Wavelength “Plan A” – All channels in O-Band

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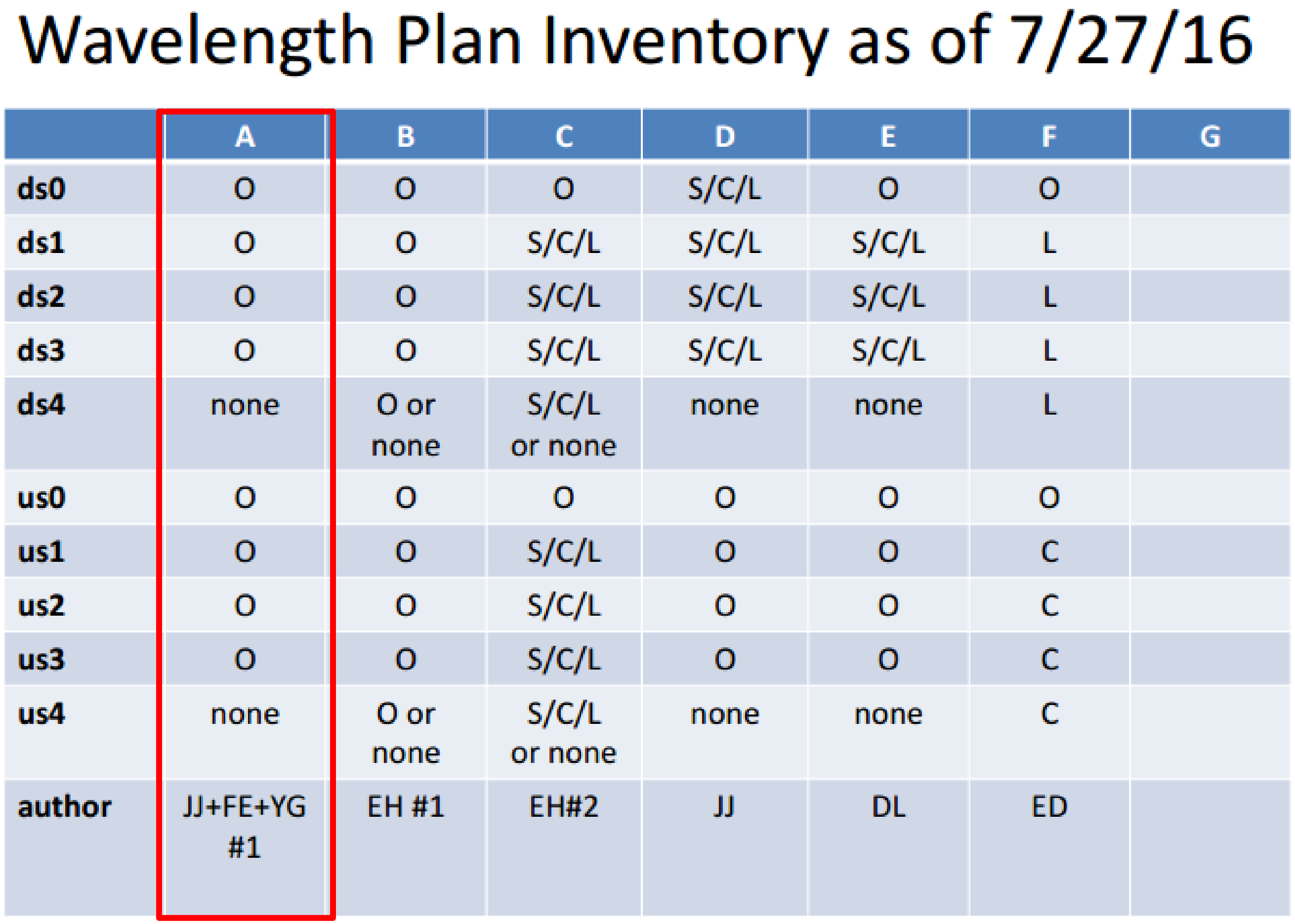
- Motivation
- Wavelength “Plan A” proposal
- Optical filter configurations
- Transmission simulation with fiber non-linearities
- Power budgets
- OLT configurations
- Conclusions

Results of July 2016 meeting

- Straw Poll #1: The 802.3ca standard shall specify wavelengths for 25G, 50G, and 100G systems in O-band.
  - Yes: 15, No: 0, Not enough information: 9
  - More information for O-band
    - Exact (detailed) wavelength plan including support for coexistence (TDM or WDM)
    - Full cost comparison between all O-band and other solutions
    - More consensus in presentations
    - Dispersion compensation analysis of all solutions
    - Full power budget for full 100G system (including mux losses) and what is needed to close the gap
- Straw Poll #2: I prefer:
  - "1+3" solution: 17, "1+4" solution:3, Need more information: 7

- A majority of task force members thus expressed a preference for a 1+3 wavelength plan in O-band, but there was not sufficient agreement to pass as a motion at the July 2016 meeting.
- An inventory of wavelength plans with "champions" was created to supply the needed information to make a decision (kramer_3ca_5_0716).

Wavelength plan inventory



Wavelength Plan Inventory as of 7/27/16

	A	B	C	D	E	F	G
ds0	O	O	O	S/C/L	O	O	
ds1	O	O	S/C/L	S/C/L	S/C/L	L	
ds2	O	O	S/C/L	S/C/L	S/C/L	L	
ds3	O	O	S/C/L	S/C/L	S/C/L	L	
ds4	none	O or none	S/C/L or none	none	none	L	
us0	O	O	O	O	O	O	
us1	O	O	S/C/L	O	O	C	
us2	O	O	S/C/L	O	O	C	
us3	O	O	S/C/L	O	O	C	
us4	none	O or none	S/C/L or none	none	none	C	
author	JJ+FE+YG #1	EH #1	EH#2	JJ	DL	ED	

This contribution

kramer_3ca_5_0716.pdf

Pros and Cons of fiber transmission bands

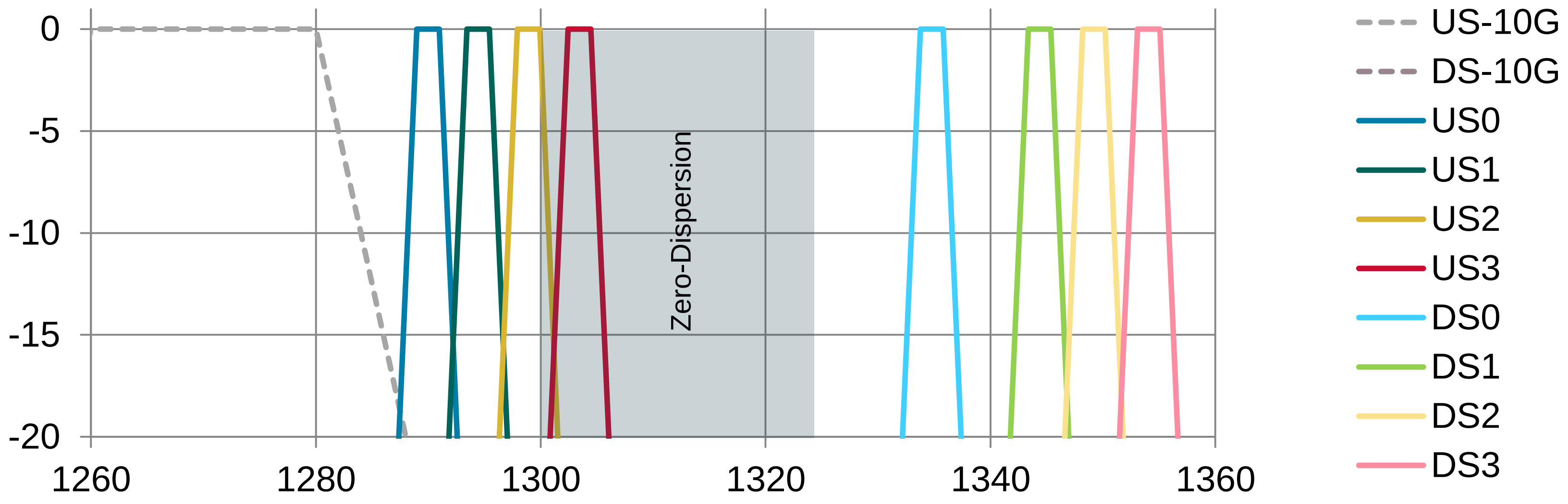
	O-Band	S-Band	C-Band	L-Band
PRO	• Lowest fiber dispersion - no DCM for 20km PMDs* • Existing cooled 100G-LR4 lasers and EMLs • Existing high power uncooled 25G lasers	• Low fiber insertion loss • Moderate fiber dispersion - no DCM for 10km PMDs • Open fiber spectrum - no coexistence objectives	• Low fiber insertion loss • Moderate fiber dispersion - no DCM for 10km PMDs • High power booster EDFAs • Low-NF preamp EDFAs	• Low fiber insertion loss • High power booster EDFAs • Low-NF preamp EDFAs
CON	• High fiber insertion loss • Limited fiber spectrum – 10G WDM coexistence and zero dispersion zone • SOA preamp has high NF • SOA booster has limited Psat	• DCM required for 20km PMDs • No existing 25G sources • SOA preamp has high NF • SOA booster has limited Psat	• DCM required for 20km PMDs • 10G WDM coexistence prevents use of 1560-1600nm	• High fiber dispersion - DCM required for all PMDs • Limited fiber spectrum – 10G WDM coexistence and OTDR band • Lower laser efficiency

* Assuming NRZ modulation format.

All O-Band wavelength plan considerations

- Low dispersion in O-Band allows simple 25G NRZ transmission without need for dispersion compensation.
  - 25G DML transmission is possible in O^- Band (up to ~1320nm)
  - 25G EML transmission is possible in O^+ Band (up to 1360nm)
- 25G O-Band sources and filters exist that can be used directly or adapted for higher power operation for NG-EPON.
  - Cooled 25G DML/EML TOSAs for 100GBASE-LR4 (~1295-1309nm, 800GHz grid)
  - Uncooled 25G DML TOSAs for 100G-CWDM4 (1270-1330nm, 20nm grid)
- Spectrum is tight due to need to coexist with 10G-EPON US at 1260-1280nm and avoid the zero dispersion at1302-1324nm to avoid FWM penalties.
  - Forces use of narrow LAN-WDM channel spacing and narrow US-DS diplexing filters which is not ideal for low cost due to the need for collimated beams.
  - Prevents the full adoption of the existing 100GBASE-LR4 grid due to FWM.
- High loss PMDs will require optical amplification. SOAs must be used for amplification in O-Band, but are not as ideal as EDFAs in C/L-Band.
  - SOA booster amps have more limited output saturation power than EDFAs
  - SOA pre-amps have considerably higher noise figure than EDFAs

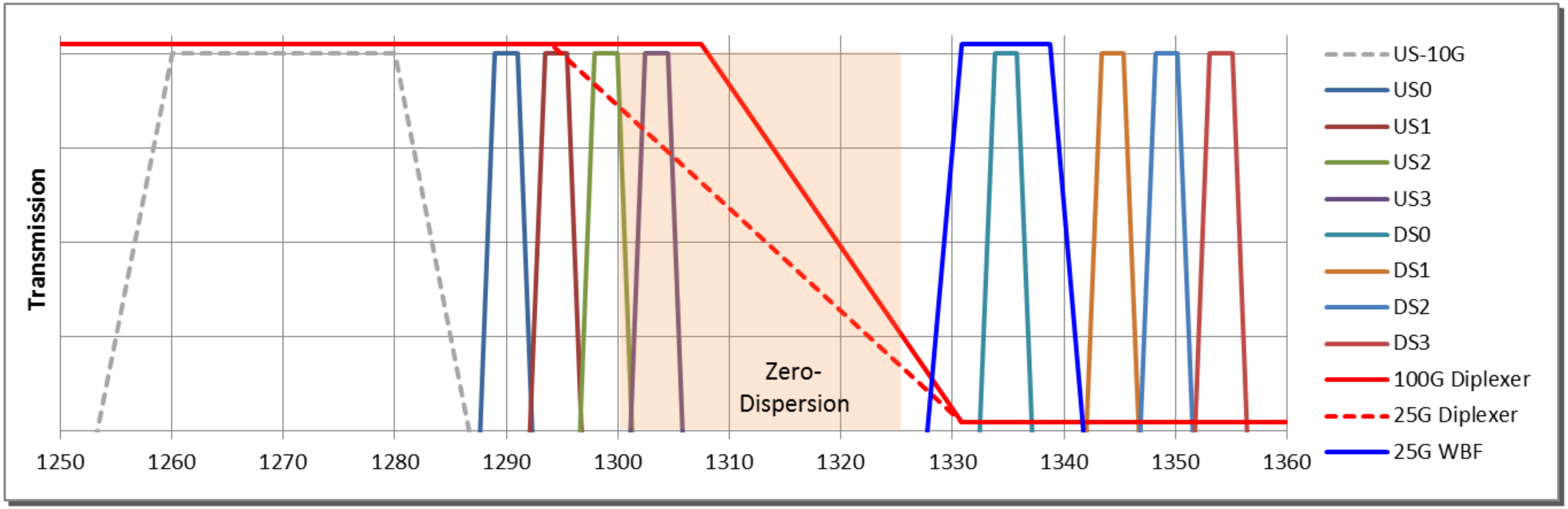
Proposed Wavelength Plan A



	Center Freq (THz)	Center WL (nm)
US0	232.400	1289.985
US1	231.600	1294.441
US2	230.800	1298.927
US3	230.000	1303.445
DS0	224.600	1334.784
DS1	223.000	1344.361
DS2	222.200	1349.201
DS3	221.400	1354.076

- WDM coexistence with 10G-EPON US at 1270±10nm
- US channels on 800GHz grid.
- Only US3 is in the zero dispersion window. Power depletion is possible, but not FWM interference.
- DS channels on 800GHz grid with 1.6THz gap between DS0 and DS1 for relaxed 25G ONU blocking filter (WBF).
- US3-DS0 diplexer gap is 29.3nm for 100G optics

ONU filters



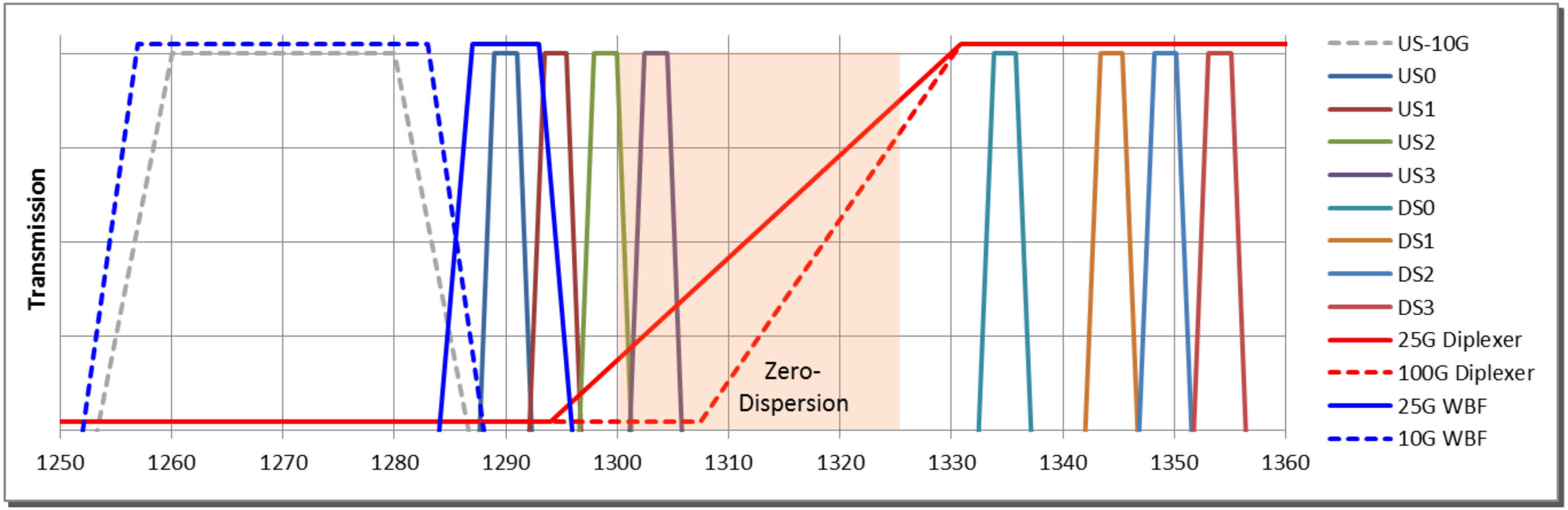
Diplexer

- For 25G ONU, DS0-US0 gap = 42.8nm. Use of non-collimated beam is difficult for 45 º diplexer.
- For 100G ONU, DS0-US3 gap = 29.3nm. Collimated beam is needed for 45 º diplexer.

25G Blocking filter

- Wide 1.6THz spacing between DS0 and DS1
- For ±1nm laser tolerance, guardband > 10nm.
- Compatible with low-cost focusing beam optics (liu_3ca_3_0716) for 0 º blocking filter.

OLT filters



Diplexer

- For 25G ONU, DS0-US0 gap = 42.8nm. Use of non-collimated beam is difficult for 45 º diplexer.
- For 100G ONU, DS0-US3 gap = 29.3nm. Collimated beam is needed for 45 º diplexer.

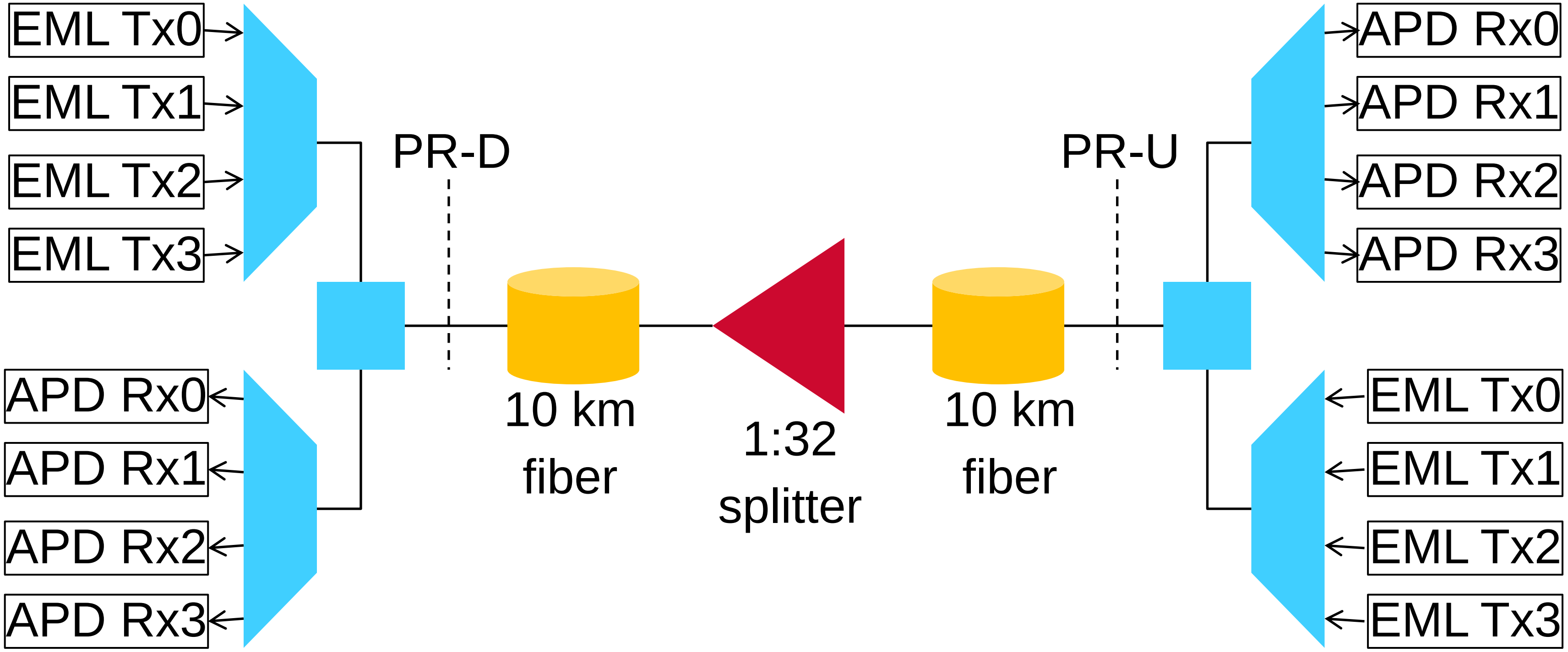
10/25G Blocking filters

- Blocking filters are needed for WDM coexistence.
- Guardband between 1270±10nm and US0±1nm is 9nm
- Can use focusing beam optics with longer focal length ROSA at slightly higher cost

10/25G TDM option

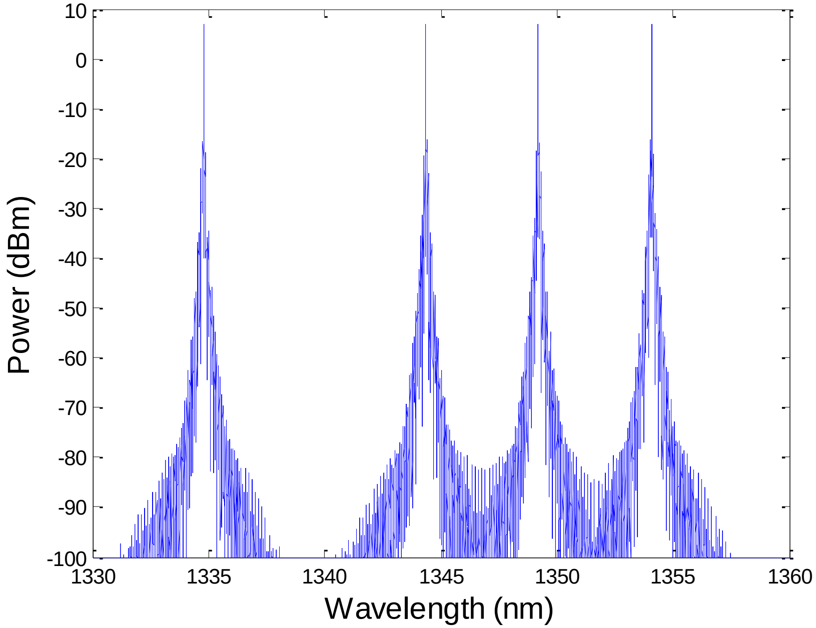
- 25G OLT can optionally be configured for TDM coexistence
- Simpler TRISA with one ROSA, no WBF’s
- Requires 10/25G dual-rate burst-mode receiver

Optical network simulated

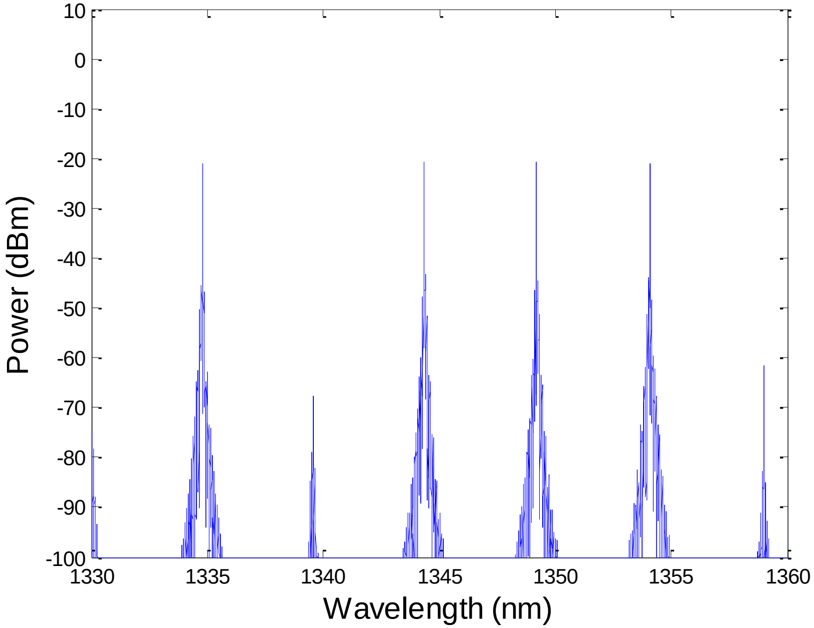


Fiber launched power is 8dBm per channel (both directions)

Downstream Spectrum



Transmitter Spectrum

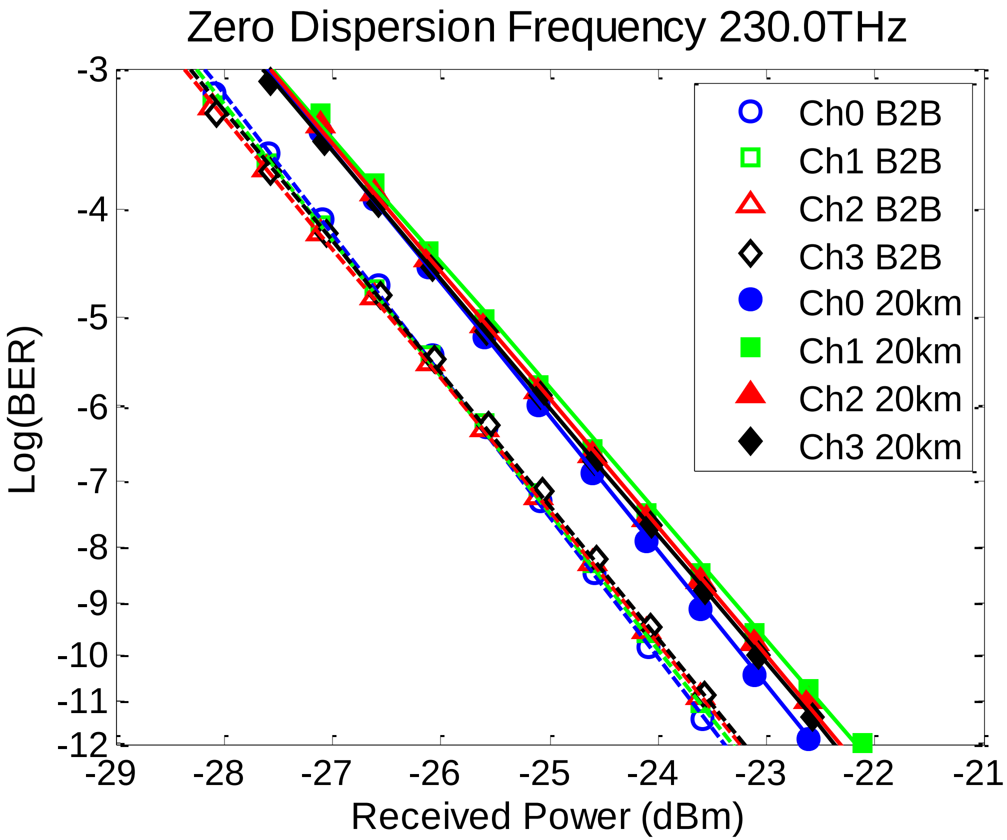


After 20km SMF fiber

Four wave mixing is clearly visible on the spectrum after 20km fiber transmission, but the spectrum components due to FWM are small.

In addition, downstream signal power is increased by 0.31dB after 20km SMF fiber, due to Raman effect, when the upstream signals are turned on.

Downstream Performance

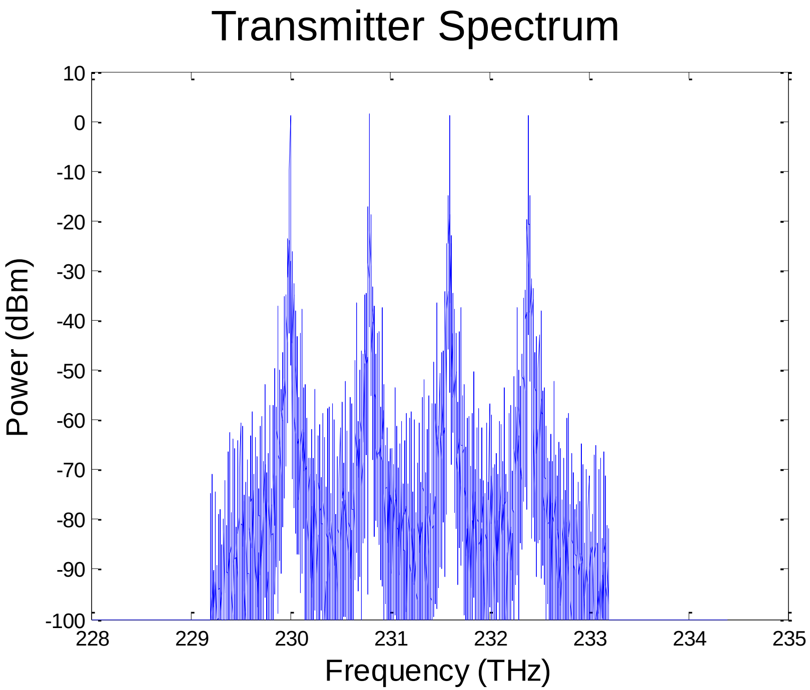


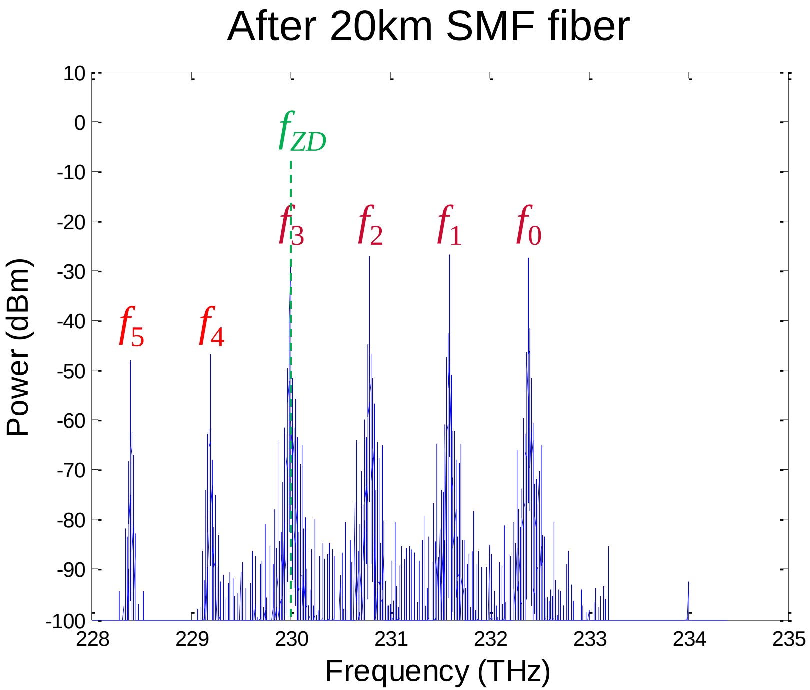
Single Channel OPP: 0.48dB due to dispersion

Multi-channel OPP: 0.57dB (ch0) 0.71(ch1) 0.79(ch2) 0.66(ch3)

Additional OPP due to fiber nonlinearity (SPM, XPM & FWM)

Upstream Spectrum
zero dispersion at ch3 (230THz)


Transmitter Spectrum


After 20km SMF fiber

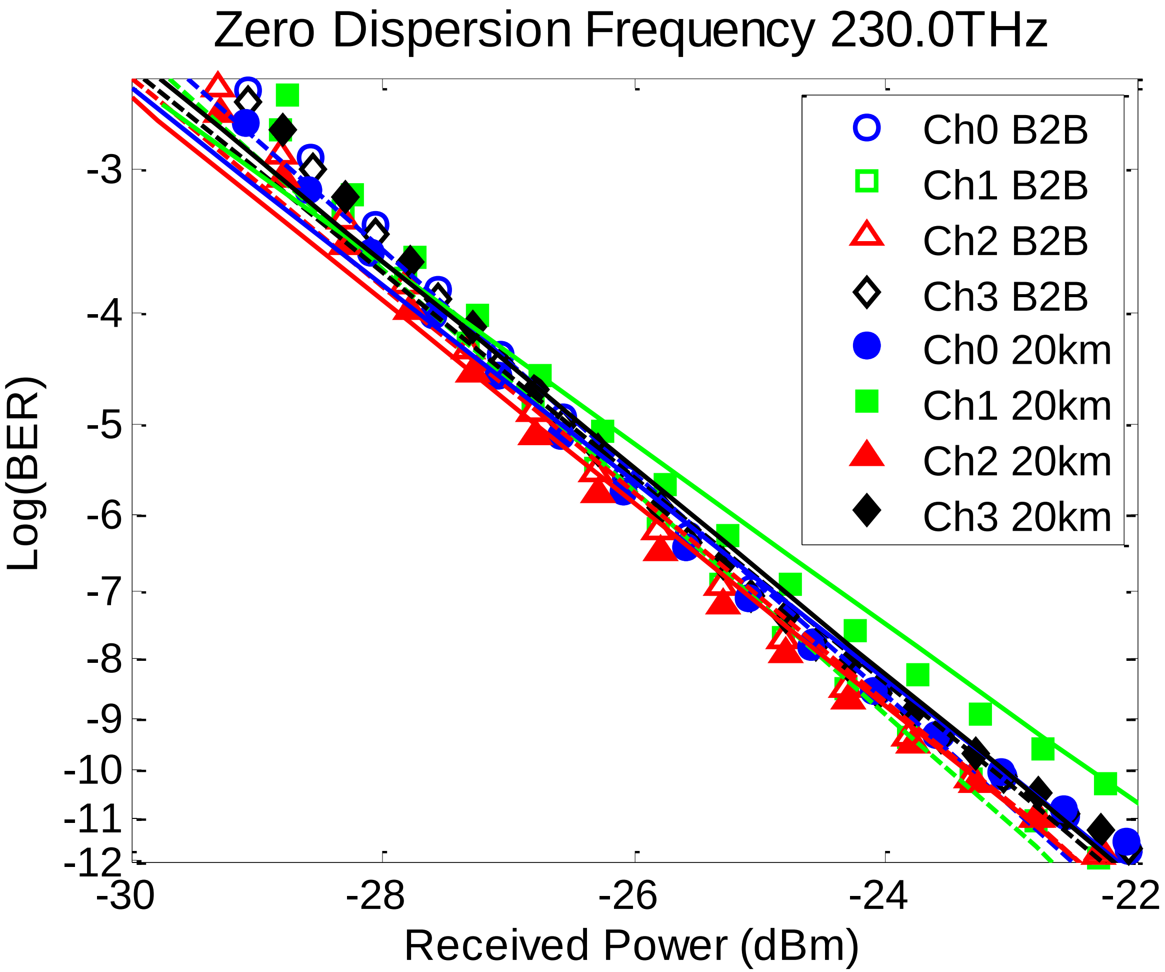
Phase matched FWM:

$$f_4 = f_3 + f_3 - f_2$$
$$f_5 = f_3 + f_3 - f_1$$

* Red font (e.g. f_4 and f_5) denotes frequencies generated by FWM
Blue font (i.e. f_0, f_1, f_2, f_3) represents signal frequencies; f_{ZD} is zero dispersion frequency.

Upstream Performance

zero dispersion at ch3 (230THz)

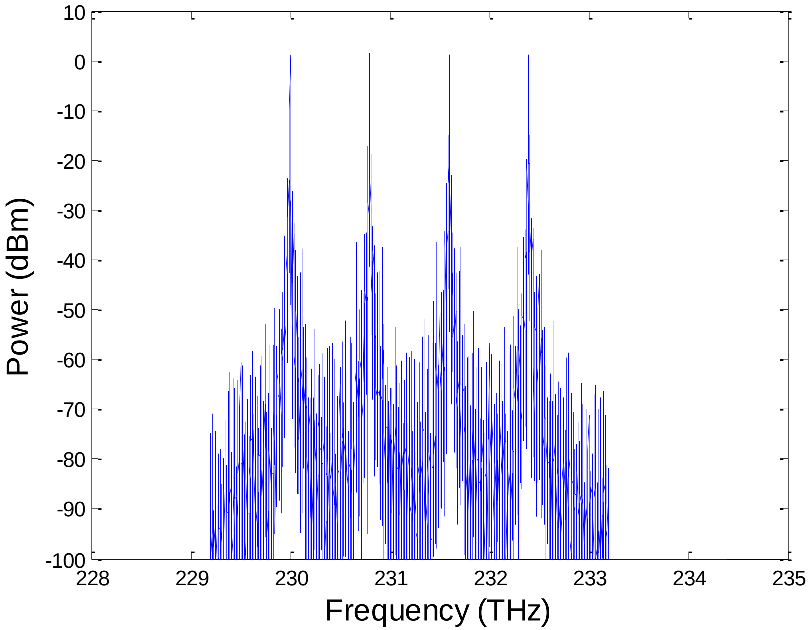

Zero Dispersion Frequency 230.0THz

Multi-channel OPP: -0.27(ch0) 0.19(ch1) -0.16(ch2) 0.06(ch3)

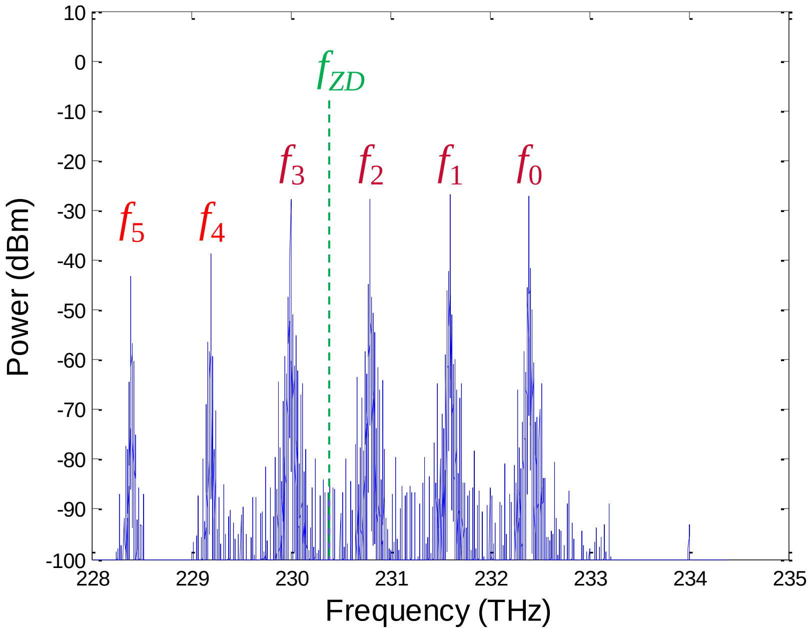
In addition, upstream signal power is decreased by 0.31dB after 20km SMF fiber, due to Raman effect, when the downstream signals are turned on.

Upstream Spectrum

zero dispersion in the middle of Ch3 (230.0THz) and Ch2 (230.8THz)



Transmitter Spectrum

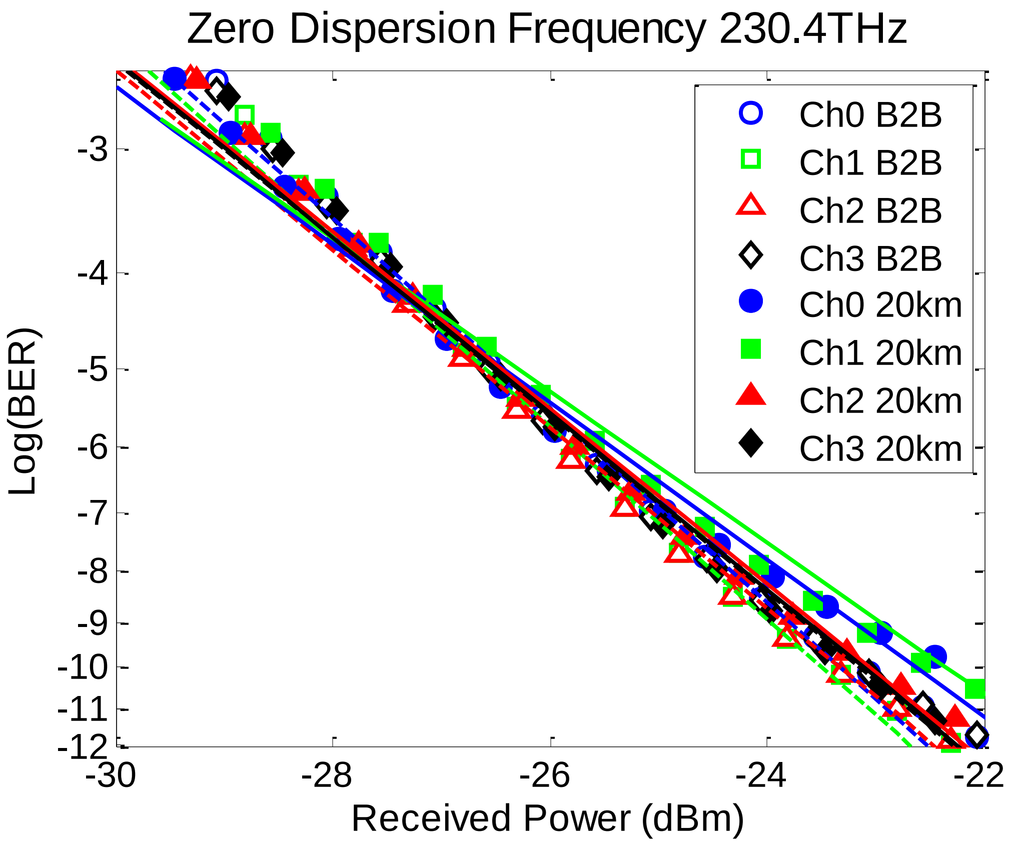


After 20km SMF fiber

Phase matched FWM:

$$f_4 = f_2 + f_3 - f_1$$
$$f_5 = f_2 + f_3 - f_0$$

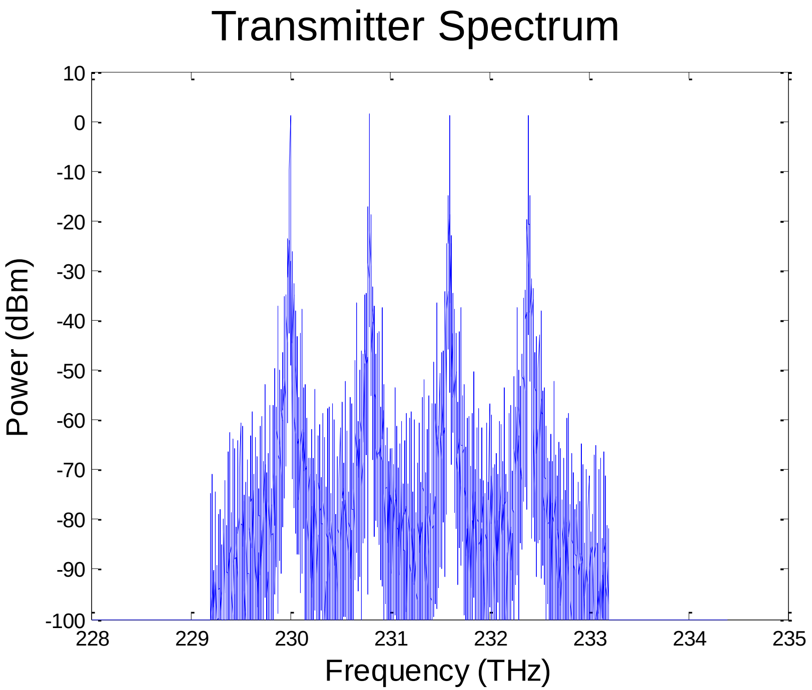
Upstream Performance
zero dispersion in the middle of Ch3 (230.0THz) and Ch2 (230.8THz)

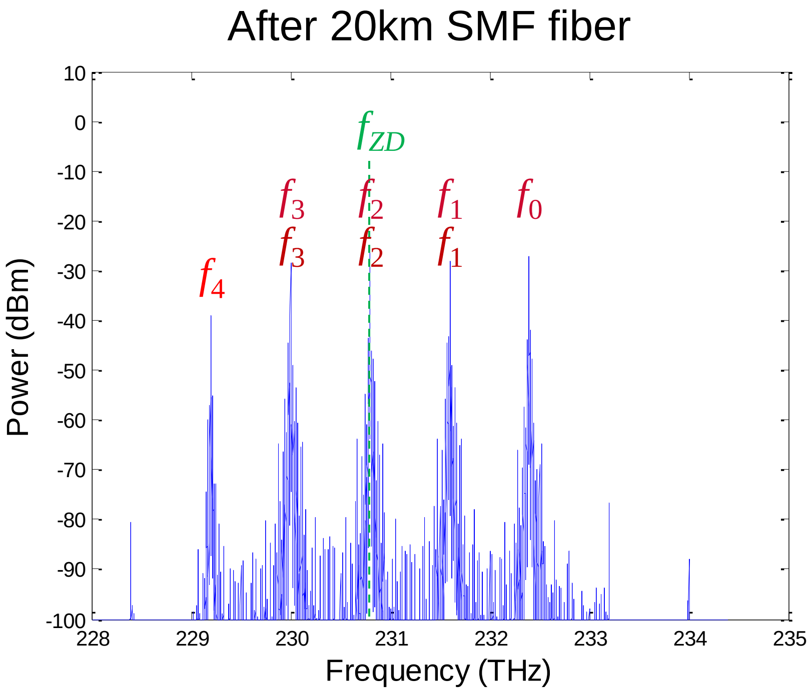


Multi-channel OPP: -0.32(ch0) 0.14(ch1) -0.05(ch2) 0.06(ch4)

Upstream Spectrum

zero dispersion at ch2 (230.8THz)
(Note: this cannot happen in G.652 fiber)



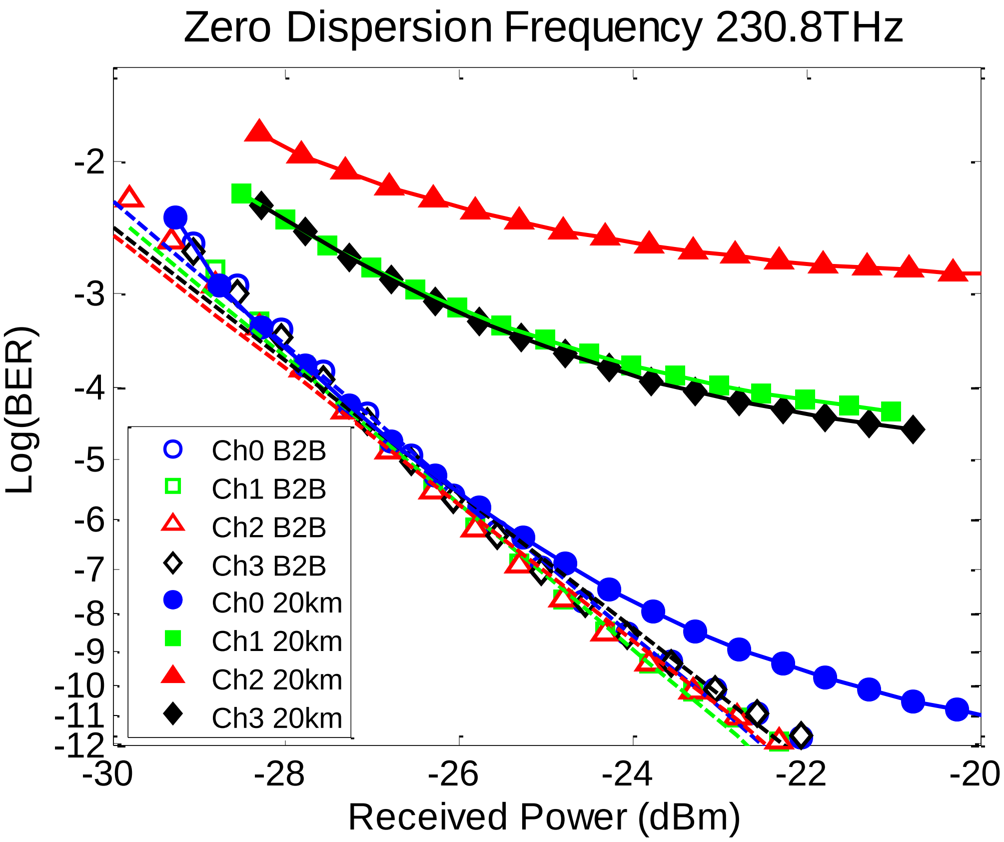


Phase matched FWM:

$$f_1 = f_2 + f_2 - f_3$$
$$f_2 = f_3 + f_1 - f_2$$
$$f_3 = f_2 + f_2 - f_1$$
$$f_4 = f_2 + f_2 - f_0$$
$$f_4 = f_3 + f_1 - f_0$$

Upstream Spectrum

zero dispersion at Ch2 (230.8THz)



While this result is not possible for NG-EPON Plan A, it shows why the existing 100GBASE-LR4 grid cannot be used.

Estimated component capabilities

- Use vendor TX data of harstead_3ca_1a_0716 at mean + 1*sigma level as a view of future laser capability
  - Vendors were asked to estimate commercial values for output power in a single-channel BOSA configuration including diplexer loss and manufacturing margin.
  - US channels will use cooled DML with ER = 6dB
    - 25G BOSA average output power = 8.2 dBm
    - 100G mux loss = 2.5dB
  - DS channels will use cooled EML with ER = 8dB
    - 25G BOSA average output power = 5.3dBm
    - 100G mux loss = 2.5dB

- Assume 25G APD has typical AOP sensitivity equal to -28dBm at BER=10^{-3} in a ROSA package (without diplexer or blocking filter) with TX ER=9dB
  - Value to be refined as more data becomes available – this is a starting point
  - Combined diplexer, 100G TFF demux and blocking filter loss = 3dB
  - ER penalty is 0.3dB for ONU RX and 1.1dB for OLT RX
  - Assume 1dB excess APD noise penalty for DML with low ER. This is highly dependent on the ratio of APD and TIA noise. Need more data.
  - Note tanaka_3ca_1_0716 showed 2dB OMA penalty between DML ER = 7dB and EML ER=10dB. Some of this could be due to difference between DML and EML eye quality.

Power budget design style

- The following budgets use the following design method
  - Defined interface is to the ODN, meaning mux losses included in the optics

- Downstream PR20, 30, and40
  - Start with achievable ONU stressed sensitivity (common across classes)
  - OLT Tx Min = ONU Str. Sen + Max Link loss
  - OLT Tx Max = OLT Tx min + reasonable tolerance
  - ONU Rx Overload = OLT Tx max – Min Link loss

- Upstream PR20, 30, and 40
  - Start with achievable ONU Tx Min power (common across classes)
  - ONU Tx Max = ONU Tx Min + reasonable tolerance
  - OLT Rx Str. Sen.= ONU Tx Min – Max Link loss
  - OLT Rx Overload = ONU Tx Max – Min Link loss

- PR10 class: Begin with PR20 then degrade ONU Tx and Rx

Disclaimer: This budget is a strawman only

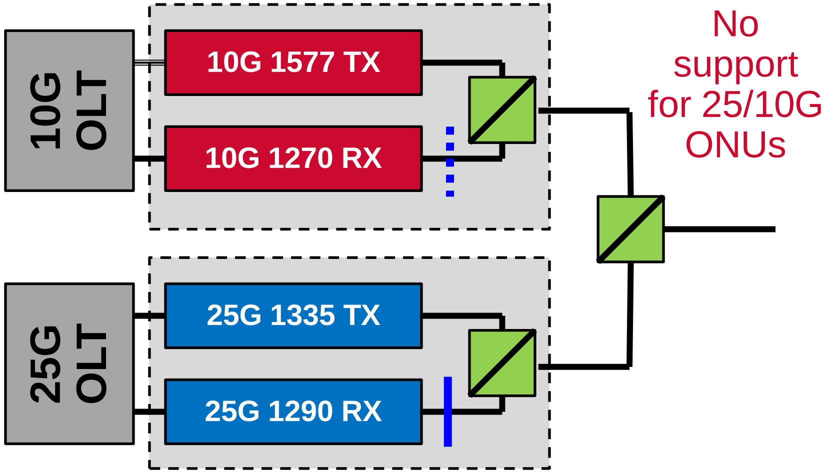
- The levels used in this budget are meant to be first level approximations
  - They are used to illustrate the basic configuration of the plan
  - To justify the nonlinear analysis previously stated
- The levels need to be optimized on several bases
  - Technical feasibility
  - Economic feasibility
  - Reliability, power consumption, environment
- Once a plan is selected, these optimizations can be finalized

Simplified power budget (100G case)

Link type	PR10	PR20	PR30	PR40
OLT Tx Max (dBm)	5	5	9	12
OLT Tx Min (dBm)	1	1	6	10
Ext. Ratio Min (dB)	8	8	8	8
Max link loss (dB)	20	24	29	33
TDP (dB)	1.5	1.5	1.5	1.5
ONU Rx Str. Sens.	-19	-23	-23	-23
Min link loss	5	10	15	18
ONU Rx Overload	0	-5	-6	-6
ONU Tx Max (dBm)	5	9	9	9
ONU Tx Min (dBm)	1	5	5	5
Ext. Ratio Min (dB)	6	6	6	6
Max link loss (dB)	20	24	29	33
TDP (dB)	1	1	1	1
OLT Rx Str. Sens.	-19	-19	-24	-28
Min link loss	5	10	15	18
OLT Rx Overload	0	-1	-6	-9

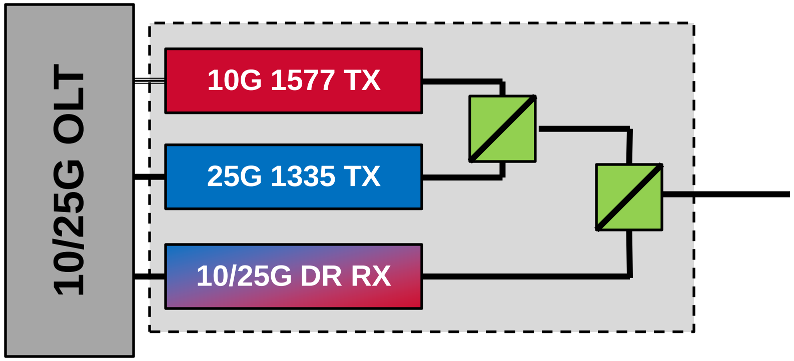
25G OLT configurations

Separate 10/10G and 25/25G OLT BOSAs

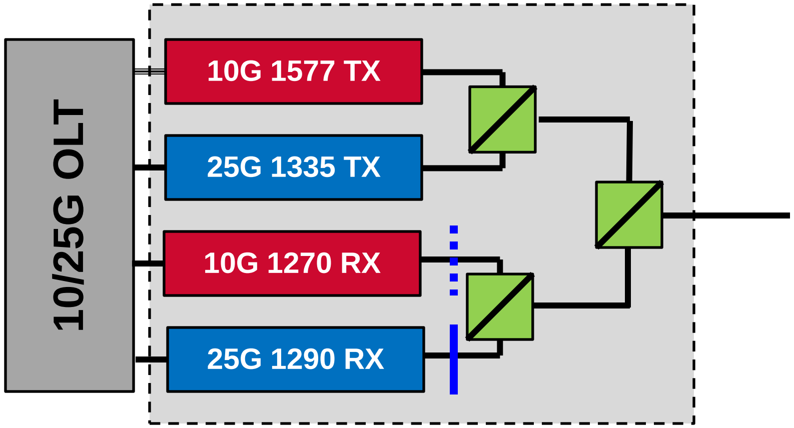


No support for 25/10G ONUs

TDM Coexisting 25/10G TRISA

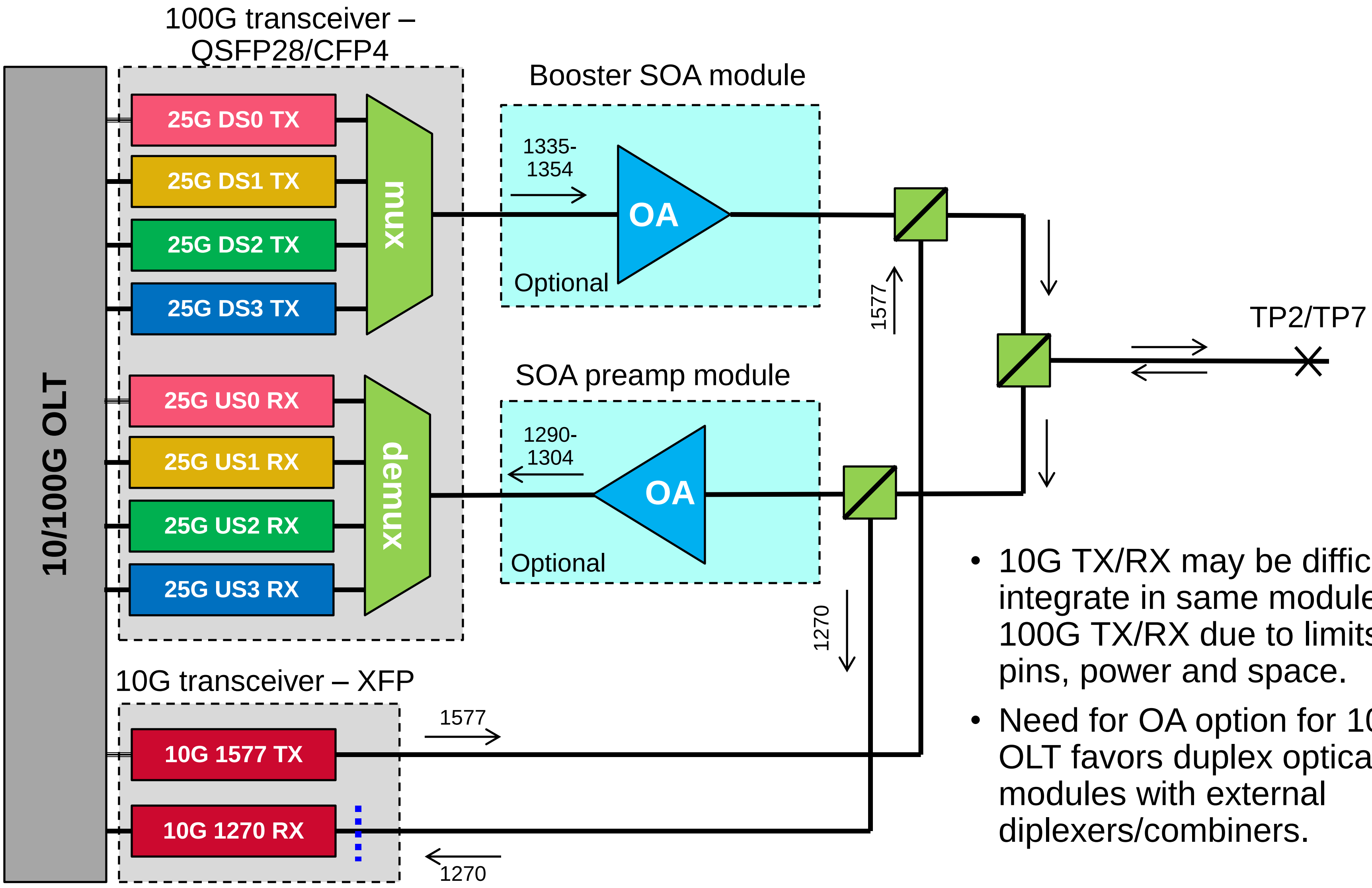


WDM Coexisting 25/10G Quad OSA



- Three possible 25G OLT configurations depending on deployment scenario
  - Separate 10/10G and 25/25G OLTs with simple BOSA optics and external diplexer (no support for 25/10G ONUs)
  - Combined 10/25G OLT with Quad OSA optics (more complex optics, supports 25/10G ONUs)
  - Combined 10/25G OLT with TRISA optics with dual-rate RX for TDM coexistence (simpler optics, but more complex TIA).
- TDM coexistence has the advantage of support for 25/10G ONUs and simplifier TRISA optics without WBFs
  - Can’t afford a sensitivity penalty for dual-rate TIA

10/100G OLT with optional SOA's for PR40



- 10G TX/RX may be difficult to integrate in same module as 100G TX/RX due to limits on pins, power and space.
- Need for OA option for 100G OLT favors duplex optical modules with external diplexers/combiners.

Conclusions

- Keeping all channels in O-band has two main advantages:
  - Low dispersion in O-Band allows simple 25G NRZ transmission without need for dispersion compensation and the cost and loss that comes with it.
  - 25G DML and EML sources and filters exist that can be used directly or adapted for higher power operation for NG-EPON.
- The main disadvantage is the limited available spectrum due to 10G-EPON coexistence and the dispersion zero window
  - Forces use of LAN-WDM channel spacing (800GHz), but this is common in several other wavelength plans as well.
  - Forces narrow US-DS guardband which is more difficult to implement without collimated beam optics which add cost.
  - Prevents the full adoption of the existing 100GBASE-LR4 grid due to FWM penalties in the zero dispersion window.
- High loss PMDs will require optical amplification in all wavelength plans. SOAs must be used for amplification in O-Band.
  - SOAs are not as ideal amplifiers as EDFAs in C/L-band but are smaller, lower cost and lower power consumption.

Thank You!