First Ever 40Gigabit Internet Connection to the Home

Challenge:

A: There was no Internet at my parents house and the local ISP's suck (the lack of performance is scary, and they have no IPv6 etc.).

B: Explain that if your house is fiber attached by a open neutral provider, there are many possibilities

C: We have hit another Bellhead bump in the road to remove unnecessary elements from the IP network. If my mother can make it work i, it must be a political/"my_job problem".

Ripe 55, Amsterdam, October 2007

Peter Löthberg, <roll@stupi.com>

Mamma NET

Why:

I’m crazy (sorry, no banana for pointing that out)
The Swedish policy scene is full of FUD
Fiber based optical networks are flexible and future proof
Video Conferencing with my parents
BBQ Bellheads said it can’t be done
It has not been done, so why not give it a try
Evaluate the performance of SUnet’s new optical network
It’s better than DSL and supports large packets
..etc...

.... and to see if I can outperform “Mr Hype” in press releases

Mamma NET

Yes, 40G to my mom's house isn't what everyone can do:

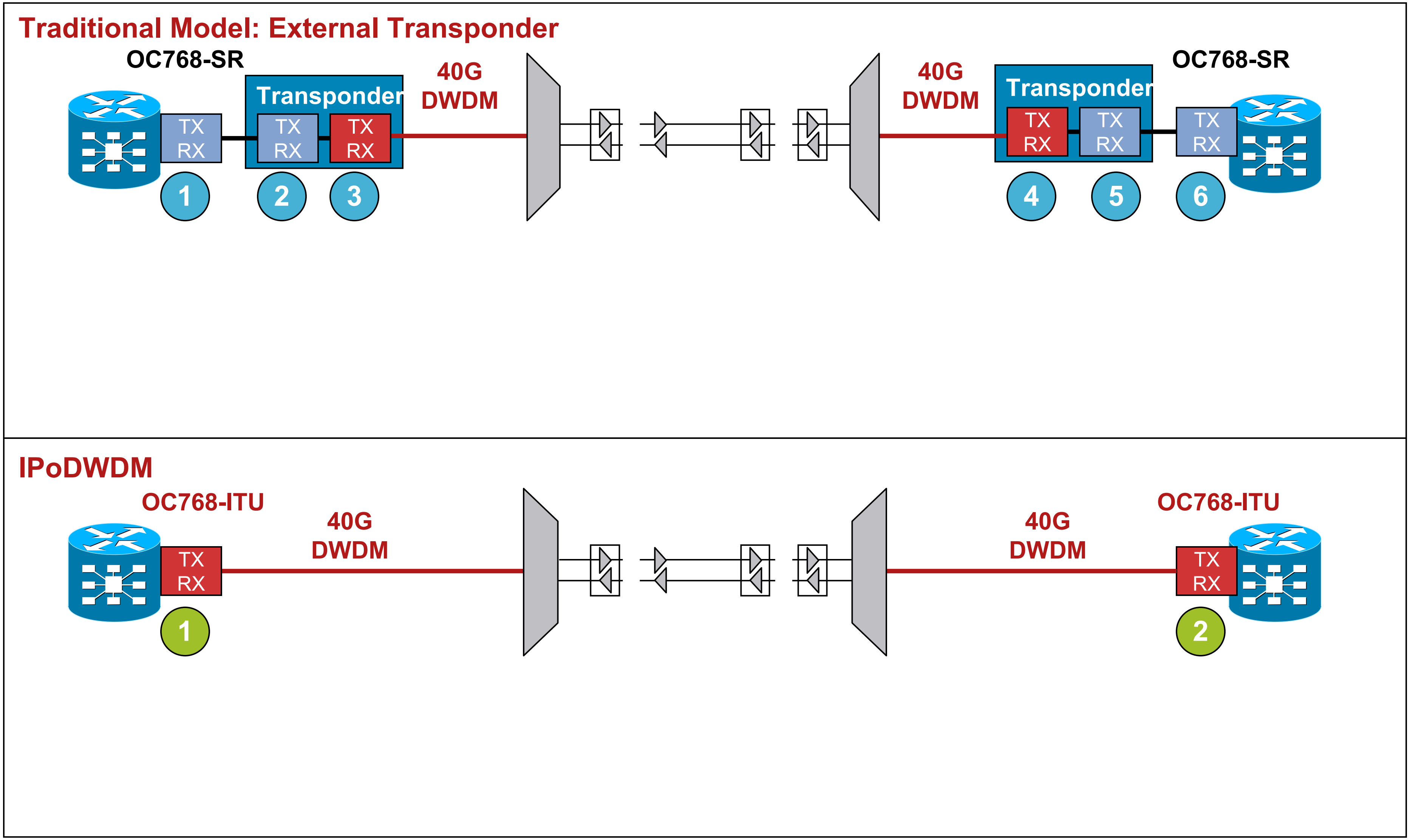
The reason I'm giving this talk at Ripe is to help you break down the barriers that your transport people put up to stop you from building more efficient IP networks.

Remember X25, Frame Delay, ATM, Routers directly attached to DWDM systems without ADM's etc

This is simple, you can do it, just look at the design criteria;

- If you have enough OSNR
- Properly manage your chromatic dispersion
- Are within PMD limits
- Properly clean your connectors

Why IPoDWDM



Traditional Model: External Transponder
OC768-SR
Transponder
TX RX
TX RX
TX RX
40G DWDM
1
2
3
40G DWDM
Transponder
TX RX
TX RX
OC768-SR
TX RX
4
5
6
IPoDWDM
OC768-ITU
TX RX
40G DWDM
1
40G DWDM
OC768-ITU
TX RX
2

Special Thanks to:....

Mom and DAD	
Hans Wallberg and Börje Josefsson	SUnet
The NuNoc STAFF	
Santa Claus, Kelly Ahuja, Björn Ehn, Walid Wakim	Cisco
Hafstein Johnsson, Raimo Vekhajarvi, Malin Thorsen	City of Karlstad
Hakan Syren,	ELTEL Networks
Ross Saunders,	Stratalight
”Ethernet Micke” Abrahamson, LM Jogback	Tele2
Marko Ivanov	Ciena
Anders Magnusson	LTU
Thomas Svensk	Imtech

Thanks to:....

”It cant be done!”	BBQ division
Niklas Montin, Håkan Karlsson, Jim Houts, Dennis Davidsson ,	
Dave Meyer, Samer Parikh, and many more	Cisco
Leon Pavlov	Mobinet
Lars Molin	Geosonic
Chase Cotton, Wes George, Björn Carlsson, Dave Harris	Sprint
Bob Rodeo, Mike Pellegrini	Ciena
Kalix Fiber	
Fredrik Holmqvist	DCS

Don’t forget to take the cards out before attempting shiping.

Greatly improves value of the 1988 WV-bus...

Moving the broadband router in to the garage.

My dad is performing damage management.

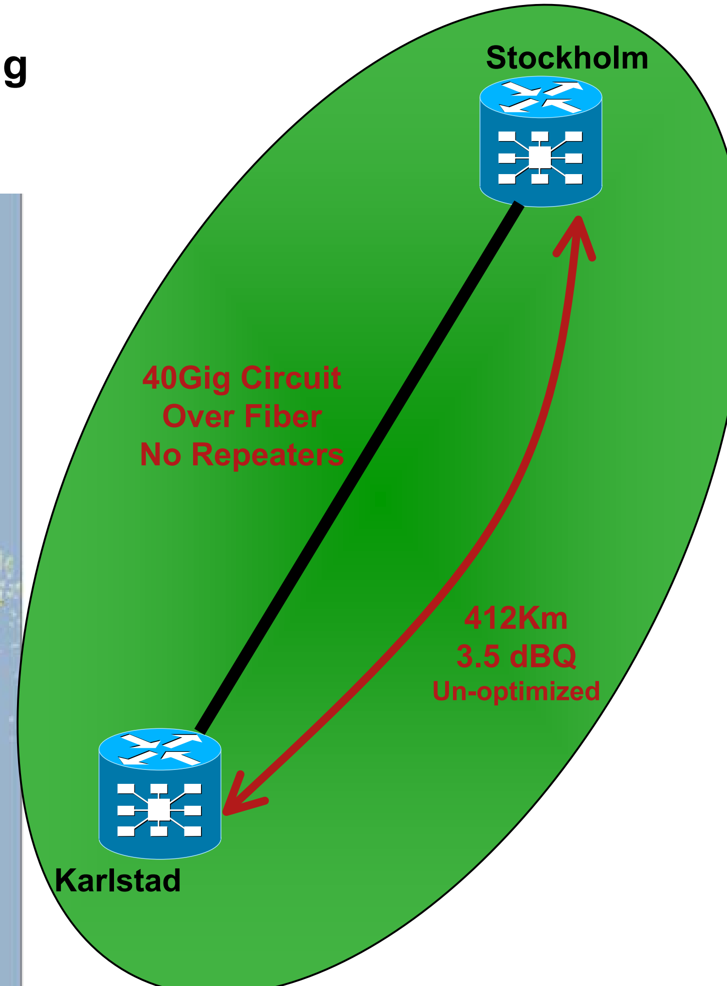
Leon is providing muscle resources

My mother Sigbritt doing the fiber installation.

World's First and Fastest Internet Connection to the home, 40Gig!

40Gig, Plug and Play Circuit Turn Up

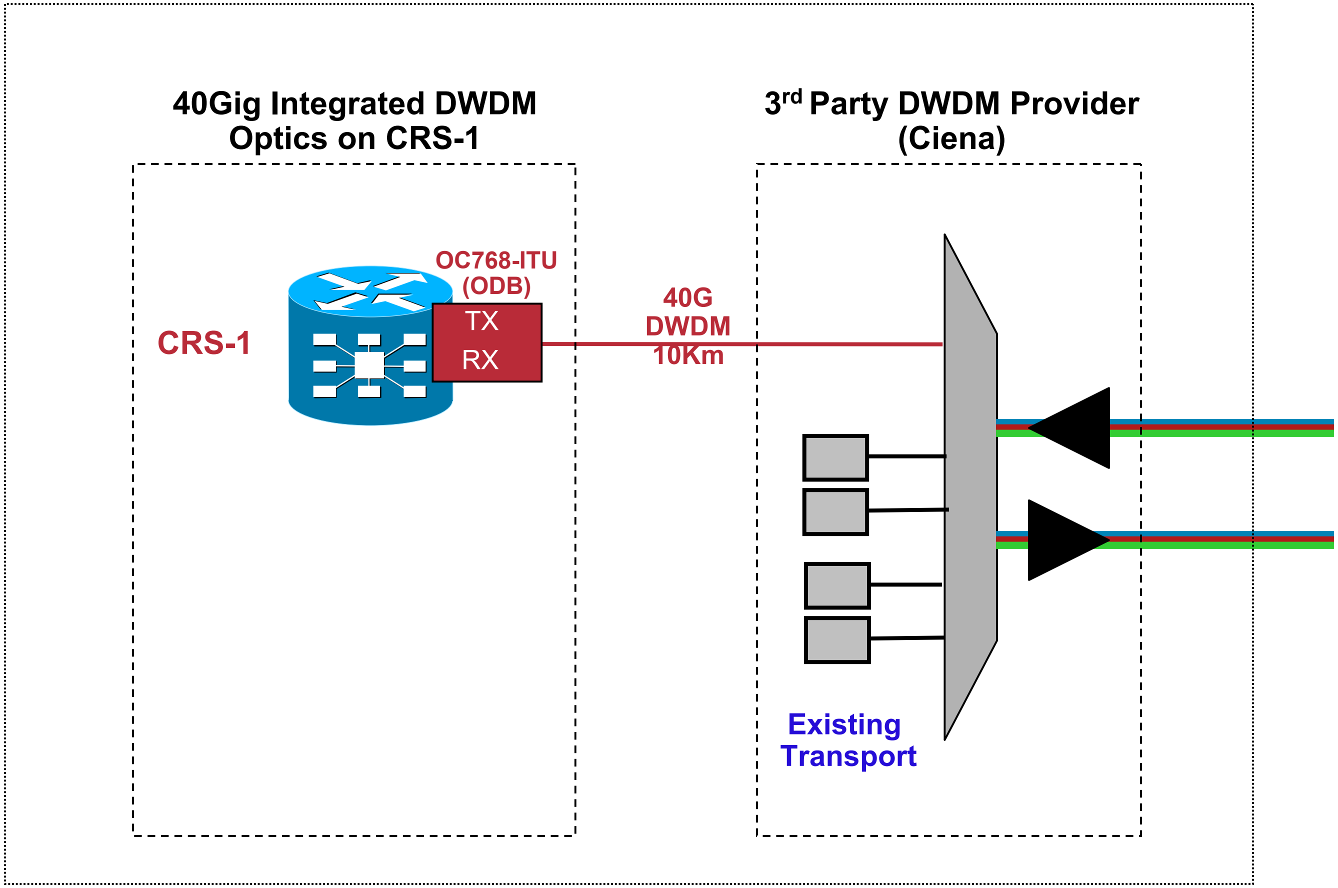
"The most difficult part of the whole project was installing Windows on Sigbritt's PC,"said Hafsteinn Jonsson of Karlstad Stadsnat.



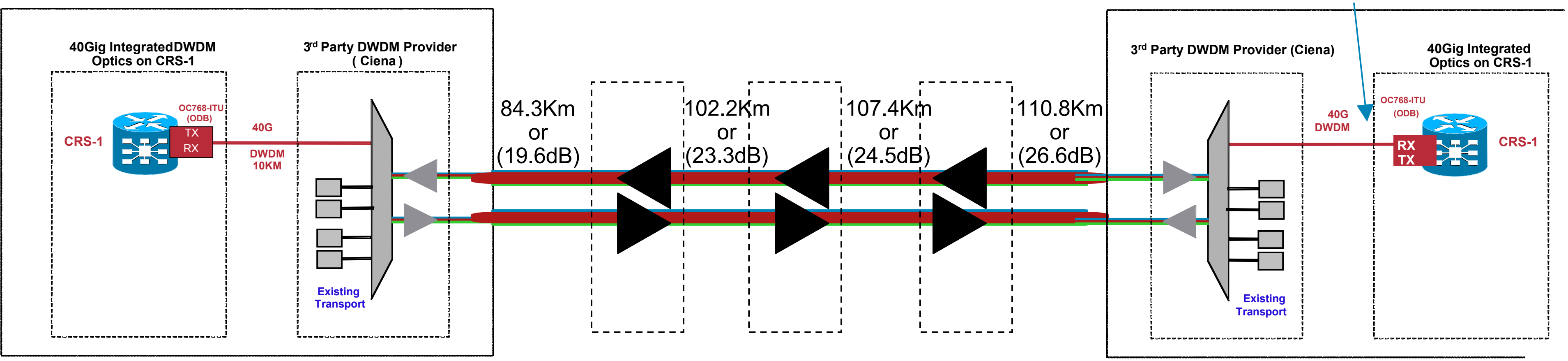
CRS-1 w/ Integrated 40Gig DWDM Optics

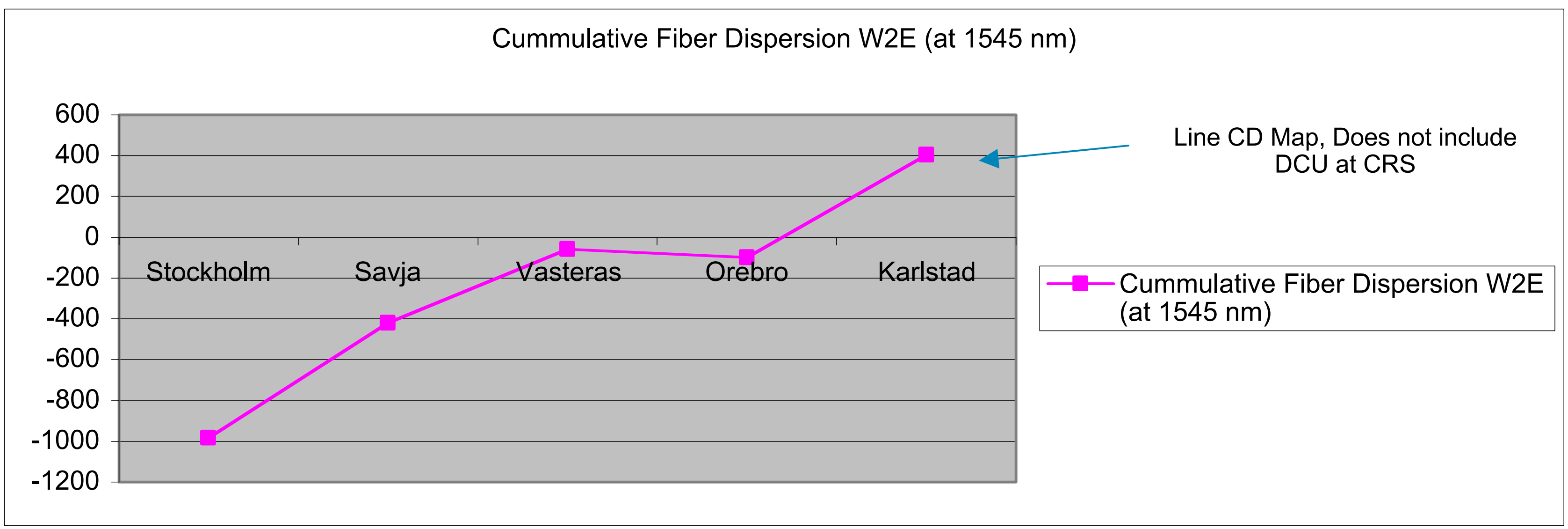
Network Layout

Connectivity at Stockholm and Karlstad

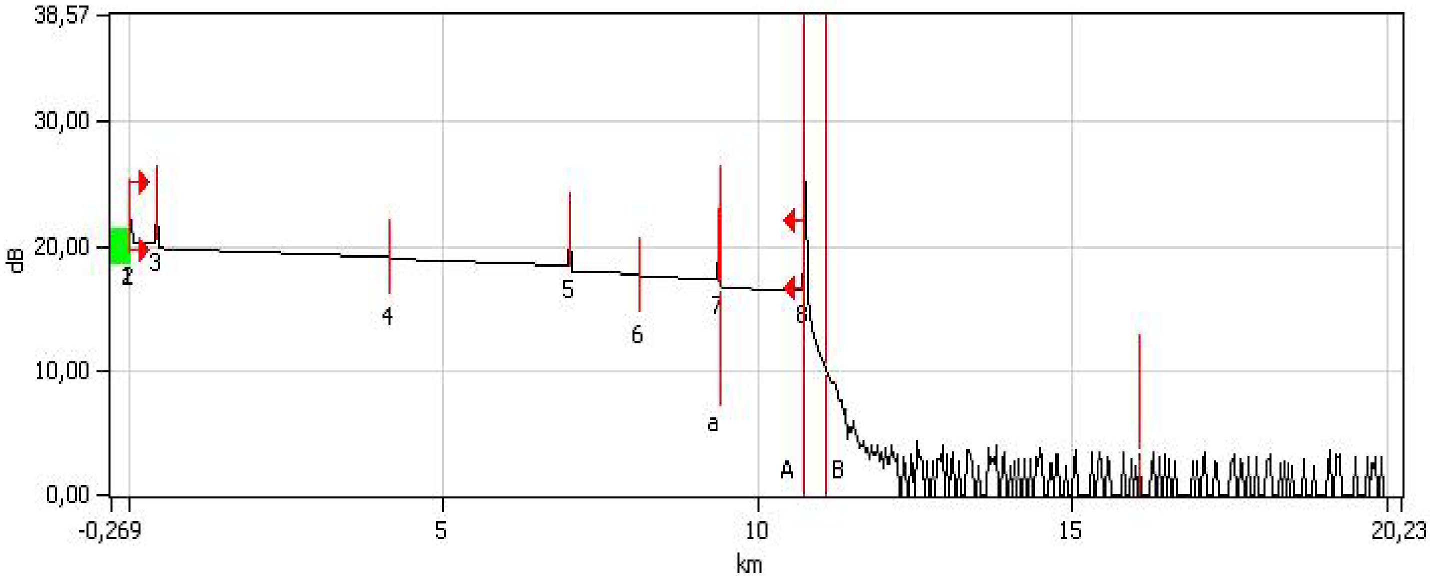


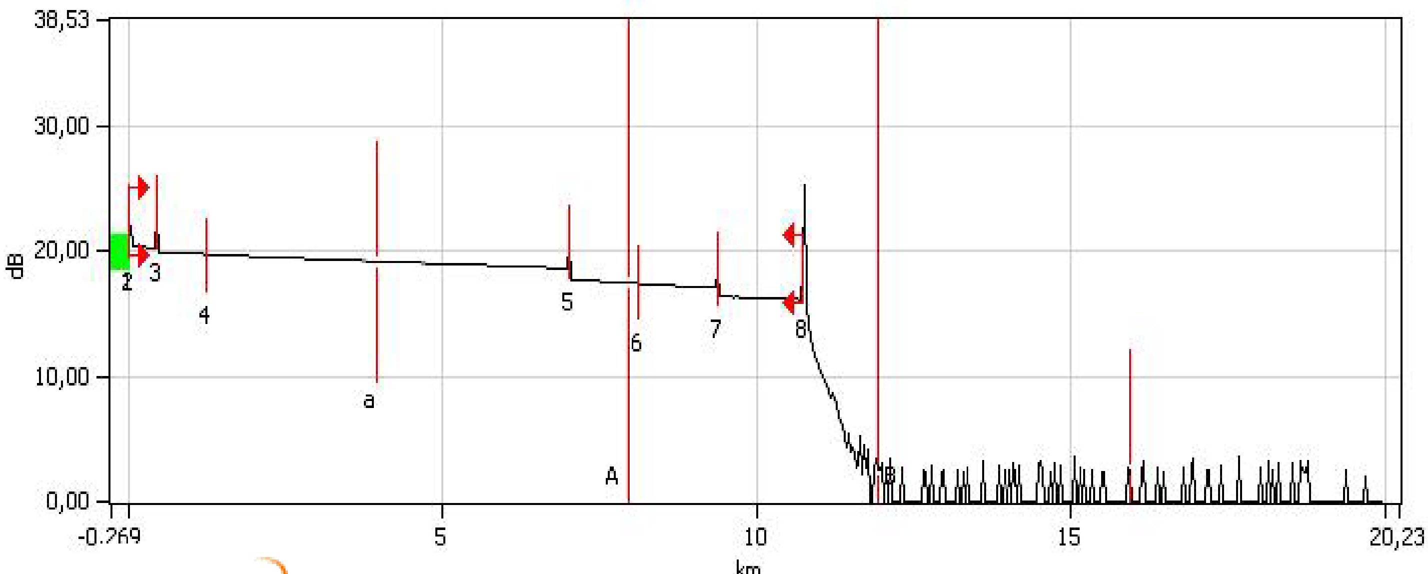
Physical Network





The Local Loop: 10 795m



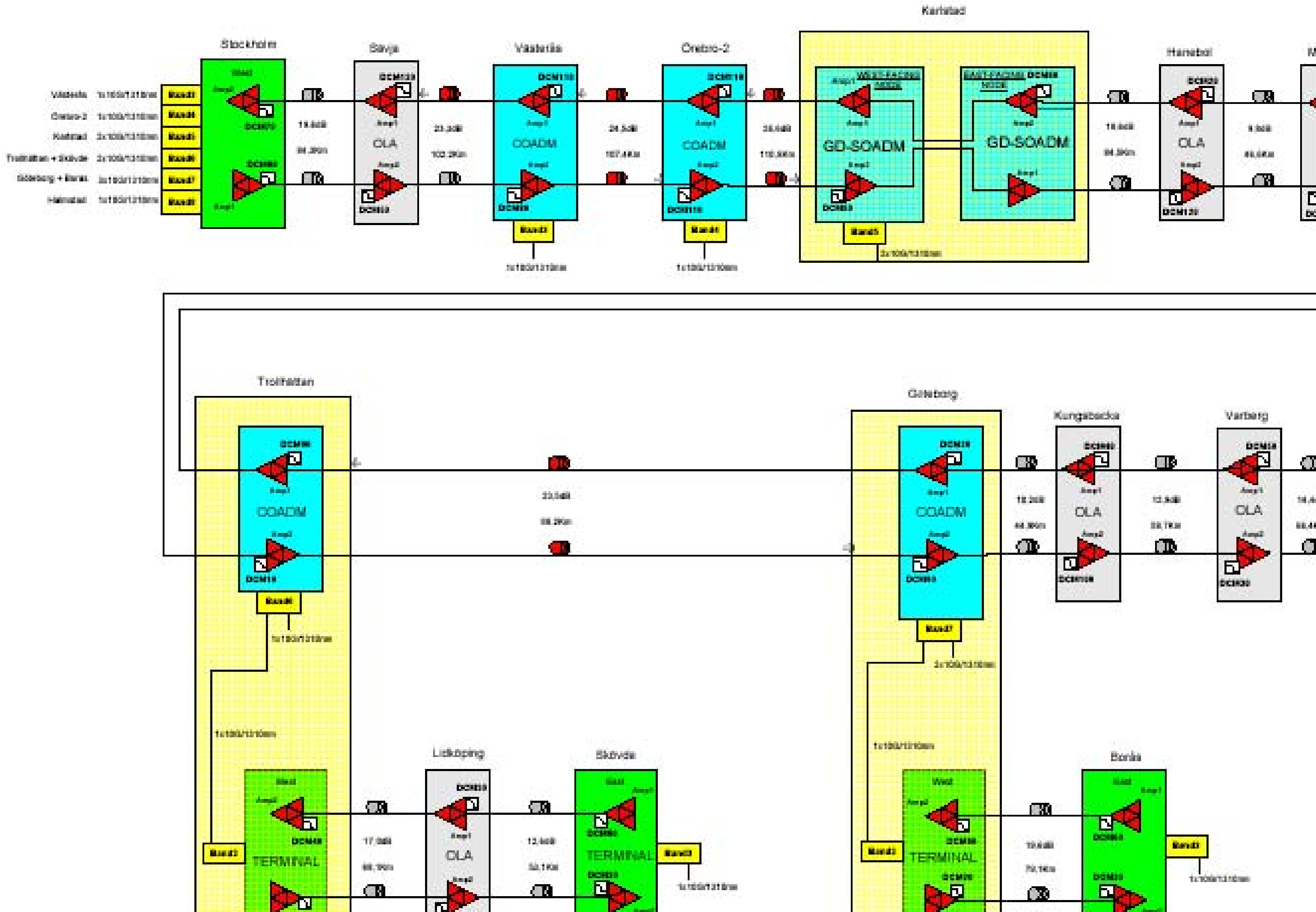


Hafstein Johnsson

Malin Thorsen

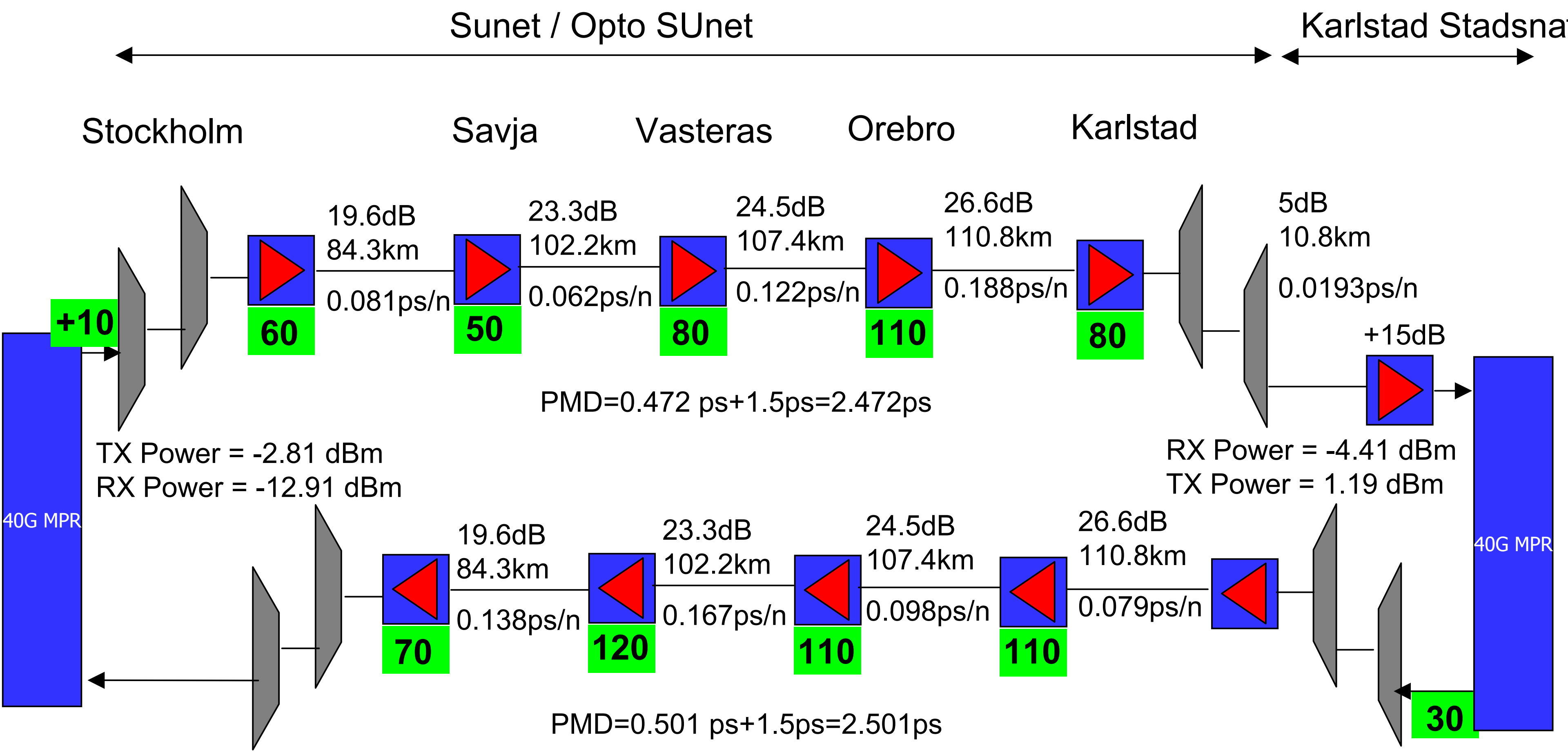
Installation and measurements by ELTEL Networks

KARLSTADS ELNÄT AB

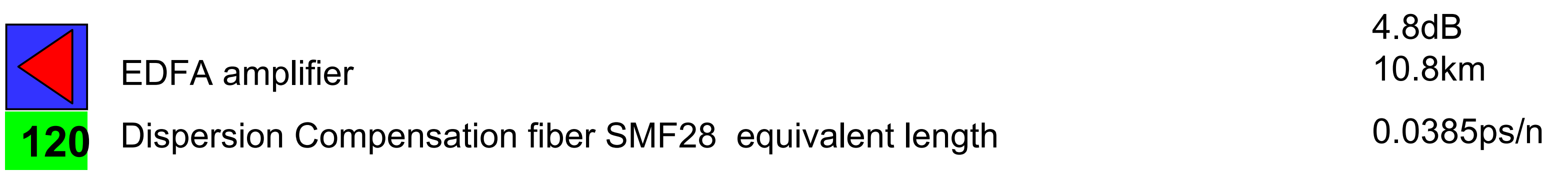


Karlstad
Stockholm
Sävja
Västerås
Örebro-2
Hanebol
OLA
COADM
COADM
GD-SOADM
GD-SOADM
OLA
Trollhättan
Göteborg
Kungsbacka
Varberg
COADM
COADM
OLA
OLA
Lidköping
Skövde
Borås
TERMINAL
OLA
TERMINAL
TERMINAL

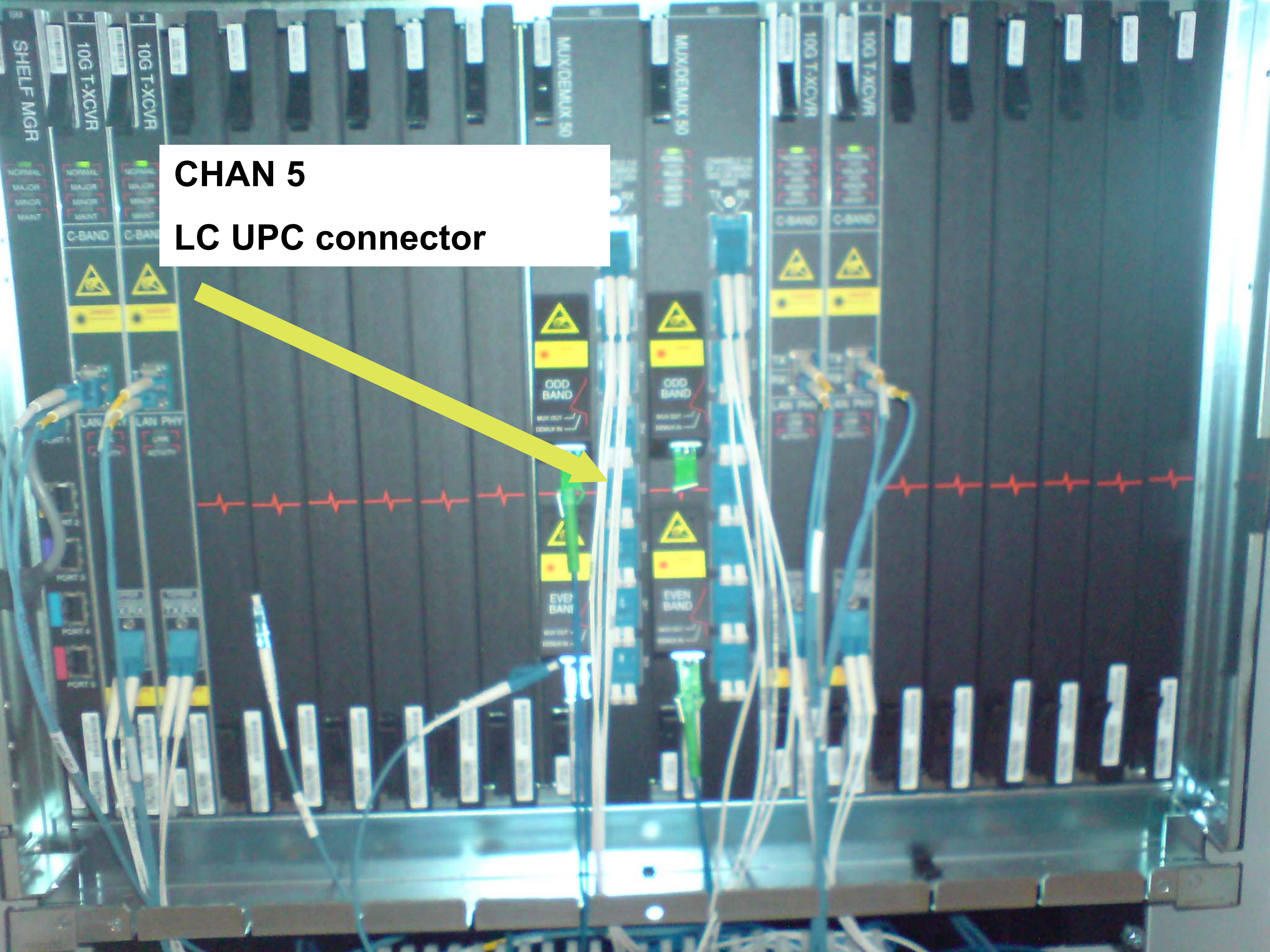
Broad Band to My Mother, Optics



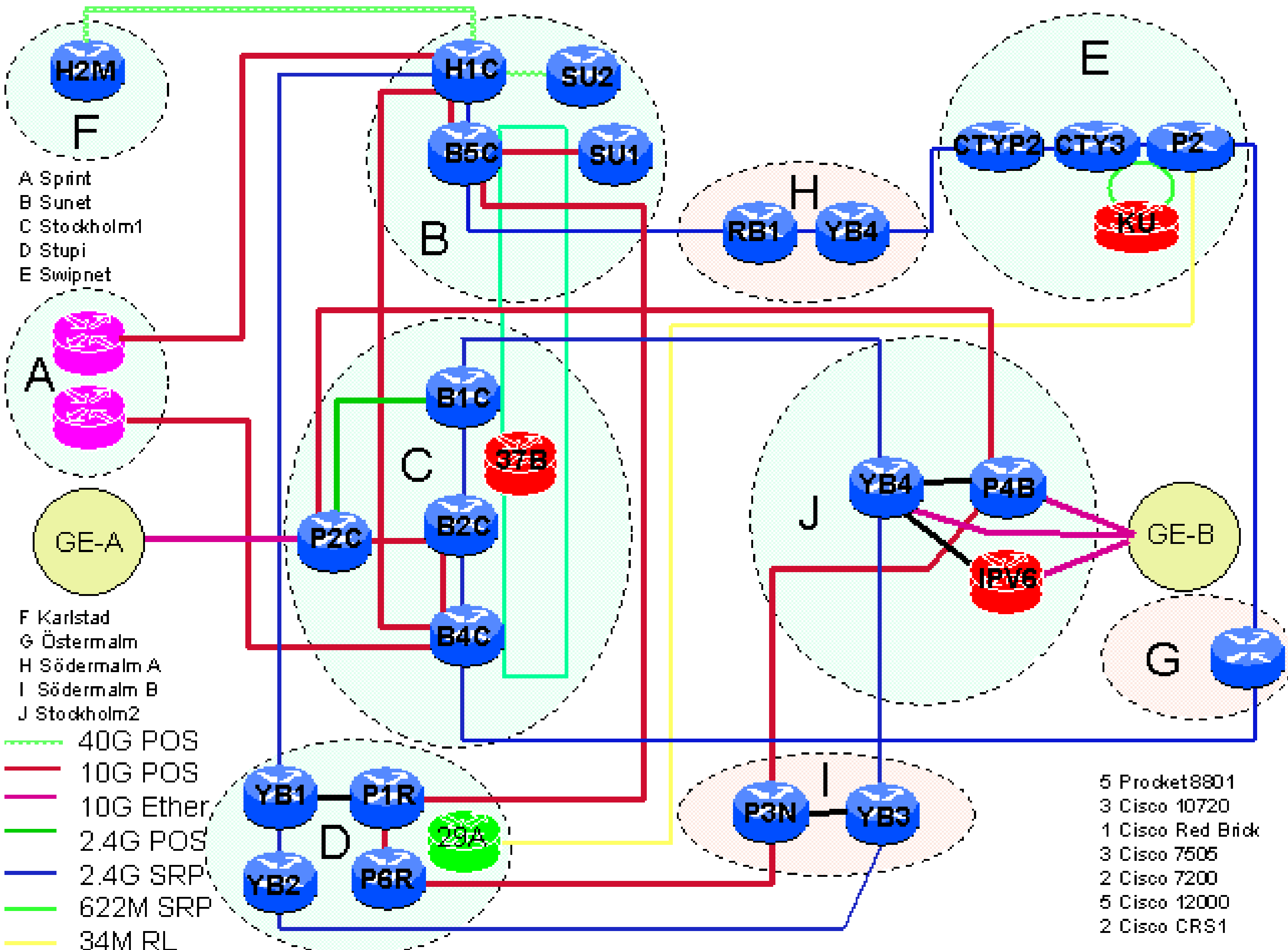
Ciena Band 5, Channel 5, Frequency = 193.30 THz, Wavelength = 1550.918 nm, MSA Channel 57




Erbium-Doped Fiber Amplifier


CHAN 5
LC UPC connector
SHELF MGR
10G T-XCVR
10G T-XCVR
MUX/DEMUX 50
MUX/DEMUX 50
10G T-XCVR
10G T-XCVR
C-BAND
ODD BAND
EVEN BAND
LAN PHY

Stupi Test Network



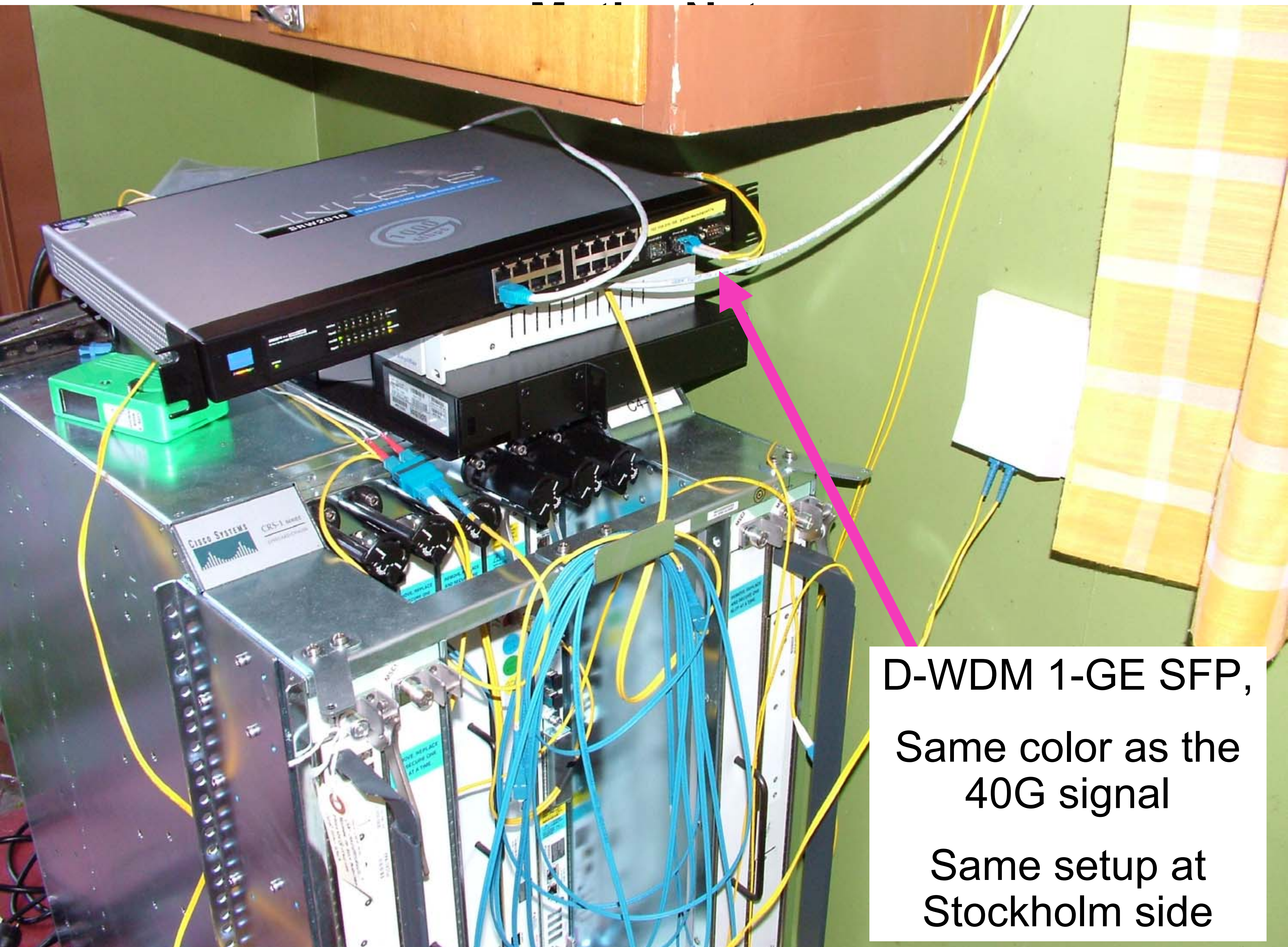
Mothers Alternate use of the broadband gateway

Power Consumption

Operated for 48 days

- Power 1.56 KW

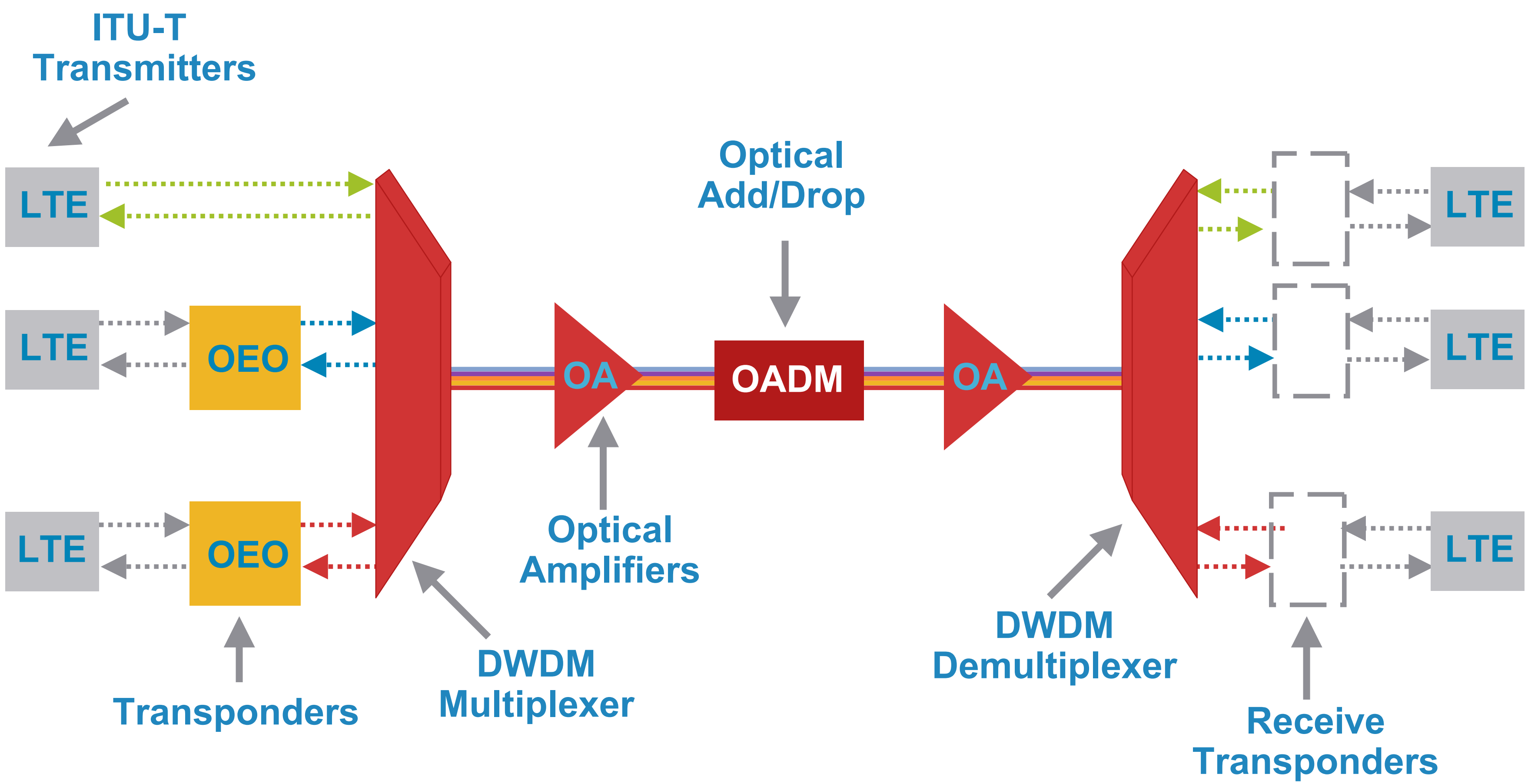
- Cost EUR 293/month


D-WDM 1-GE SFP,
Same color as the 40G signal
Same setup at Stockholm side


C4–2

Optical Impairments

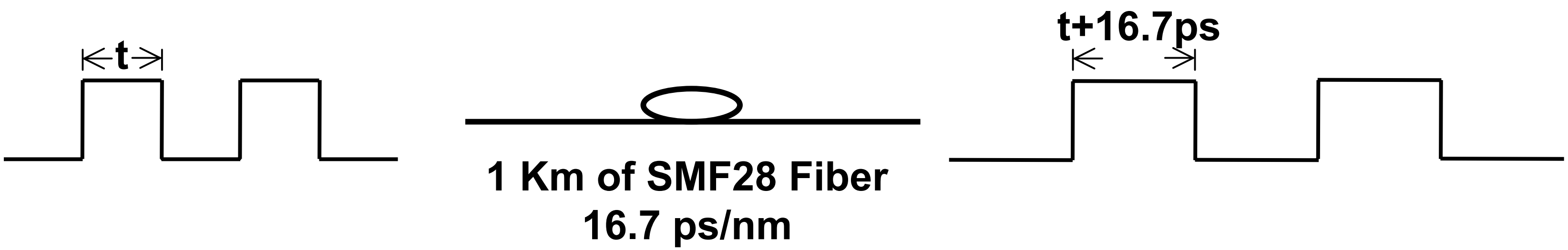
DWDM Building Blocks



Optical Impairments

- Chromatic Dispersion (CD)

  The refractive index of fiber has a wavelength dependence. This causes the higher frequencies to travel faster then lower frequencies causing a pulse broadening effect. Measured in ps/nm*km, threshold / limit measured in ps/nm.



  Confusion, do I want it or not? Is it good or bad?

  Reducing Dispersion will increase distance and performance

    Reducing / Eliminating Dispersion will also increase nonlinear effects thus limiting distance / performance

  Dispersion Compensating Units (DCUs) are used to compensate for CD

Optical Impairments

- Optical Signal-to-Noise Ratio

  Compensate for Attenuation with Optical Amplifier

  Compensate for Dispersion with DCU

- Can we now travel an infinite distance without Regen?

  No! We are limited by OSNR (besides other effects)

- As we start to cascade Amplifiers we introduce noise in the form of ASE

  Signal degradation caused by 2 factors:

  1. Noise to noise beatings
  2. Noise to signal interference

  #1 we can take care of using a narrowband filter

  #2 is the true problem since it is beating against the actual signal hence key limiting factor

Optical Impairments

- How do we calculate Signal to Noise?

  In its simplest form OSNR is:

  OSNR = 58 + Pin - NF - 10*log(N) - 10*log(M)

  Where:

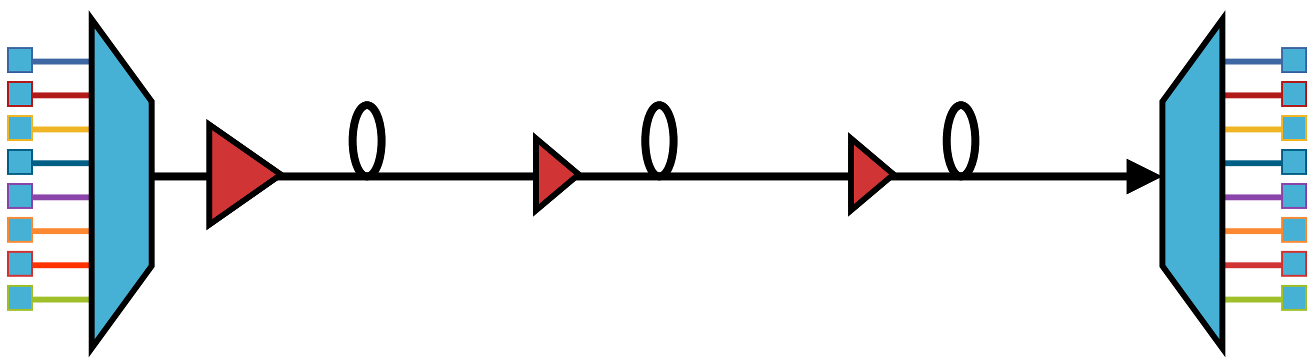
  58 = power density in 0.1nm BW

  Pin = input to EDFA

  NF = Noise Figure of EDFA

  N = # of Optical Channels

  M = # of Amps in cascade



Optical Impairments

G.709 and Forward Error Correction (FEC)

- Ethernet is the transport of choice

  Performance Monitors similar to SONET would be required to ensure proactive monitoring and health of system

- Solution

  Wavelength monitoring via standards based G.709

  Provides SONET like OAM&P

  Standard specifies OTU1(2.5G), OTU2(10G) and OTU3(40G)

- Ethernet cost with SONET like OAM&P

Optical Impairments

G.709 Wrapper

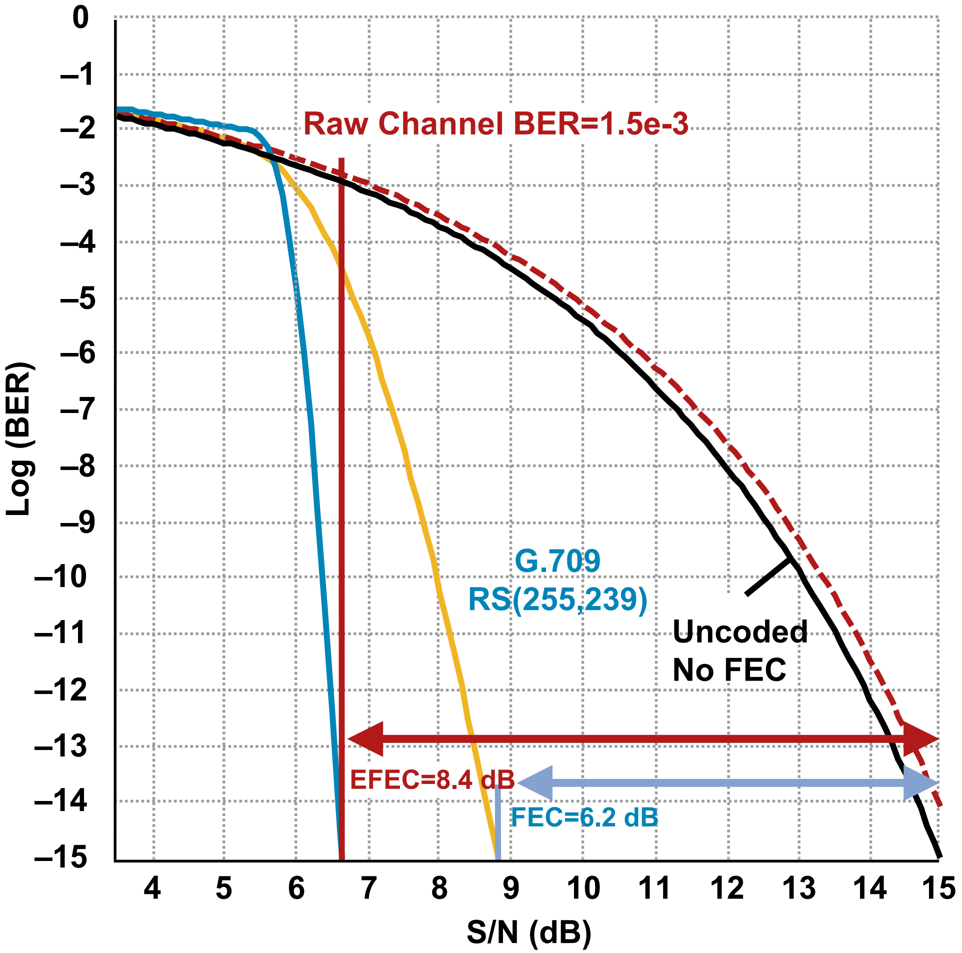
- Client Signal
- OPU*k*Ń Optical Channel Payload Unit
- ODU*k*Ń Optical Channel Data Unit
- OTU*k*Ń Optical Channel Transport Unit
- Alignment

***k* Indicates the Order:**

1	2.5G
2	10G
3	40G

Optical Impairments
FEC

- FEC extends reach and design flexibility, at "silicon cost"
- G.709 standard improves OSNR tolerance by 6.2 dB (at 10^{-15} BER)
- Offers intrinsic performance monitoring (error statistics)
- Higher gains (8.4dB) possible by enhanced FEC (with same G.709 overhead)

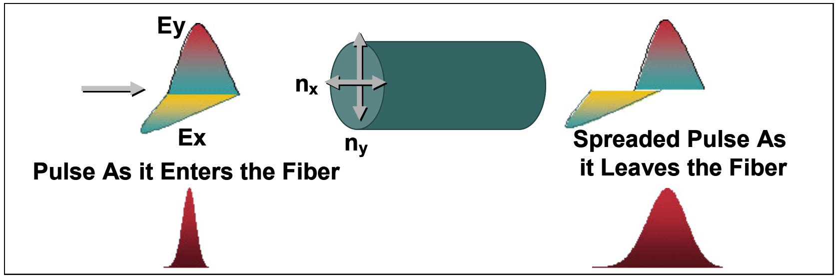


Benefit: FEC/EFEC Extends Reach and Offers 10^{-15} BER

Optical Impairments

- Polarization Mode Dispersion (PMD)

  Since fiber cores are not perfectly symmetrical, the light will travel down the X and Y axis at different rates leading to a pulse broadening effect. This is a function of a coefficient multiplied by the square root of the total distance measured in $ps/km^{1/2}$



  Function of bit rate, greater the bit rate the greater the dependence on PMD

  PMD is statistical in nature, one must account for mean value rather then instantaneous

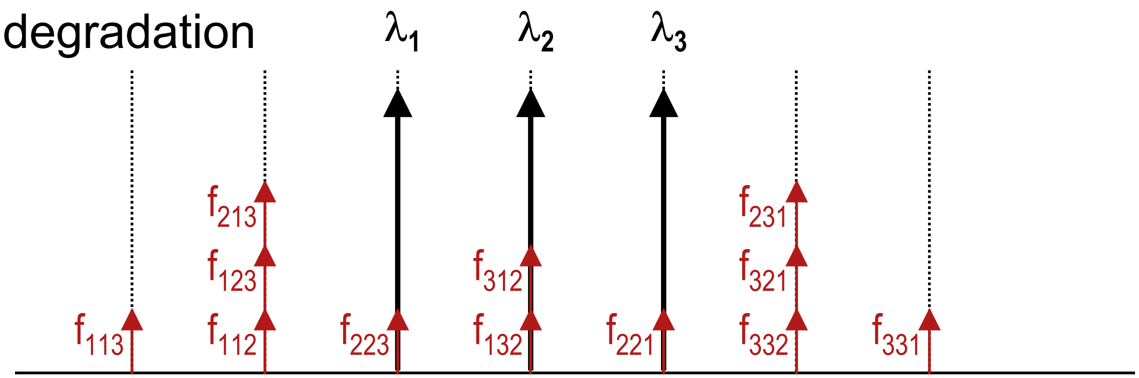
  PMD compensators are available

Optical Impairments

- FPM or FWM

  Beating between two channels at their difference frequency, modulates the phase at that frequency generating new tones as side bands.
  These new products interfere with other channels

  BER degradation



Total Beats = N(N-1)^2

- Counter Measures

  Unequal Channel Spacing

  Increase Channel Spacing

  Chromatic Dispersion, waves alternate in and out of phase, reducing mixing efficiency

Optical Impairments

- XPM

  This arises due to the weak dependence of the refractive index on intensity: $n=n_0 + n_2*I$. Here the nonlinear refractive index modulates one of the carriers onto the other.

  Pulse broadening gets exaggerated with Chromatic Dispersion

- Counter Measures

  Chromatic Dispersion, the group velocity causes the interfering pulse to walk thru the other

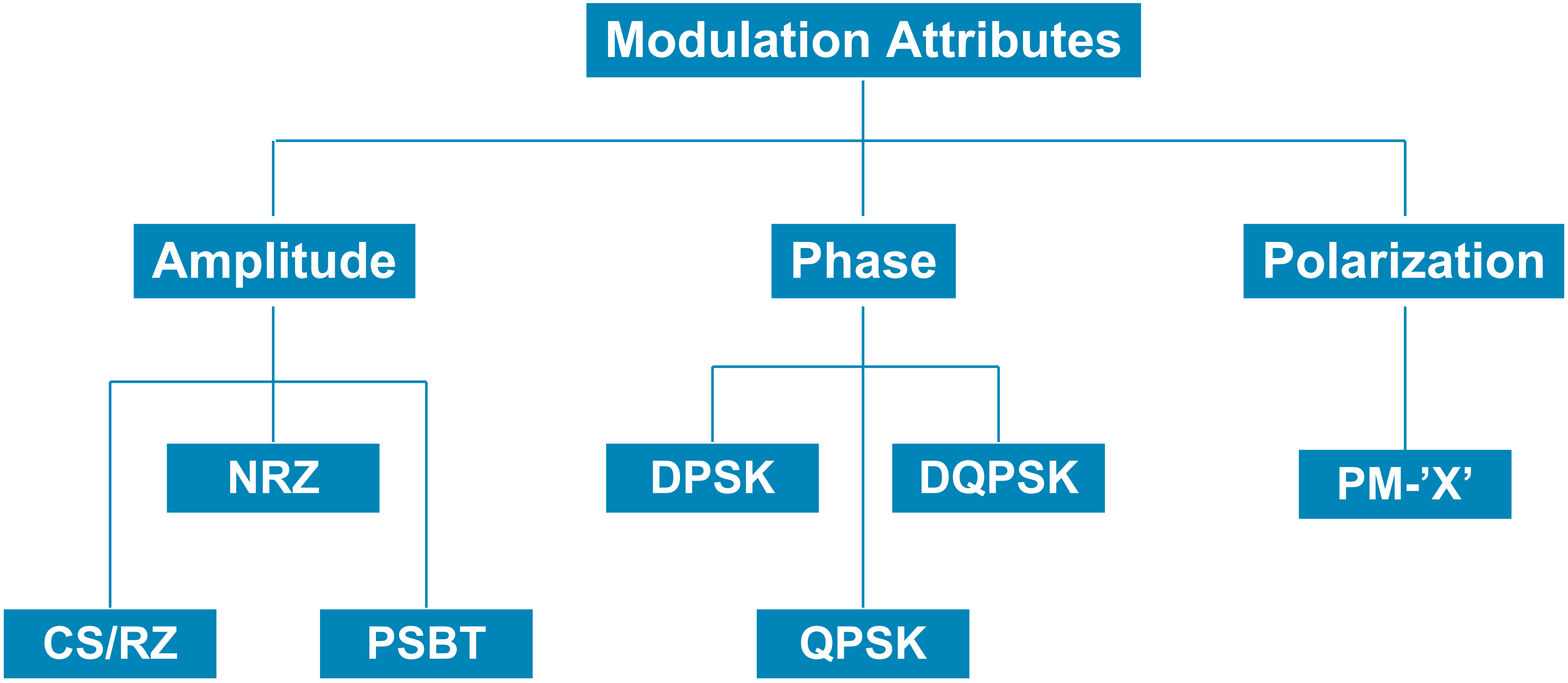
  Larger spacing between carriers

Modulation Schemes

Acronyms

- (N)RZ—(Non) Return to Zero
- PSBT—Phase Shaped Binary Transmission
- CS-RZ—Carrier Suppressed Return to Zero
- DPSK—Differential Phase Shift Keying
- DQPSK—Differential Quadature Phase Shift Keying
- QPSK—Quadature Phase Shift Keying
- PM-'X'—Polarization Multiplexing

Modulation Schemes

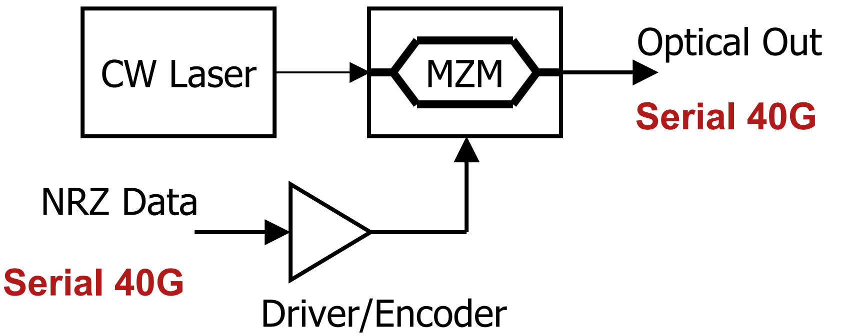


Where 'X' Can Be DPSK, DQPSK, QPSK, etc. …

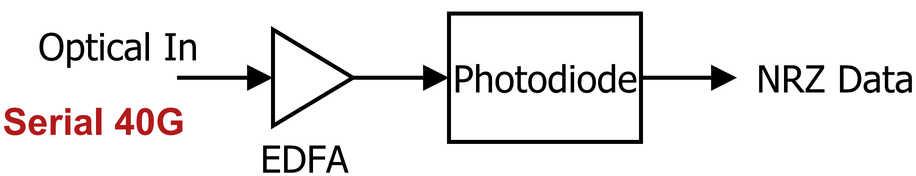
Modulation Schemes

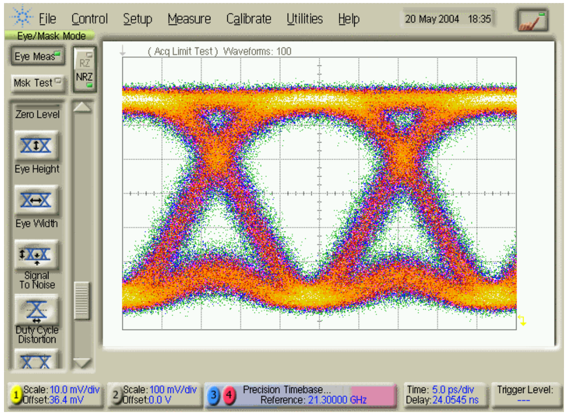
PSBT Implementation

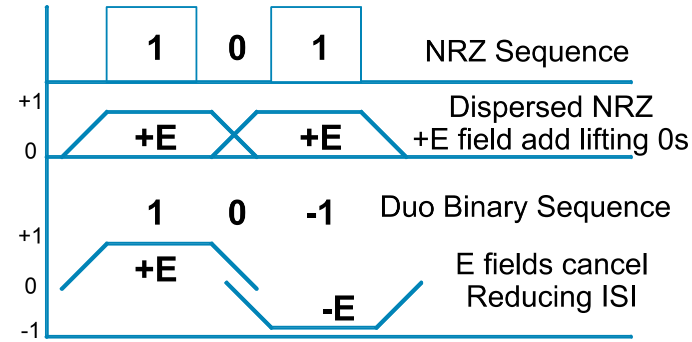
Tx Block Diagram

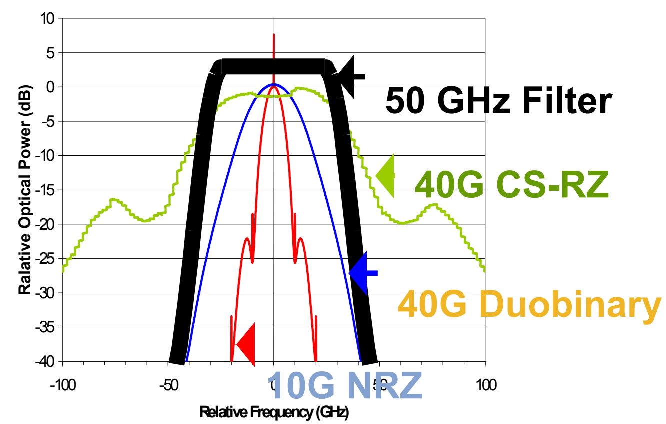


Rx Block Diagram

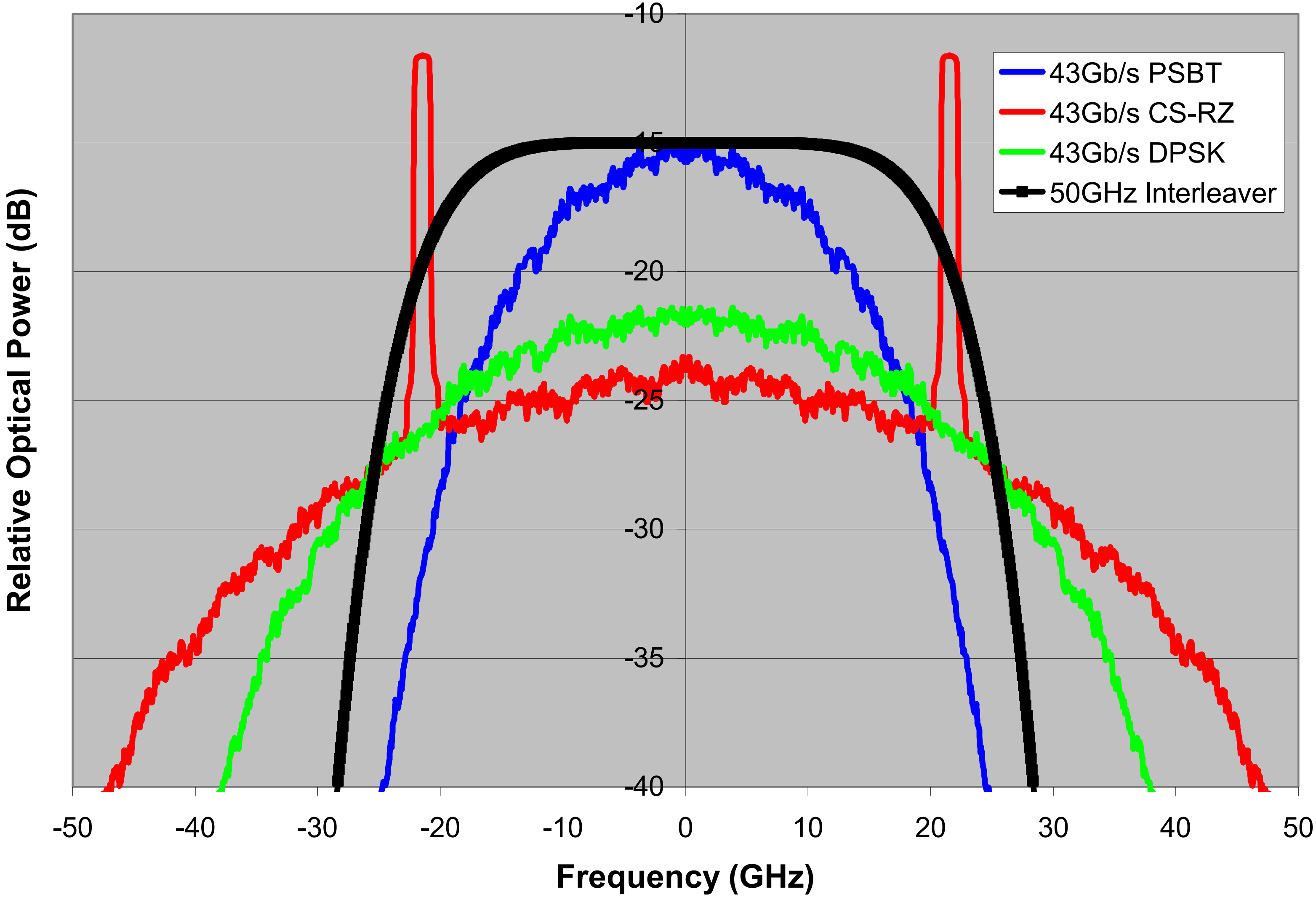






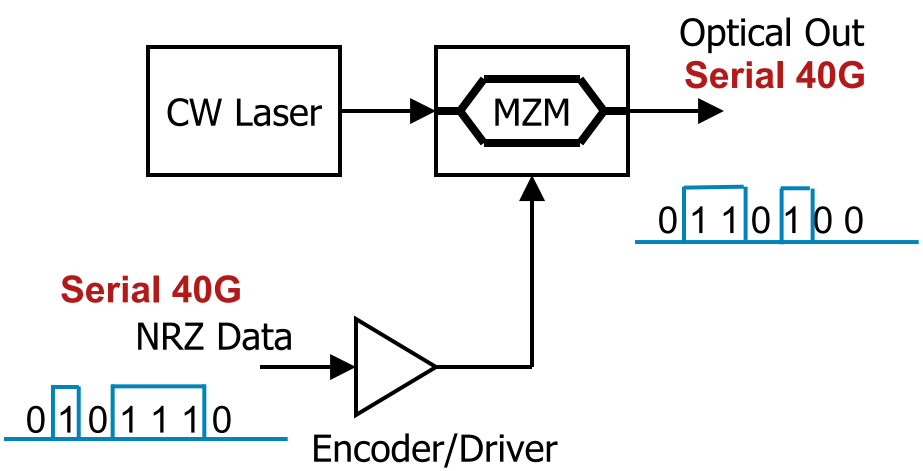


DWDM Filter Compatibility

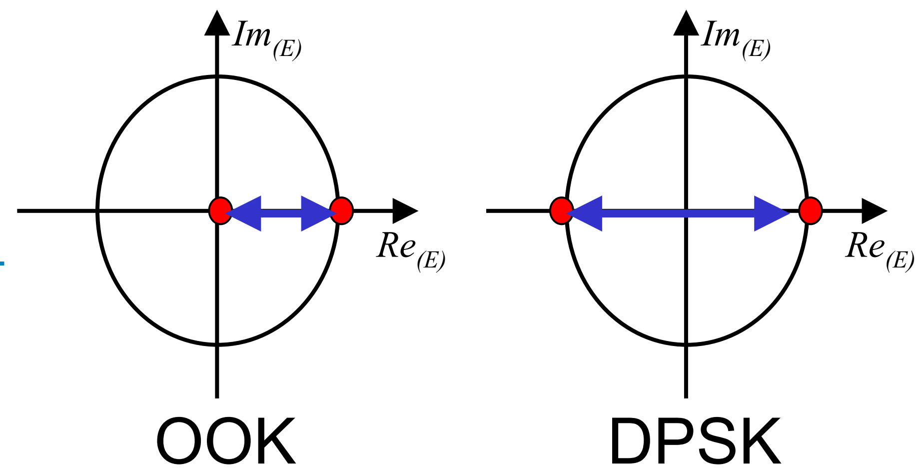


Modulation Schemes
DPSK Implementation

Tx Block Diagram

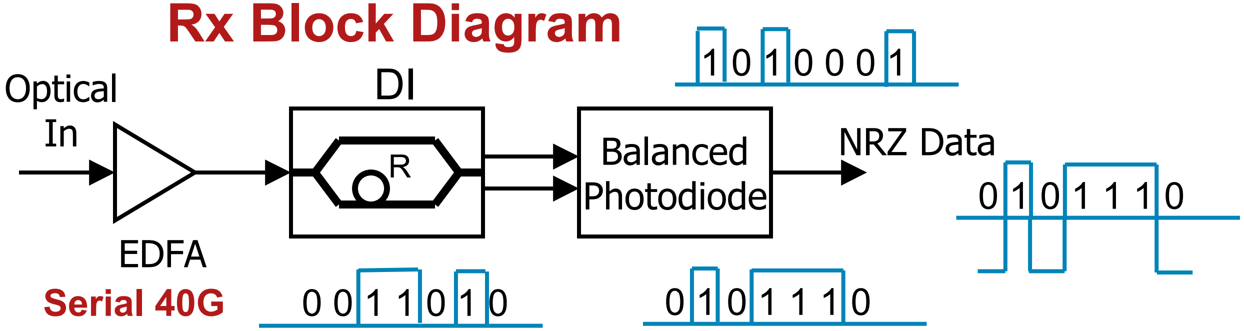


Why Is DPSK Have Better OSNR Performance?



As You Can See, Symbol Separation Is a Factor of 2 for the Same Average Power Hence 3 dB First Order.

Rx Block Diagram



Some Modulation Schemes of today

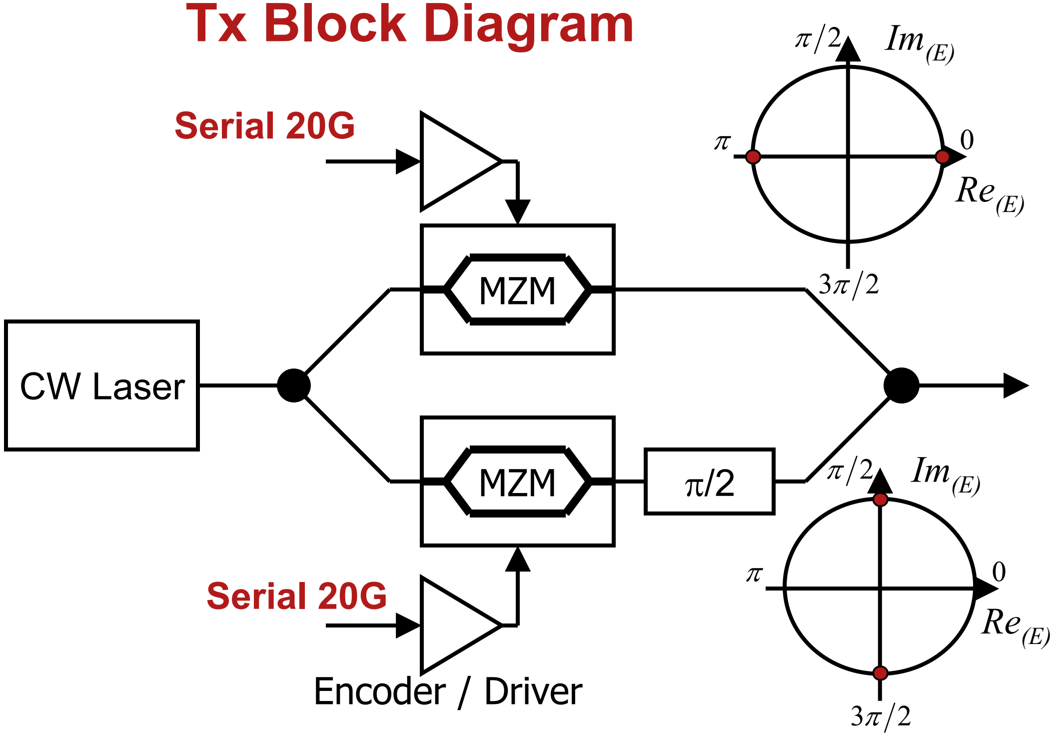
Comparison Table

	OOK	PSBT	DPSK	DQPSK	QPSK	PM-(D)QPSK
OSNR Sensitivity	16dB/ 0.1nm	16dB/ 0.1nm	13dB/ 0.1nm	15dB/ 0.1nm	13dB/ 0.1nm	11dB/ 0.1nm
PMD Tolerance	1ps	2.5ps	2.51ps	5ps	5ps	10ps
CD Tolerance	+/– 50ps/nm	+/– 150ps/nm	+/– 100ps/nm	+/– 200ps/nm	+/– 200ps/nm	+/– 800ps/nm
Electronics Complexity	**Medium**	**Medium**	**Medium**	**Low**	**Low**	**High**
Photonics Complexity	**Low**	**Low**	**Low**	**Medium**	**High**	**High**

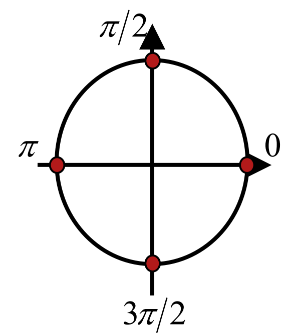
Modulation Schemes

DQPSK Implementation

Tx Block Diagram



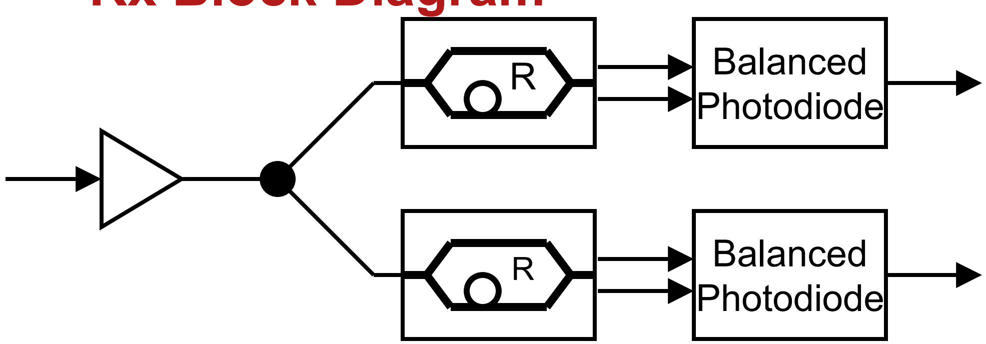
Basically DPSK with π/2 Phase Shift



Four Phase Levels:
Decoder:

Phase	Data
0	0 0
π/2	1 0
−π/2	0 1
π	1 1

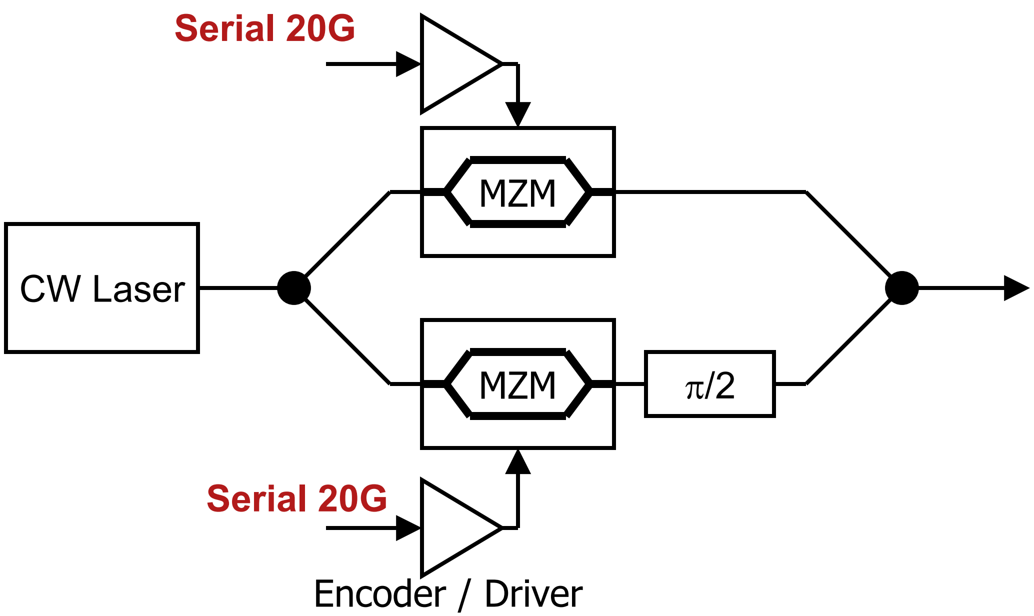
Rx Block Diagram



- While maintaining full data rate we half the line rate thus improving both CD and PMD robustness
- More robust to OSNR then OOK although not as robust as DPSK due to separation

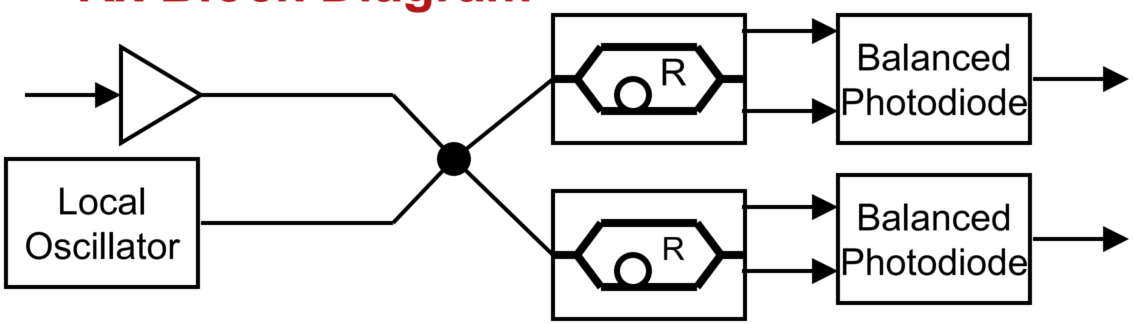
Modulation Schemes
QPSK Implementation

Tx Block Diagram



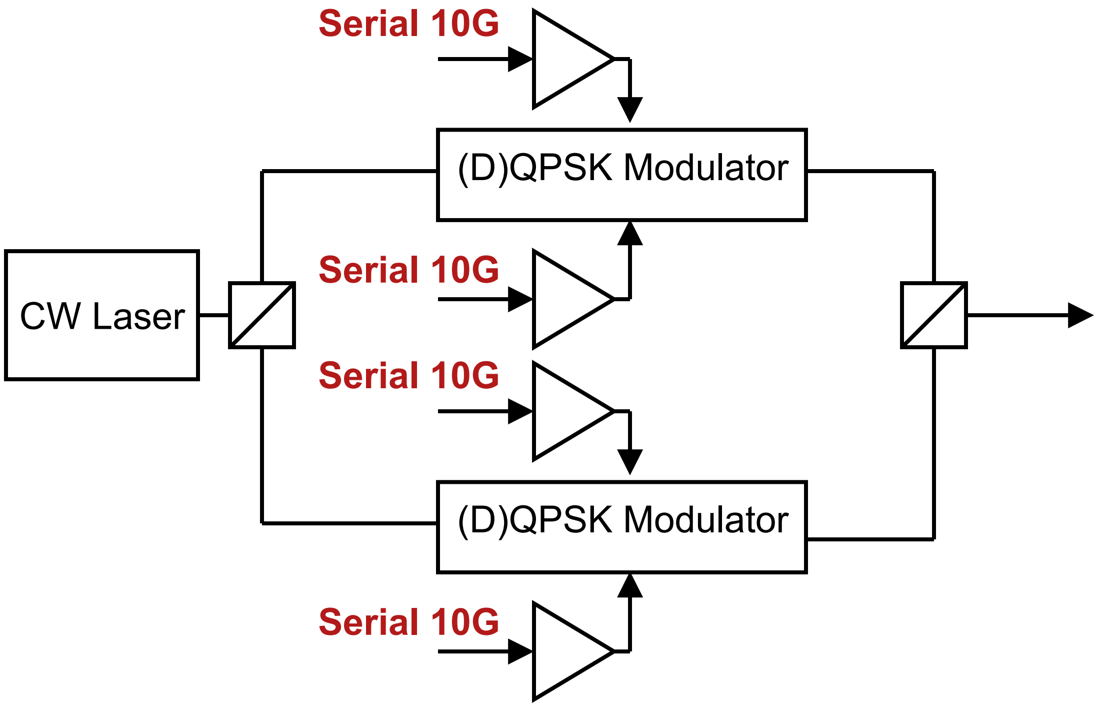
- Similar to DQPSK although utilizes coherent detection
- More complex and costly to implement, requires a laser source at Rx

Rx Block Diagram

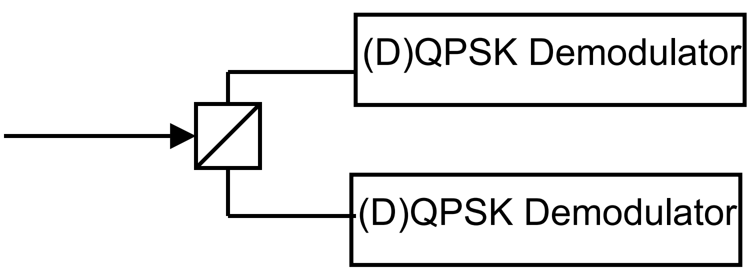


Modulation Schemes
Polarization Mux (PM)-(D)QPSK

Tx Block Diagram



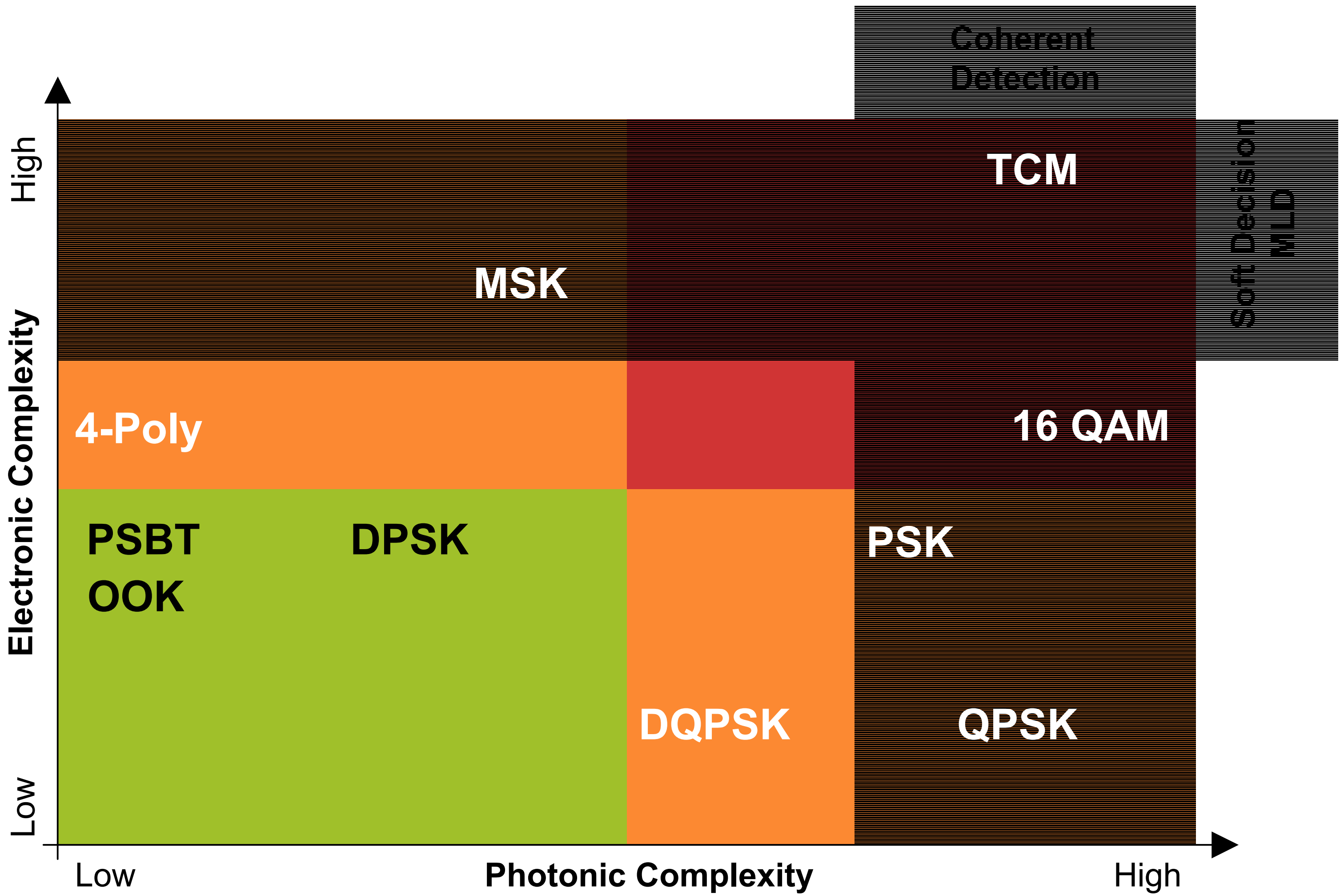
Rx Block Diagram



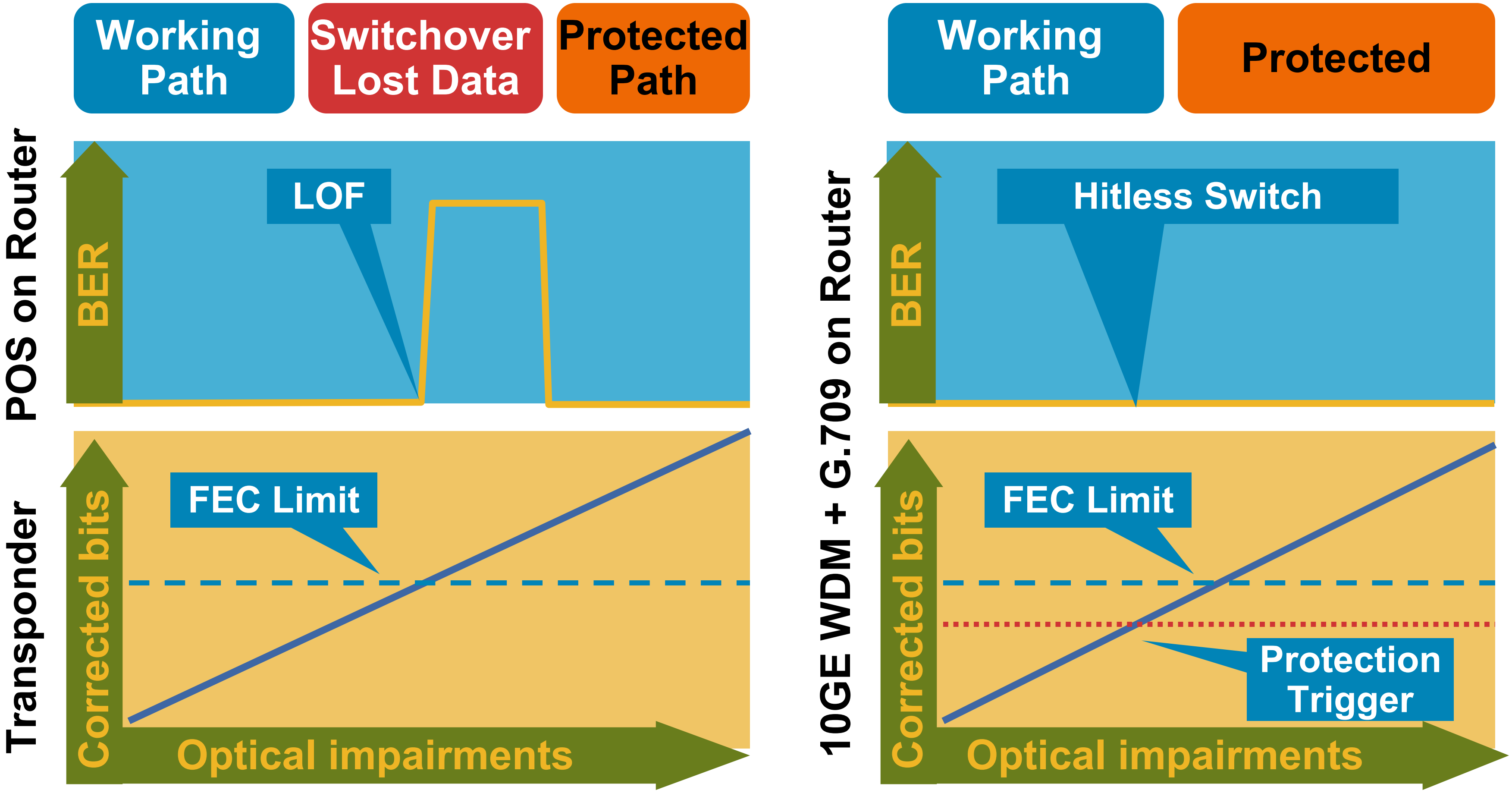
- Theoretically 10 Gig performance
- Utilized 10Gig electronics
- Must control polarization
- Most complex of all schemes

Modulation Schemes

Implementation Complexity



Why IPoDWDM
Possible Feature



Superior Protection Compared to Transponder-Based Networks

Network Architecture

Design Considerations

Noise and Impairment Limit: OSNR

- Noise Tolerance of 40G Receiver differs from 10G

	40G IPoDWDM Transceiver	10G Transponder
Launch Powers	0 dBm	0 dBm
Rx Windows	5 to –18 dBm	0 to –23 dBm
OSNR (.1nm)	~ 18.6 dB	~ 15 dB

Network Architecture

Design Considerations

Noise and Impairment Limits: Dispersion

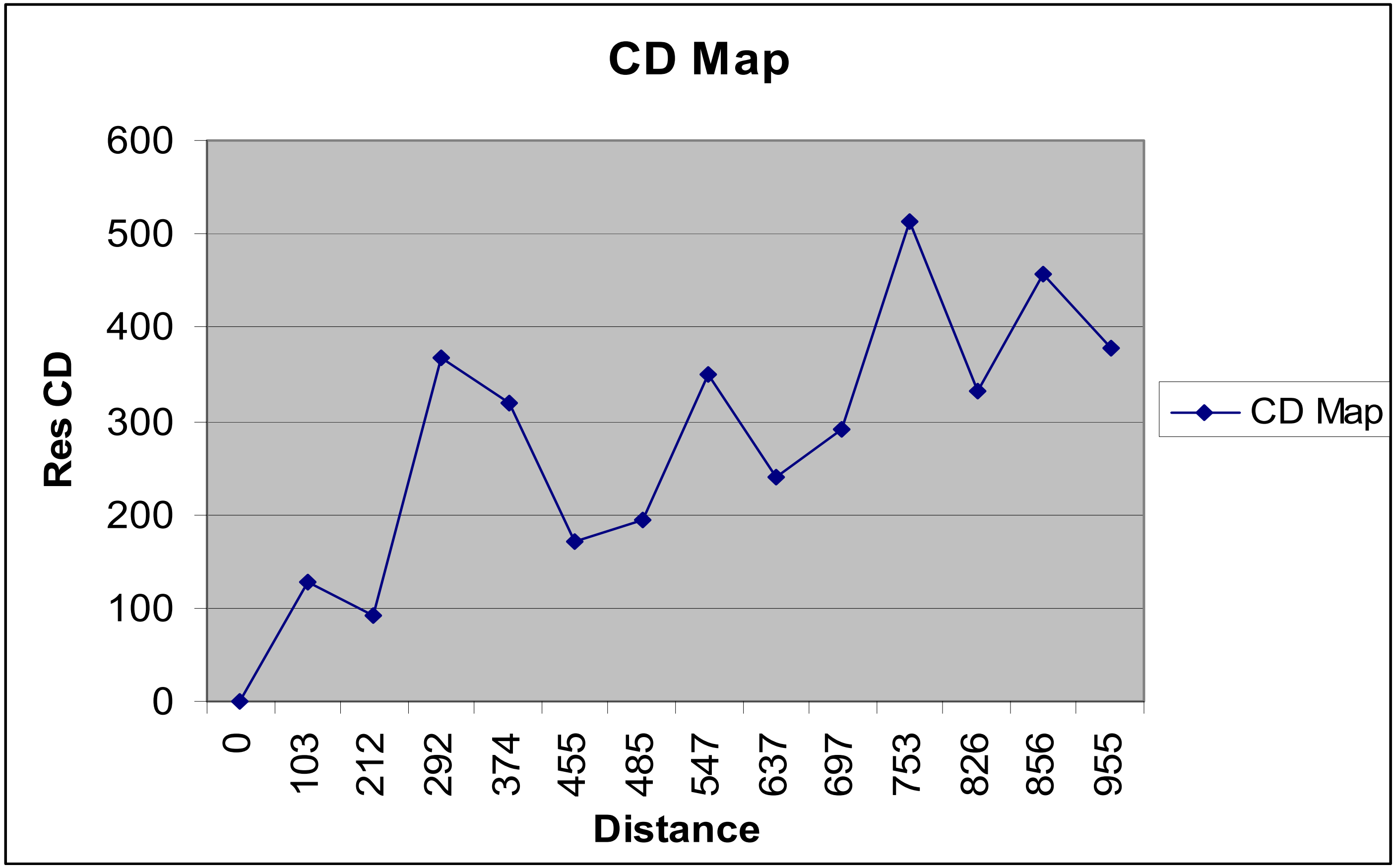
- Impairment Tolerance of 40G Receiver differs from 10G

	40G IPoDWDM Transceiver	10G Transponder
CD	+/– 150 ps	+/– 2000 ps
PMD	2.5 ps	10 ps

Network Architecture

Design Considerations

Noise and Impairment Limits: Dispersion (Cont.)



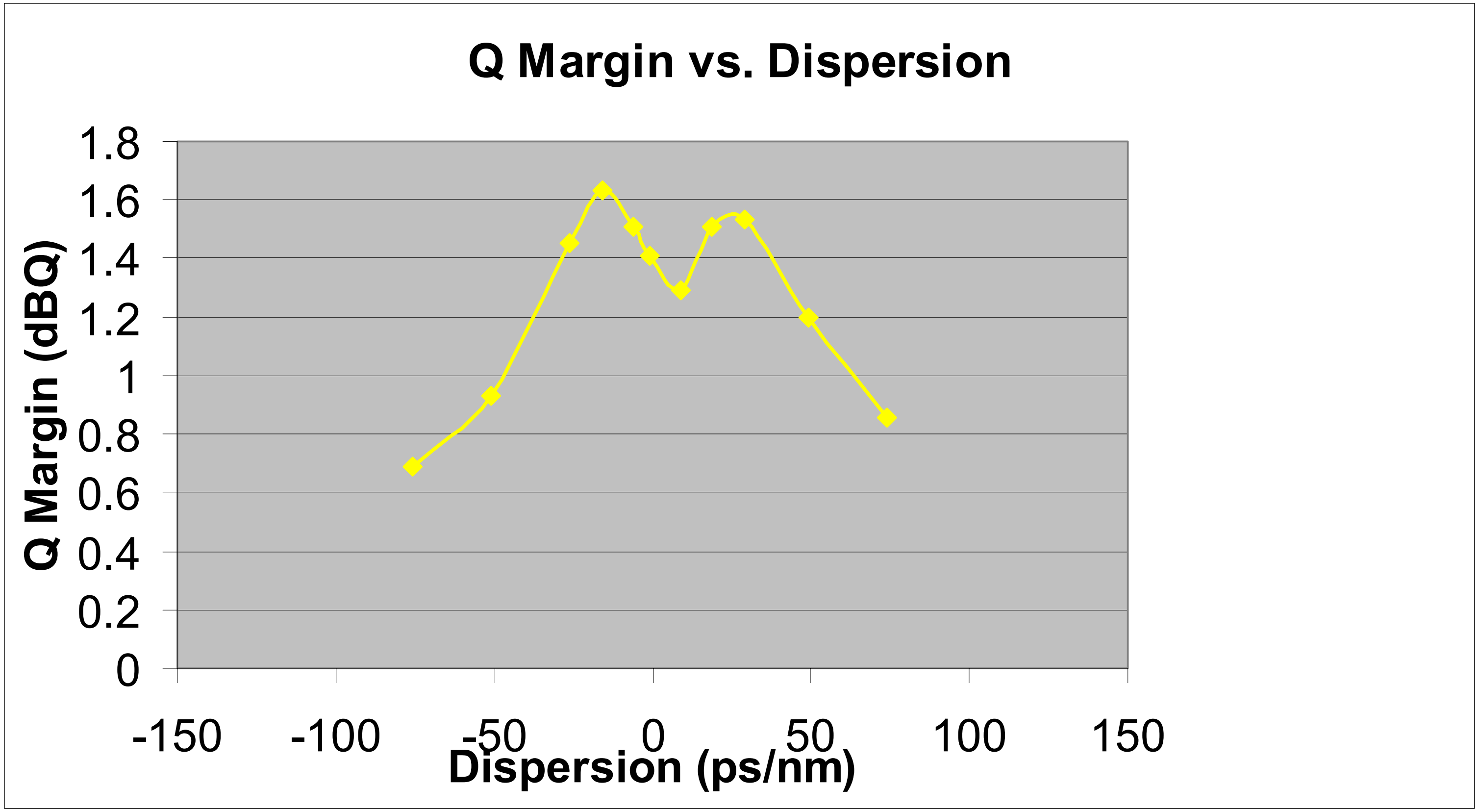
954 km Link Across 8 ROADM Nodes and 6 Line Amplifier Nodes

Network Architecture

Design Considerations

Noise and Impairment Limits: Dispersion (Cont.)

Fine Tuning Dispersion for Optimal Operating Margin



Network Architecture

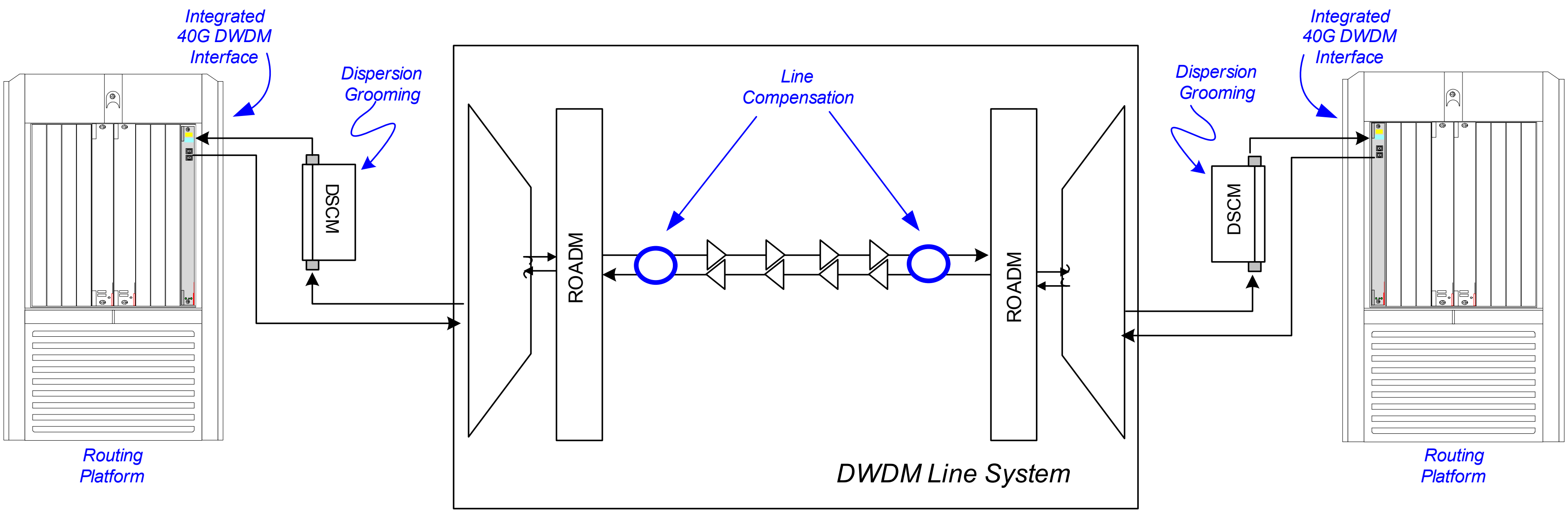
Design Considerations

Noise and Impairment Limits: Dispersion (Cont.)

- Smaller Window of Tolerance for Chromatic Dispersion

  Line Compensation was deployed throughout the network to solidify the “Open” Architecture

  Dispersion Grooming is deployed at the receiver where needed



Network Architecture

Design Considerations

System Engineering: Engineering for Dispersion

- Calculating Line Dispersion:

$$CD_{SMF}(\lambda) = \frac{S_0}{4}\left(\lambda - \frac{\lambda_0^{\,4}}{\lambda^3}\right)$$

$S_0 = 0.092$ ps/(nm^2 * km)

$\lambda_0 = 1311$nm

- Determining Residual Dispersion:

$$CD_{RES}(\lambda) = CD_{SMF}(\lambda) - Comp_{Line}(\lambda)$$

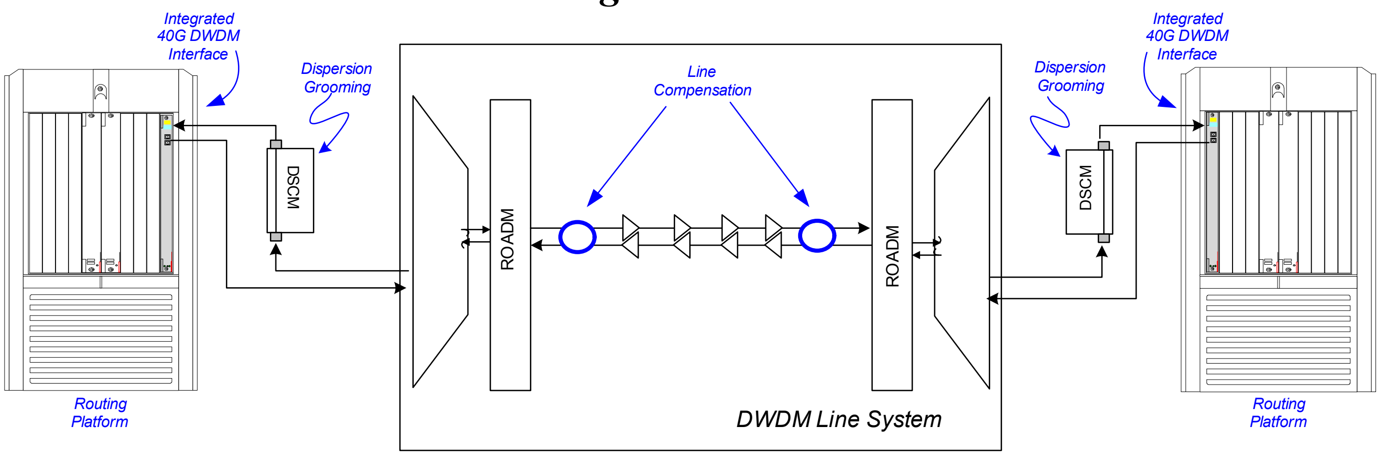
Network Architecture

Design Considerations

Engineering for Dispersion (Cont.)

If the Residual Dispersion, CD_{RES}, is outside of the Receiver's CD Tolerance window, additional Dispersion Grooming must be performed via additional compensation.

$$CD_{RX} = CD_{RES} - [CD_{Grooming}]$$



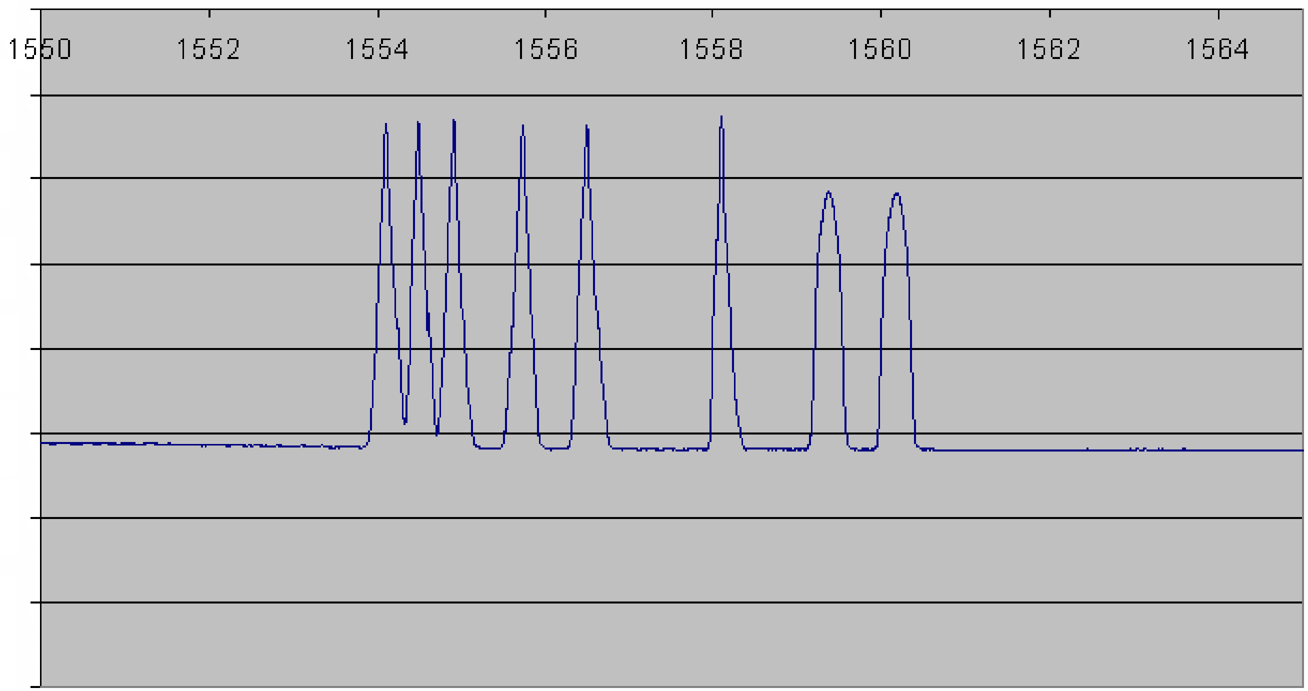
For an IPoDWDM Transceiver with a CD Receiver Tolerance of +/– 150 ps, the dispersion at the receiver, CD_{RX}, must be:

$$-150 \text{ ps} < CD_{RX} < +150 \text{ ps}$$

Network Architecture
Design Considerations

Spectrum Analysis of 954 km Link

6 x 10G Production Channels + 2 x 40G Production Channels



Measured (shown): 18.95dB (0.1nm RBW)

PostFEC BER (bps): 0

Network Architecture
Design Considerations

- Fiber Characterization is a must
- OTDR for **loss** and Distance
- Dispersion Compensation
  - Electronic/Tunable Dispersion Compensation
  - Coherent Receivers
- PMD Compensation
- ORL/Reflectance
- OSNR Gains
  - Narrow Band Filters
  - RAMAN Amplifiers

SMF28 fiber

No Slope Compensation

No TDC

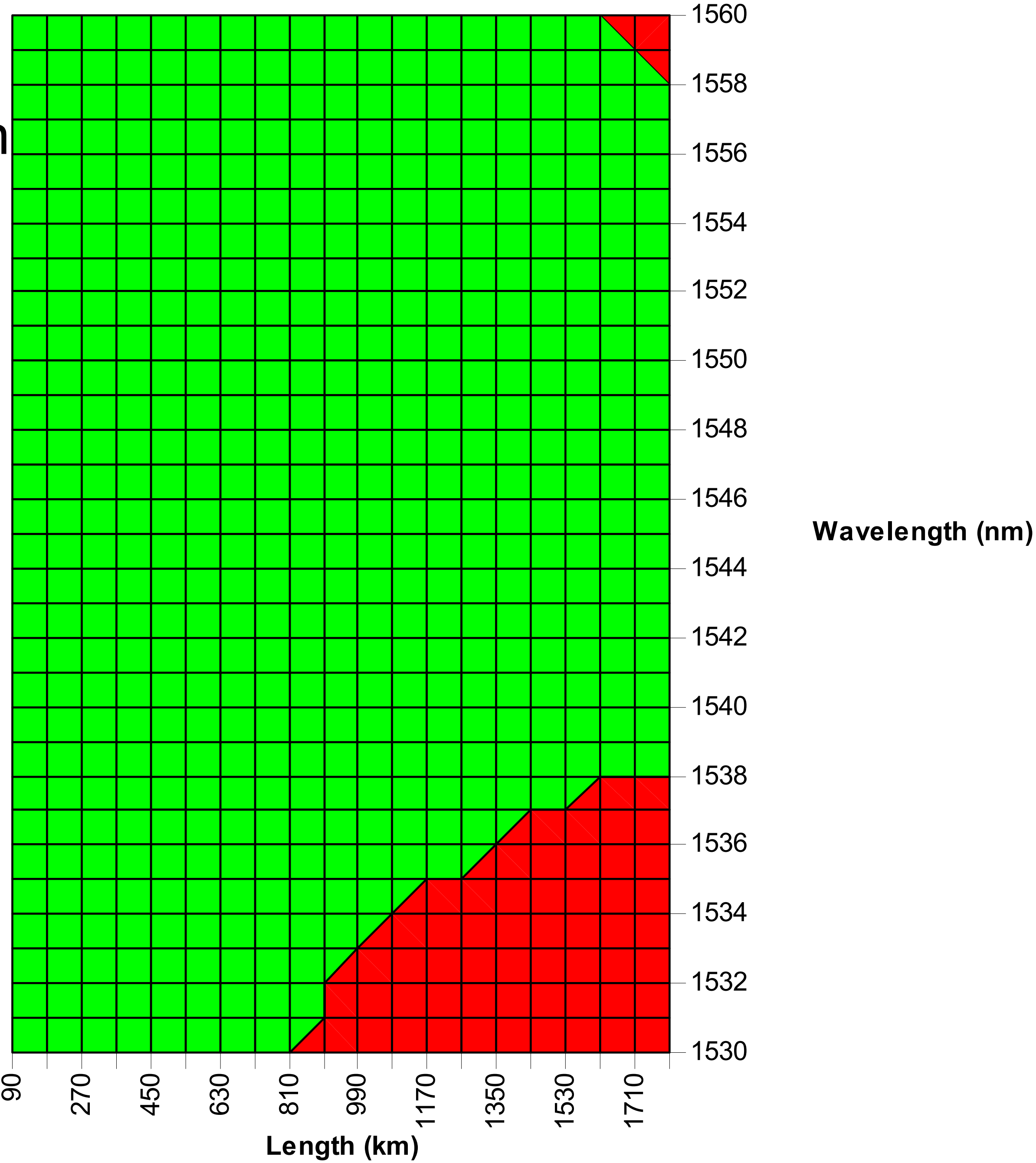
No PMD

SMF28 fiber

No Slope Compensation

TDC

No PMD

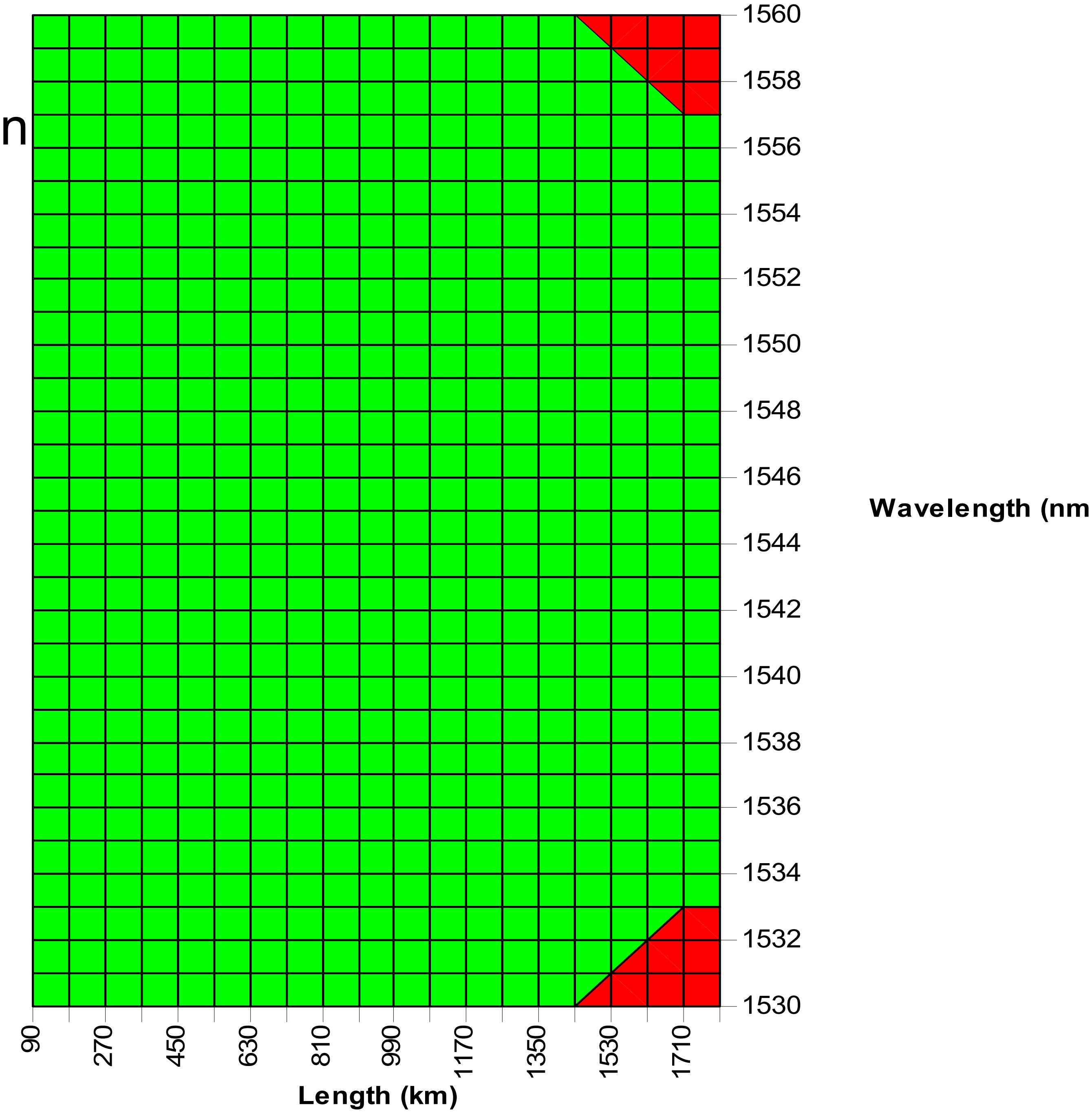


SMF28 fiber

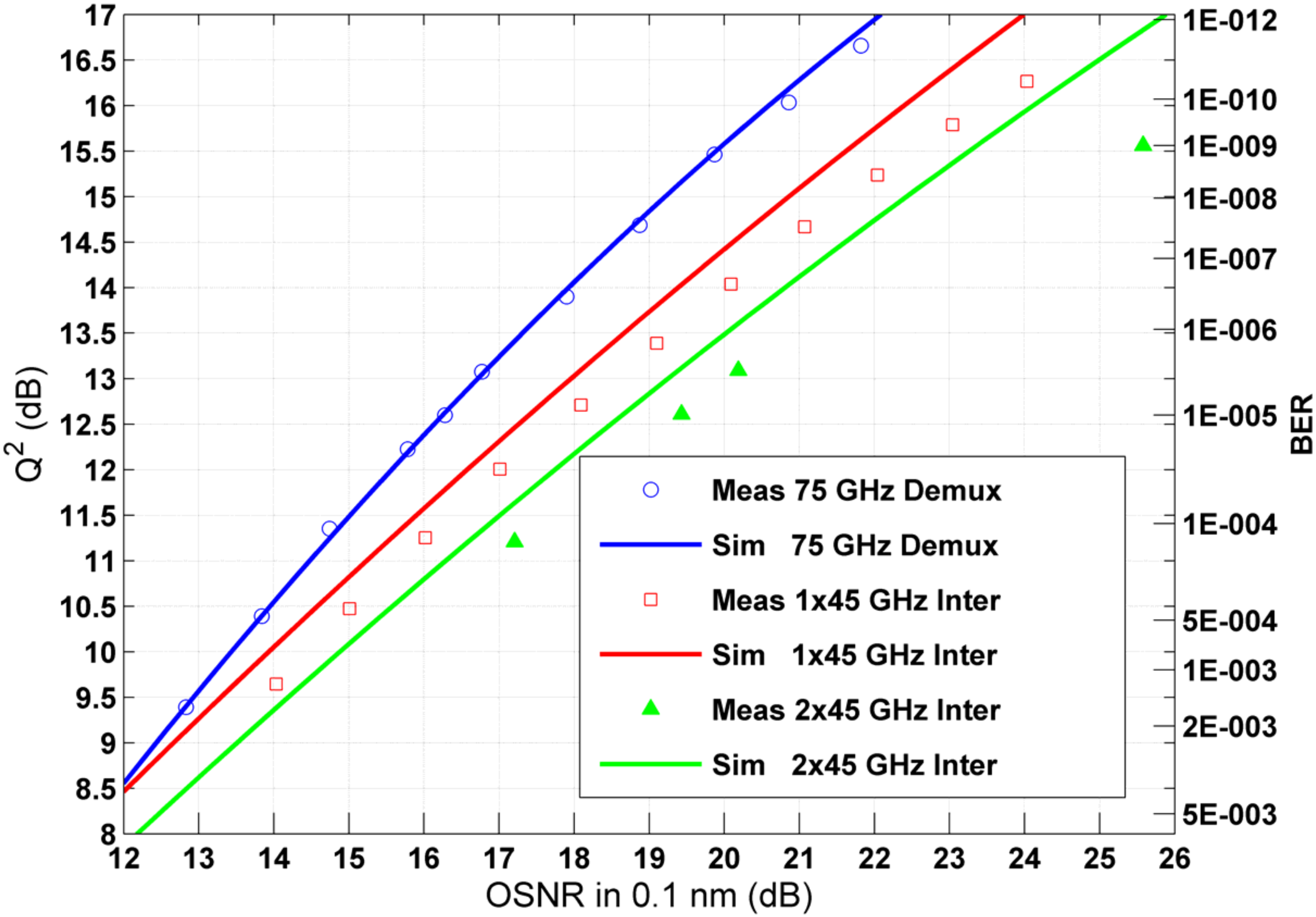
Slope Compensation

TDC

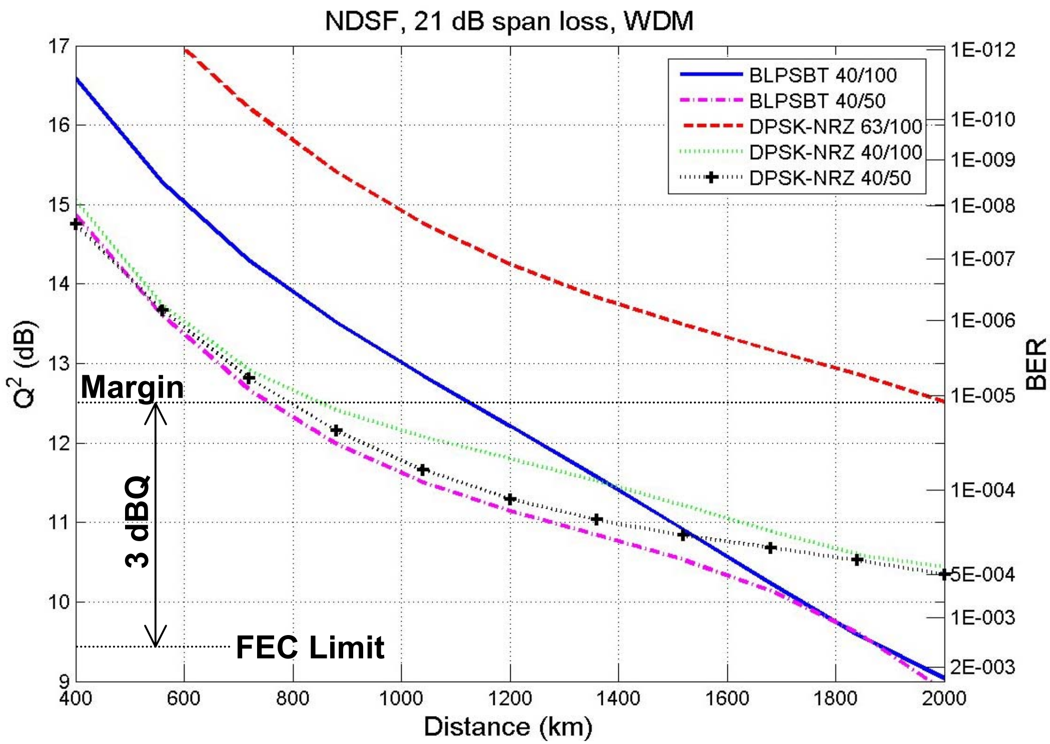
No PMD



Watch out for enemy tactics: Back to Back Systems, ROADMs, ...



PSBT and DPSK Distances on NDSF



Format	Reach (km)
BL-PSBT 40/100	1128
DPSK-NRZ 40/100	852
DPSK-NRZ 40/50	795
BL-PSBT 40/50	760

Calculated at
3 dBQ margin

BBQ: But that's only 400Km...

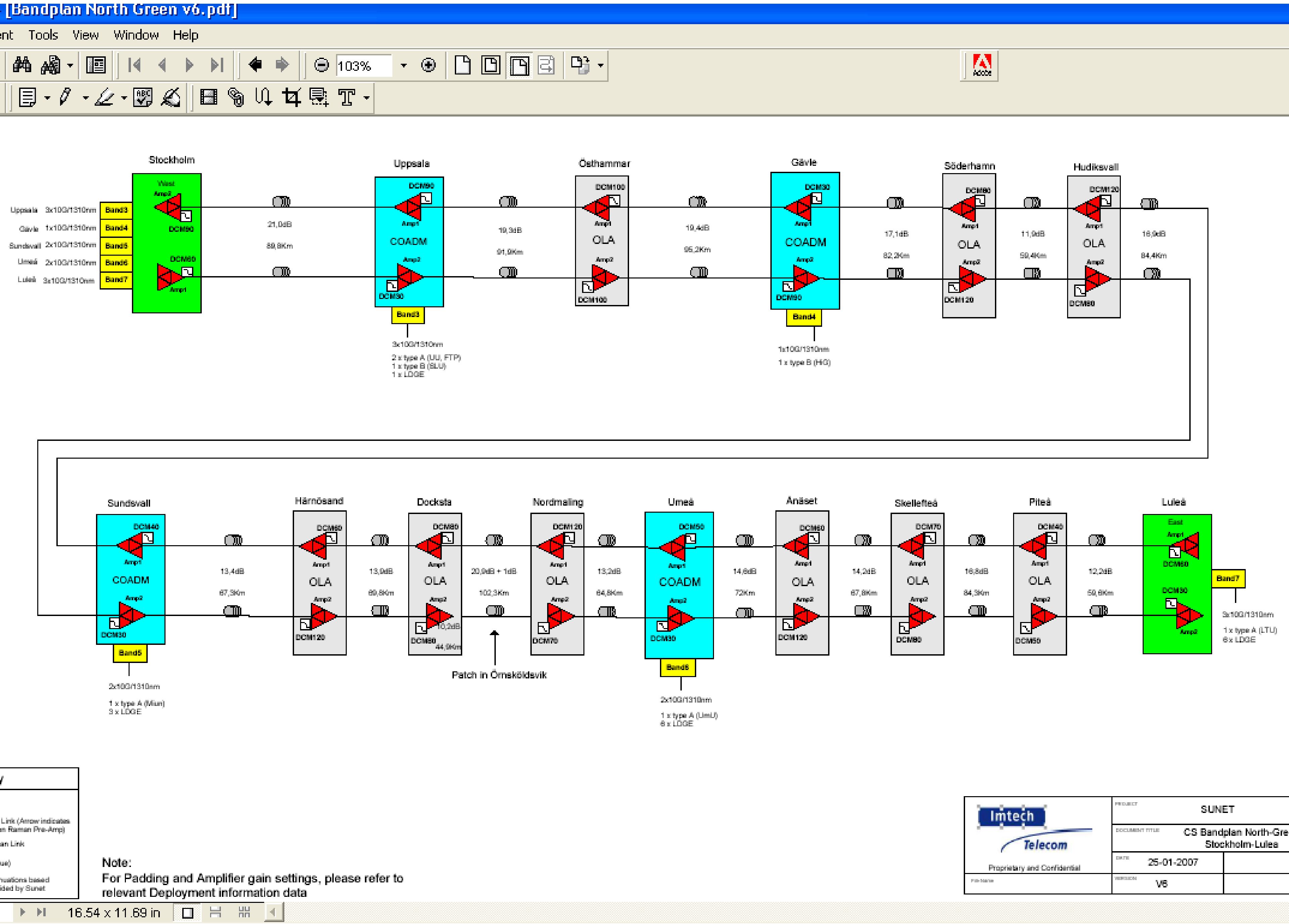
OK, let's make it longer..

Stockholm – Lulea

SMF28 fiber lenght is 1090
Positivie PMD compensation is 46km
PMD N->S is 0.905ps+1.5ps=2.4ps
PMD S->N is 1.655ps+1.5ps=3.15ps
Total 1090909M + 46000M = 1136909M
EDFA's in System 15
COADM's in System 4
Stockholm->Lulea Extra EDFA 1

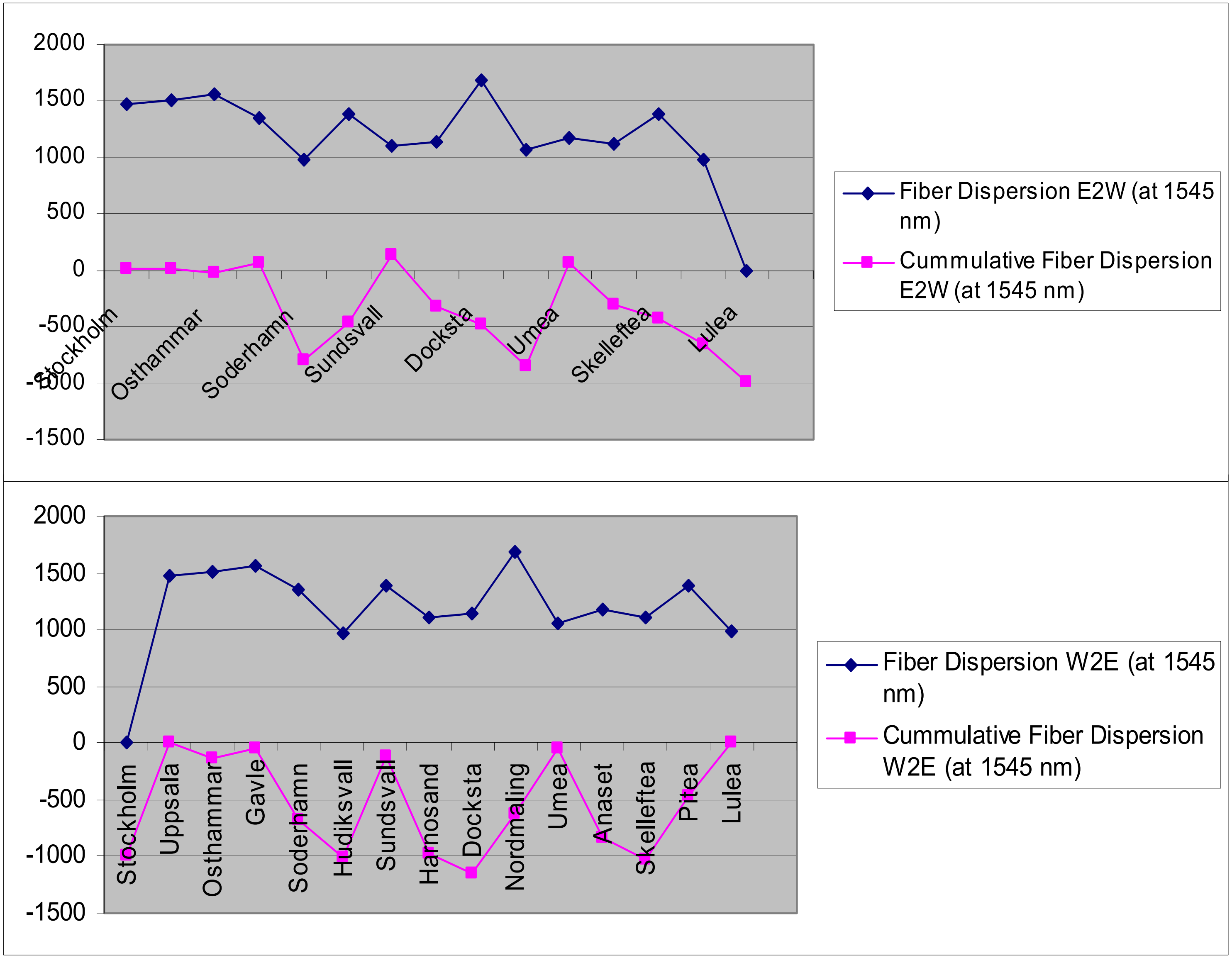
Lulea is 1000KM away... (total project 2800Km drive)


HAPARANDA 200
PITEÅ 31



[Bandplan North Green v6.pdf]
Tools View Window Help
103%
Stockholm
Uppsala 3x10G/1310nm Band3
Gävle 1x10G/1310nm Band4
Sundsvall 2x10G/1310nm Band5
Umeå 2x10G/1310nm Band6
Luleå 3x10G/1310nm Band7
Uppsala
COADM
Band3
3x10G/1310nm
2 x type A (UU, FTP)
1 x type B (SLU)
1 x LDGE
21,0dB
89,8Km
Östhammar
OLA
19,3dB
91,9Km
Gävle
COADM
Band4
1x10G/1310nm
1 x type B (HiG)
19,4dB
95,2Km
Söderhamn
OLA
17,1dB
82,2Km
Hudiksvall
OLA
11,9dB
59,4Km
16,9dB
84,4Km
Sundsvall
COADM
Band5
2x10G/1310nm
1 x type A (Miun)
3 x LDGE
13,4dB
67,3Km
Härnösand
OLA
13,9dB
69,8Km
Docksta
OLA
20,9dB + 1dB
102,3Km
Patch in Örnsköldsvik
Nordmaling
OLA
13,2dB
64,8Km
Umeå
COADM
Band6
2x10G/1310nm
1 x type A (UmU)
6 x LDGE
14,6dB
72Km
Ånäset
OLA
14,2dB
67,8Km
Skellefteå
OLA
16,8dB
84,3Km
Piteå
OLA
12,2dB
59,6Km
Luleå
Band7
3x10G/1310nm
1 x type A (LTU)
6 x LDGE
Note:
For Padding and Amplifier gain settings, please refer to relevant Deployment information data
Imtech Telecom
Proprietary and Confidential
SUNET
CS Bandplan North-Gre
Stockholm-Lulea
25-01-2007
V6
16.54 x 11.69 in

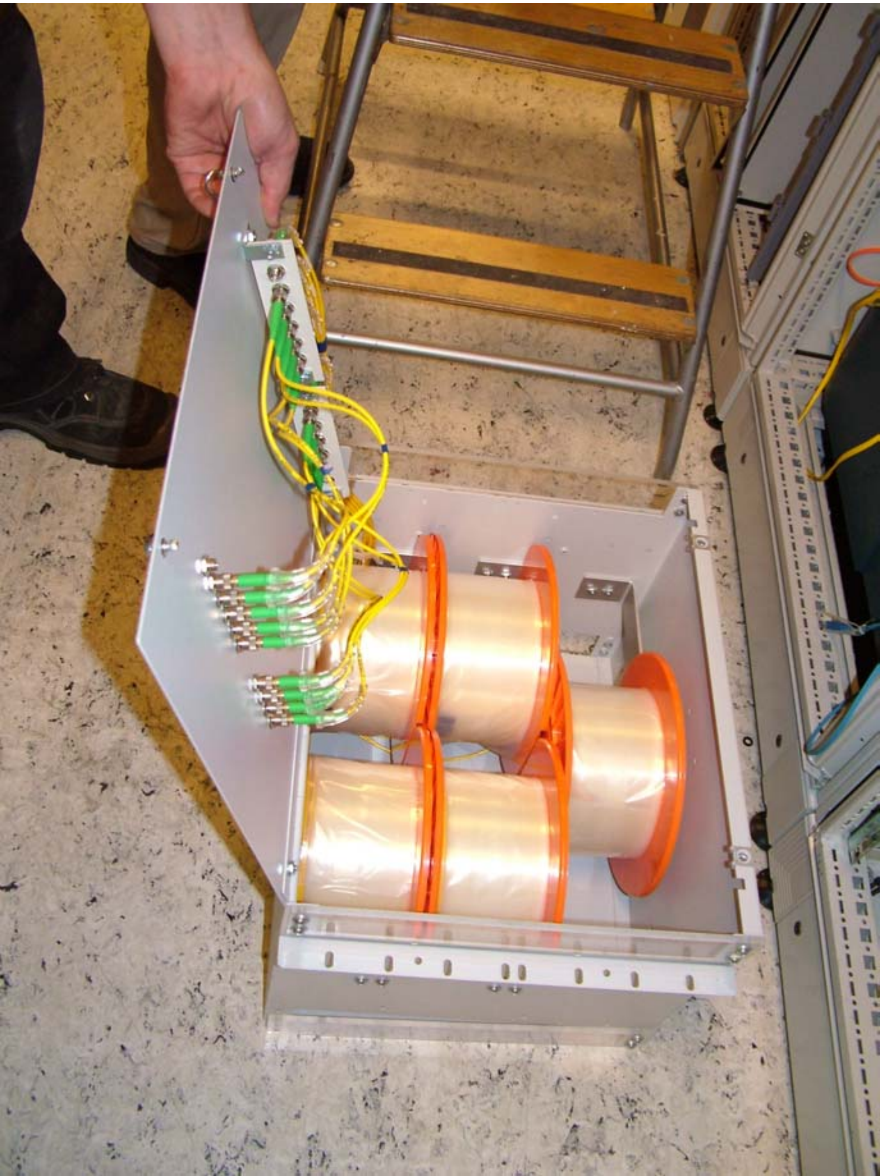
Stockholm – Lulea dispersion map



N->S

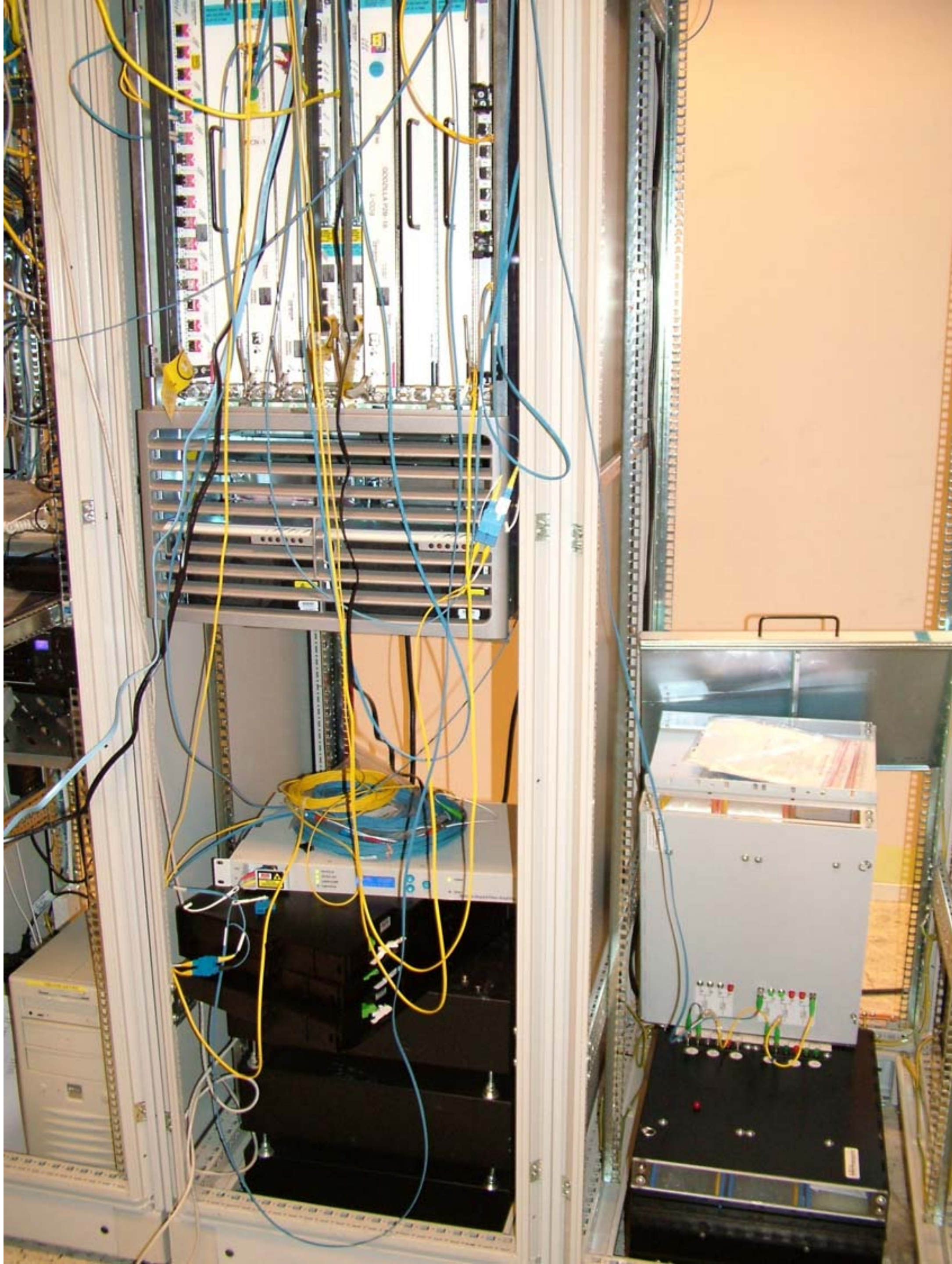
S->N (Need to add SMF28)

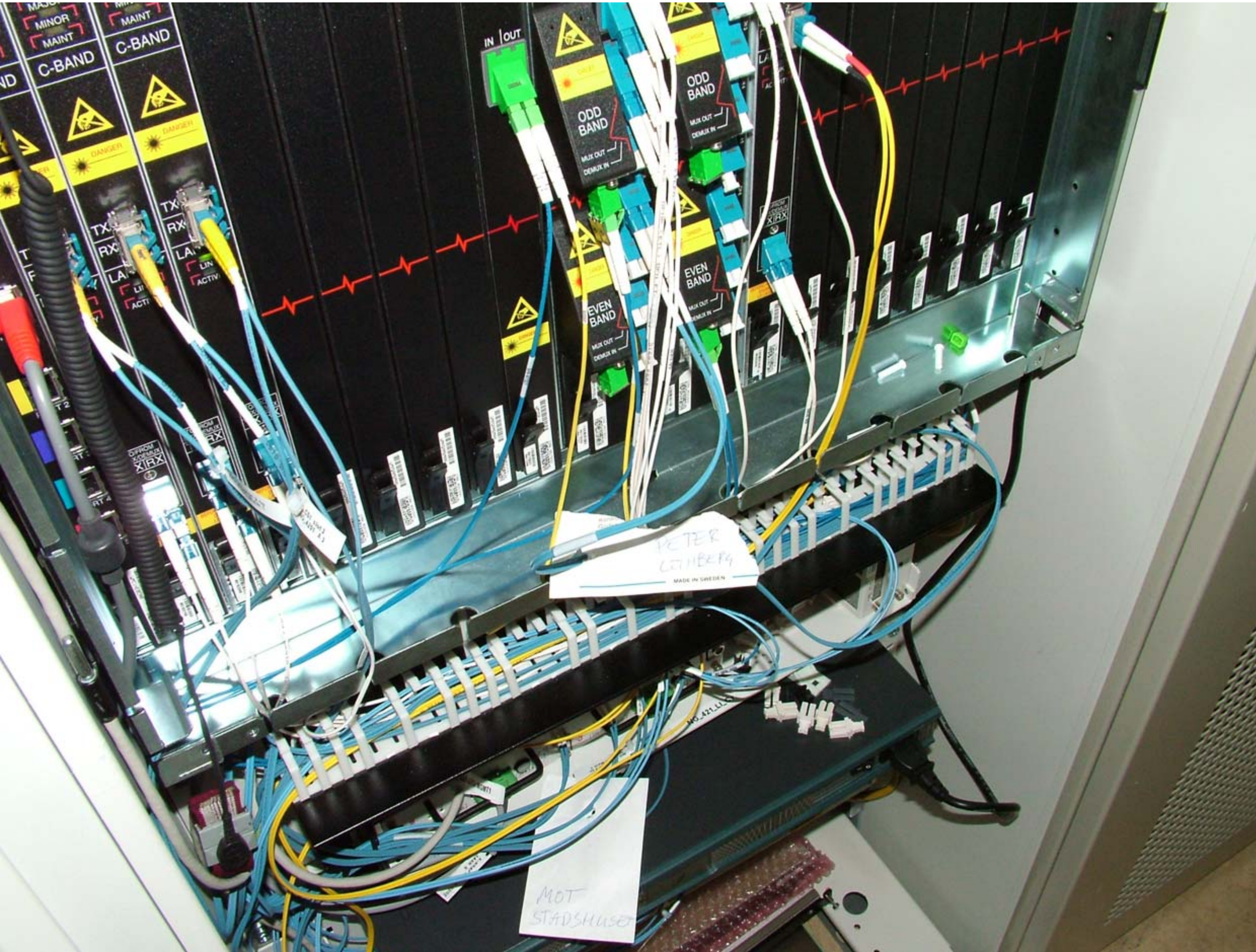
MotherNet



CRS1 and DCM in Stockholm

(Peter Style Instrall)




MINOR
MAINT
C-BAND
C-BAND
DANGER
TX
RX
IN
OUT
ODD BAND
MUX OUT
DEMUX IN
ODD BAND
MUX OUT
DEMUX IN
EVEN BAND
MUX OUT
DEMUX IN
EVEN BAND
MUX OUT
DEMUX IN
PETER LÖTHBERG
MADE IN SWEDEN
MOT STADSHUSET

OK, ENOUGH!

Questions?