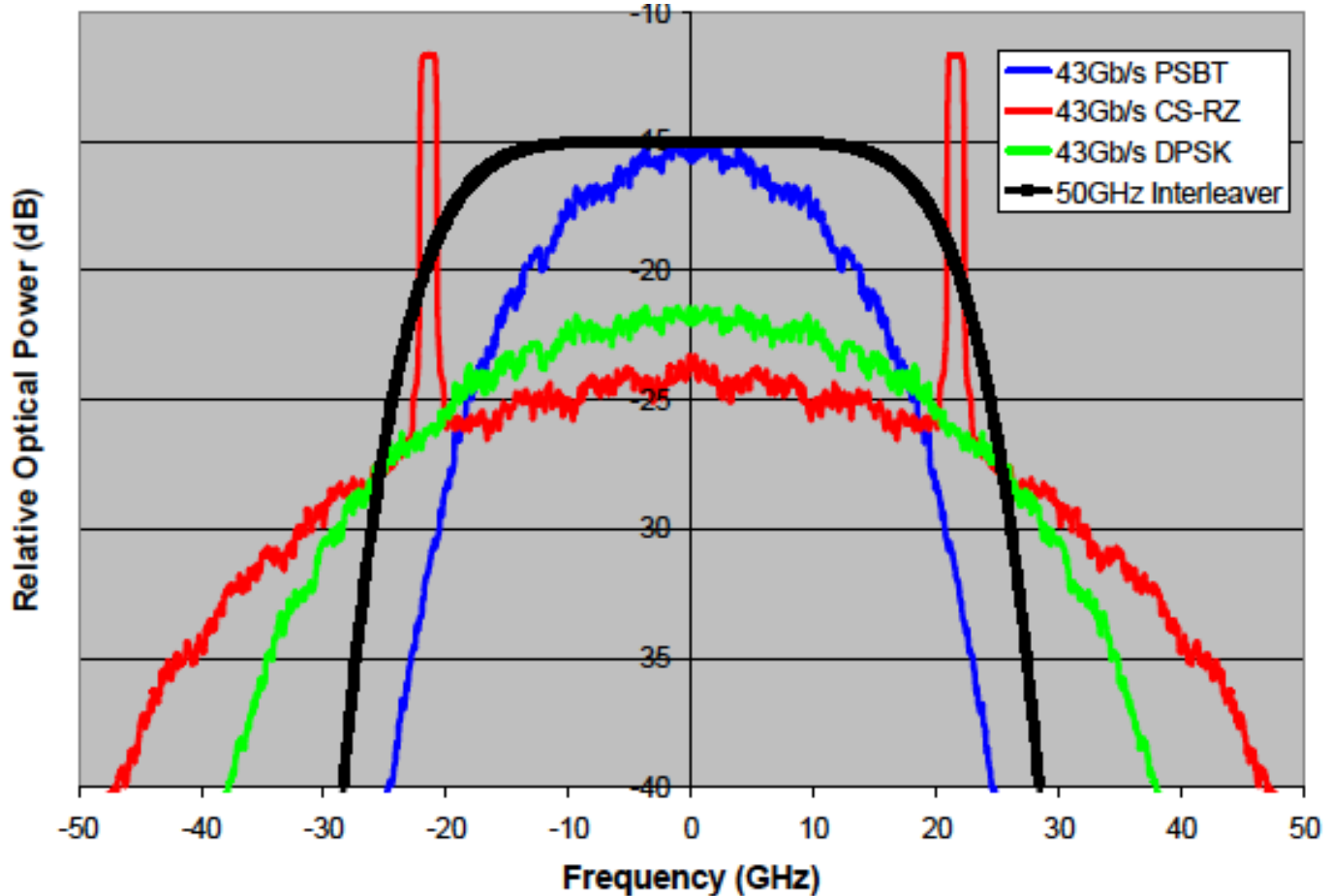




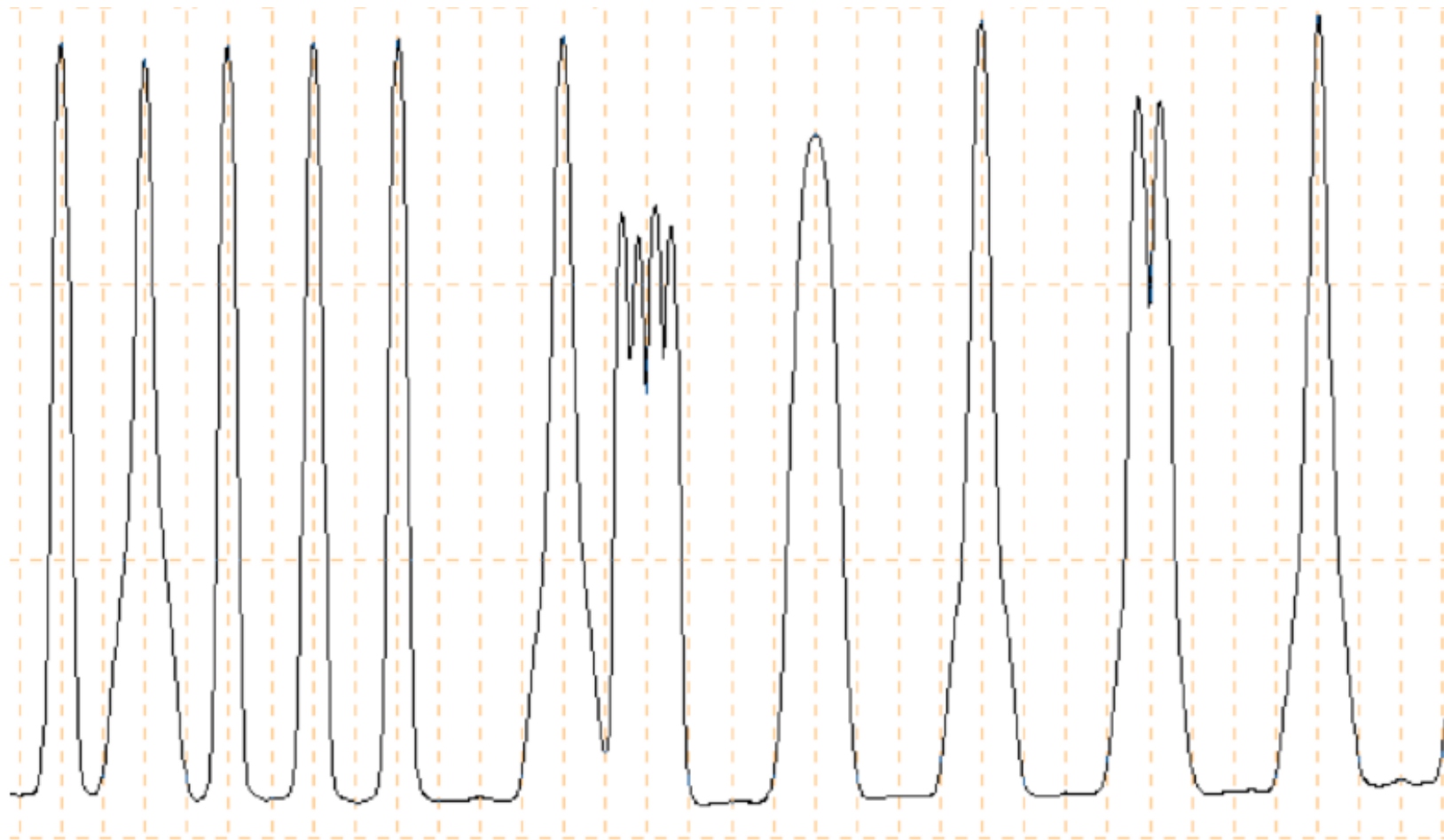
Solution: Modulation Schemes (Think Modems)

- **Co-FDM – Coded Frequency Division Multiplexing**
 - Uses multiple closely spaced orthogonal sub-carriers
- **Amplitude**
 - PSBT – Phase Shaped Binary Transmission
- **Phase**
 - DPSK - Differential Phase-Shift Keying
 - ADPSK – Adaptive DPSK
 - QPSK - Quadrature Phase-Shift Keying
 - DQPSK – Differential QPSK
- **Polarization**
 - PM-QPSK – Polarization Muxed QPSK
 - DP-QPSK – Dual Polarization QPSK
 - DP-QPSK & Co-FDM

Modulation Schemes Continued



10G & 40G Signals



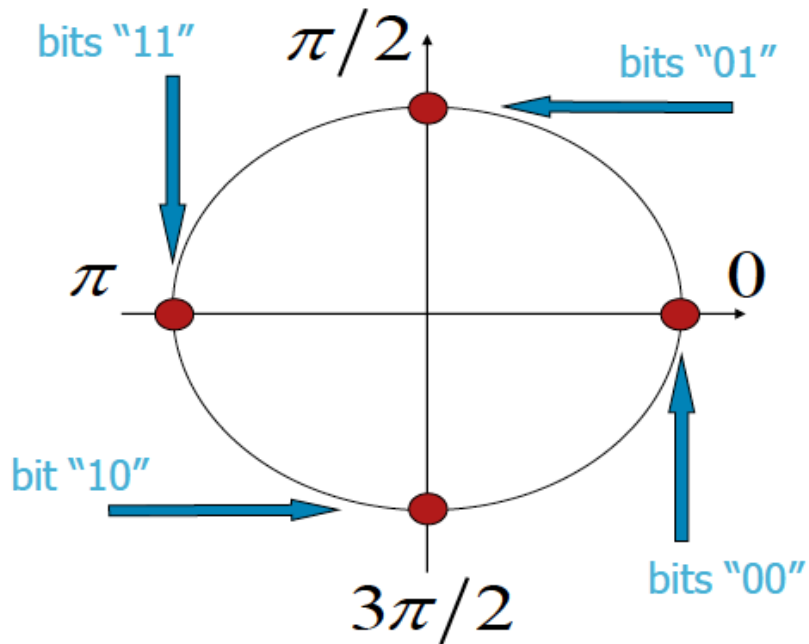


And The Winners Are

- Short and Medium Distance 40 & 100G
 - Varies Greatly Per Vendor
- Long Haul 40G & 100G
 - Some flavor of PM-QPSK

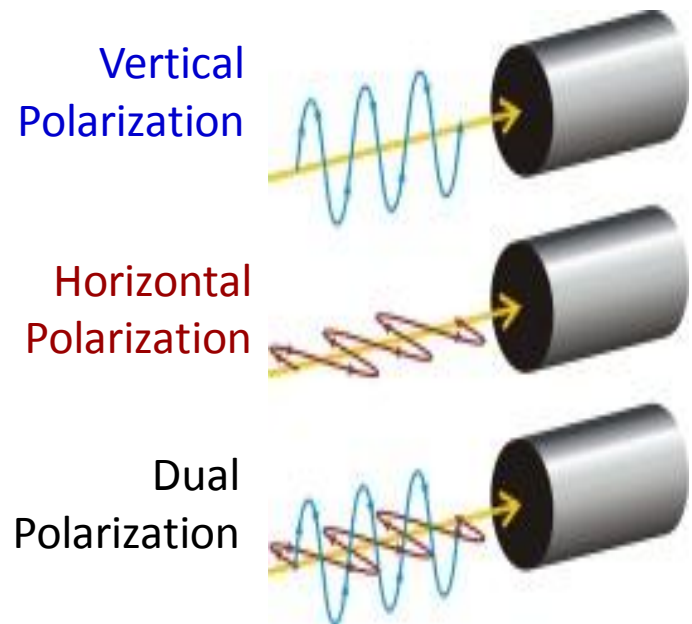
- QPSK

- 2 Bits per signal
- 20GBits in 10Gbaud Signal



- Dual Polarization

- ∞ One QPSK Signal per Polarization
- ∞ 2 20GBits Signals in 10Gbaud Symbol





DP-QPSK Continued

- **Polarization Mode**
 - Requires Coherent Detection
 - PM Works better with high dispersion
- **Remove DCUs for Better Performance**
 - Will no longer support Legacy 10G transponders
- **NLR has Low Dispersion E – Leaf Fiber**
 - “Better” fiber actually reduces performance

<i>Type</i>	<i>Dispersion @1550</i>	<i>Vintages</i>
SMF	17 ps/nm/km	1980-
E-LEAF	4 ps/nm/km	1996-
TrueWave RS	4.5 ps/nm/km	1996-
TrueWave Classic	2 ps/nm/km	1992-1996



- DQPSK modulation 40G card
 - Shipping this month in R9.2
 - Works alongside 10G
 - Guard Band Required between 10G & 40G Waves
- Next Gen 40Gb CP-QPSK (Coherent Pol-Mux QPSK) expected sometime in 2H CY2010.
 - 80ch Unregenerated reach > 2500km without DCUs
 - TBD with DCUs
- Working within the confines of the OIF standard for modulation (CP-QPSK) for 100G



Cisco DQPSK 40G (9.2) on NLR

- **Starlight to Washington – No Changes**
 - 40 Channel @ 40G
 - Extra Regen in Cleveland
 - 300Ghz guard band between 40G & 10G
- **Kansas to Starlight - No Changes**
 - 40 Channel @ 40G
 - Extra Regen in St Louis
 - 200Ghz guard band between 40G & 10G
- **Kansas to Dallas – Opt-Bst Required in Dallas**
 - 32 Channel @ 40G
 - 200Ghz guard band between 40G & 10G



Cisco DQPSK 40G (9.2)

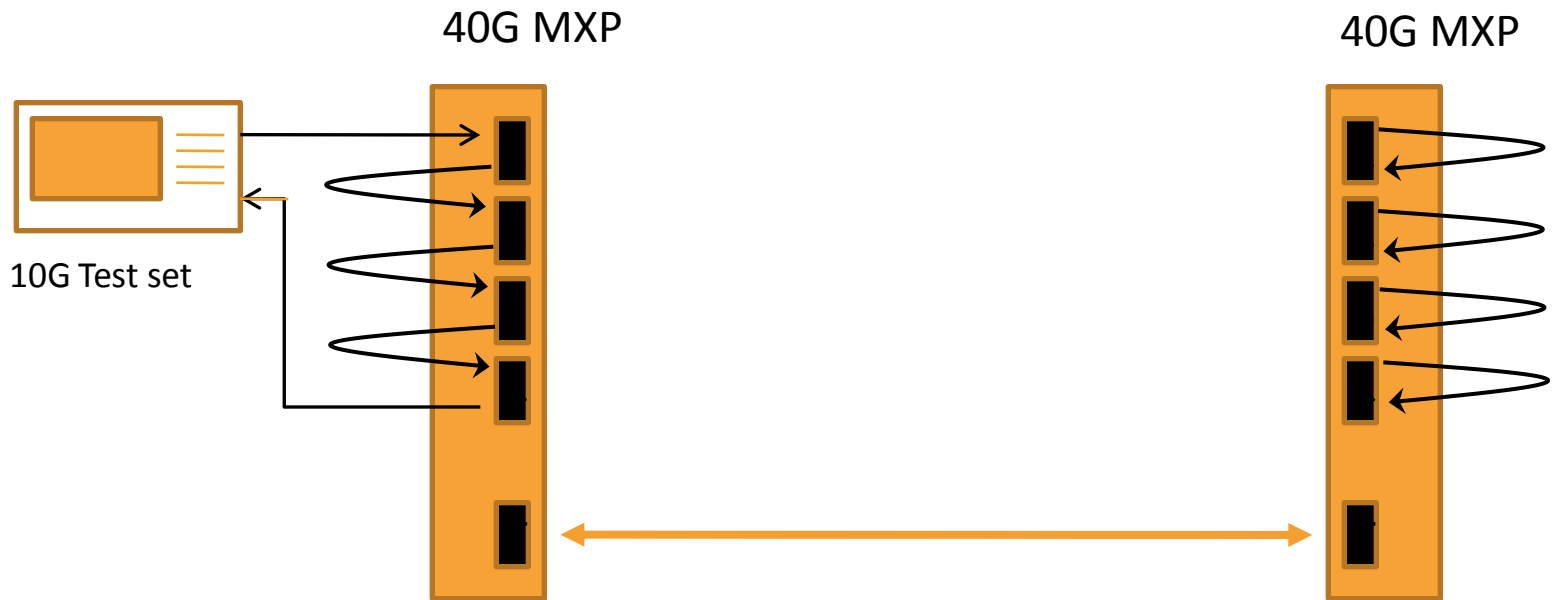
- Dallas to Houston – No Changes
 - 32 Channel @ 40Gig
 - 200Ghz guard band between 40G & 10G
- Houston to Baton Rouge – No Changes
 - 32 Channel @ 40Gig
 - 200Ghz guard band between 40G & 10G

Questions so far?
Next: Live testing to date

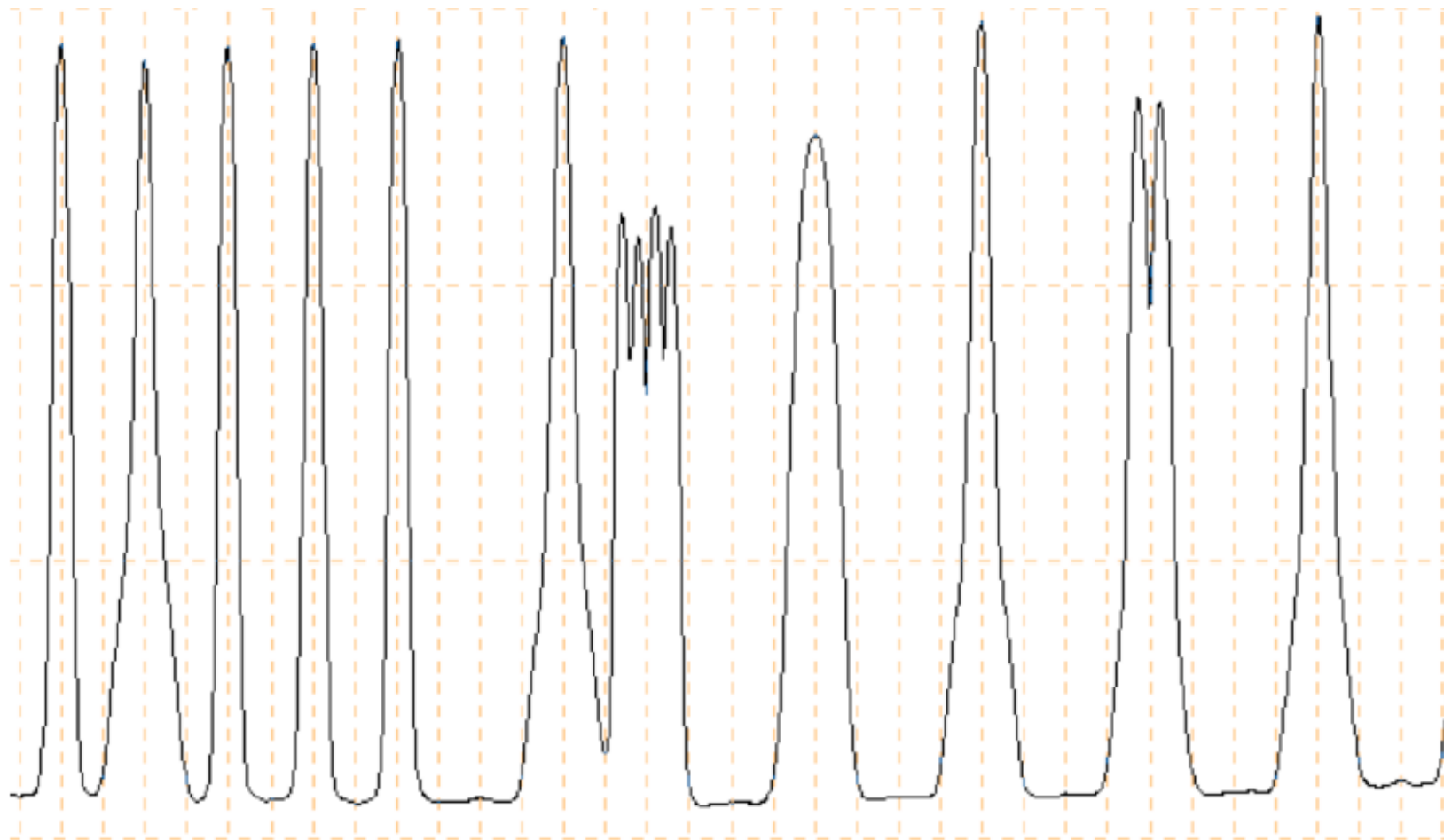


NATIONAL LAMBDA RAIL

- Two Rounds of testing so far
 - Darkstrand sponsored 3rd party transponders, SEAT-SUNN 09/09
 - Nortel
 - Ekinops
 - Adva
 - ~1600 km
 - Cisco 40G EFT, ATLA-WASH 03/10
 - ~1300 km



10G & 40G Signals



SEAT-SUNN test results (briefly)

- **Nortel failed**
 - Modulation schemes vulnerable to unwanted cross phase modulation
 - Would seem to work better with dispersion in the system
- **Ekinops passed, but only on a very short span**
 - Essential 4 x 10g lambdas spaced at 25ghz
 - Also not tolerant of XPM
- **Adva worked ok**
 - ADPSK
 - 9.4×10^4 Pre FEC BER



ATL Site 1558.98 Quick Test – Optical power

ATL 40G MXP Test Set Connection - Cisco Transport Controller

File Edit View Tools Help

Summary | Network Explorer

ATL 40G MXP Test Set Connection S...

0 CR 0 MJ 2 MN

Eqpt: 40G-MXP-C
Status: Active
Service State: IS-MR

Port 1-1 (0C192):IS-MR:Unprot
Port 2-1 (0C192):IS-MR:Unprot
Port 3-1 (0C192):IS-MR:Unprot
Port 4-1 (0C192):IS-MR:Unprot
Port 5 (Trunk):IS-MR:Unprot

40G-MXP-C

Port	GFP/WIS
1	
2	
3	
4	
05	

Alarms | Conditions | History | Circuits | Provisioning | Maintenance | Performance

Optics PM | Current Values | Historical PM

Param	Port 1 (Client)	Port 2 (Client)	Port 3 (Client)	Port 4 (Client)	Port 5 (Trunk)
Laser Bias (%)	43.6	39.4	39.8	38.5	49.1
RX Optical Pwr (dBm)	-3.9	-4	-6.8	-2.6	-10.7
TX Optical Pwr (dBm)	-3.2	-3.9	-2.4	-2.9	-0.1

OTN PM

Directions: Near End Far End

Intervals: 15 min 1 day

Refresh

Auto-refresh: None Help

Current statistics at March 4, 2010 4:50:25 PM EST

NET CKT Java Heap: 14 of 508 MB



1558.98 Quick Test

CTP predicts better performance : Pre-FEC BER $\sim 1e-5$ (15 min period) – 568k/sec

ATL 40G MXP Test Set Connection 5...

0 CR 0 MJ 2 MN

Eqpt: 40G-MXP-C
Status: Active
Service State: IS-NR

Port 1-1 (0C192):IS-NR:Unprot
Port 2-1 (0C192):IS-NR:Unprot
Port 3-1 (0C192):IS-NR:Unprot
Port 4-1 (0C192):IS-NR:Unprot
Port 5 (Trunk):IS-NR:Unprot

40G-MXP-C

Port GFP/WIS

Param	Curr	Prev	Prev-1	Prev-2	Prev-3	Prev-4	Prev-5	Prev-6	Prev-7	Prev-8	Prev-9	Prev-10	Prev-11	Prev-12	Prev-13	Prev-14	Prev-15	Prev-16	Prev-17
Bit Errors	161,036,060	511,135,407	58,560,899	105,410,202...															
Uncorrectable Words	0	0	0	30,535,777...															

Directions: Near End Far End

Intervals: 15 min 1 day

Port: 5 Refresh

Auto-refresh: None

Baseline Clear... Help

15-minute, near-end registers for at March 4, 2010 4:48:10 PM EST

NET CKT Java Heap: 13 of 508 MB



1534.2 Quick Test

Pre-FEC BER ~ 1e-4 (prev 15 min period) – 5.8m/sec

The screenshot shows the Cisco Transport Controller interface for the 'ATL 40G MXP Test Set Connection'. The top status bar indicates 0 CR, 0 MJ, and 1 MN. The left sidebar shows the device '40G-MXP-C' is active with service state 'IS-NR'. The main area displays a network diagram with a yellow box highlighting the '40G-MXP-C' device and its 'GFP/WIS' port. Below the diagram is a table of performance metrics for 'ITU-T G.709 PM' and 'FEC PM'.

Param	Curr	Prev	Prev-1	Prev-2	Prev-3	Prev-4	Prev-5	Prev-6	Prev-7	Prev-8	Prev-9	Prev-10	Prev-11	Prev-12	Prev-13	Prev-14	Prev-15
Bit Errors	1,105,384,503	5,262,373,138	3,889,663,903	39,637,586,...	511,135,407	58,560,899	105,410,202,...										
Uncorrectable Words	0	0	0	11,070,940,...	0	0	30,535,777,...										

At the bottom, there are controls for 'Directions' (Near End/Far End), 'Intervals' (15 min/1 day), a 'Port' dropdown set to '5', a 'Refresh' button, and an 'Auto-refresh' dropdown set to 'None'. There are also 'Baseline', 'Clear...', and 'Help' buttons.

NET CKT Java Heap: 18 of 508 MB



1534.2 overnight test

The screenshot displays the Cisco Transport Controller interface for the 'ATL 40G MXP Test Set Connection'. The main window shows a summary of the connection status and a table of performance metrics.

Summary:

- Eqpt: 40G-MXP-C
- Status: Active
- Service State: IS-NR
- Port 1-1 (OC192): IS-NR: Unprot
- Port 2-1 (OC192): IS-NR: Unprot
- Port 3-1 (OC192): IS-NR: Unprot
- Port 4-1 (OC192): IS-NR: Unprot
- Port 5 (Trunk): IS-NR: Unprot

Performance Metrics Table:

Param	Curr	Prev
BIT Errors	147,783,066,725	302,056,127,720
Uncorrectable Words	0	52,972,658,006

Directions: Near End (selected), Far End

Intervals: 15 min (selected), 1 day

Port: 5 [Refresh]

Auto-refresh: None

Buttons: Baseline, Clear..., Help

1-day, near-end registers for at March 5, 2010 9:58:28 AM EST

NET CKT Java Heap: 8 of 508 MB

Thanks



NATIONAL LAMBDA RAIL