

Economics of 4x100G PAM4 vs. 8x50G PAM4 and 8x50G NRZ

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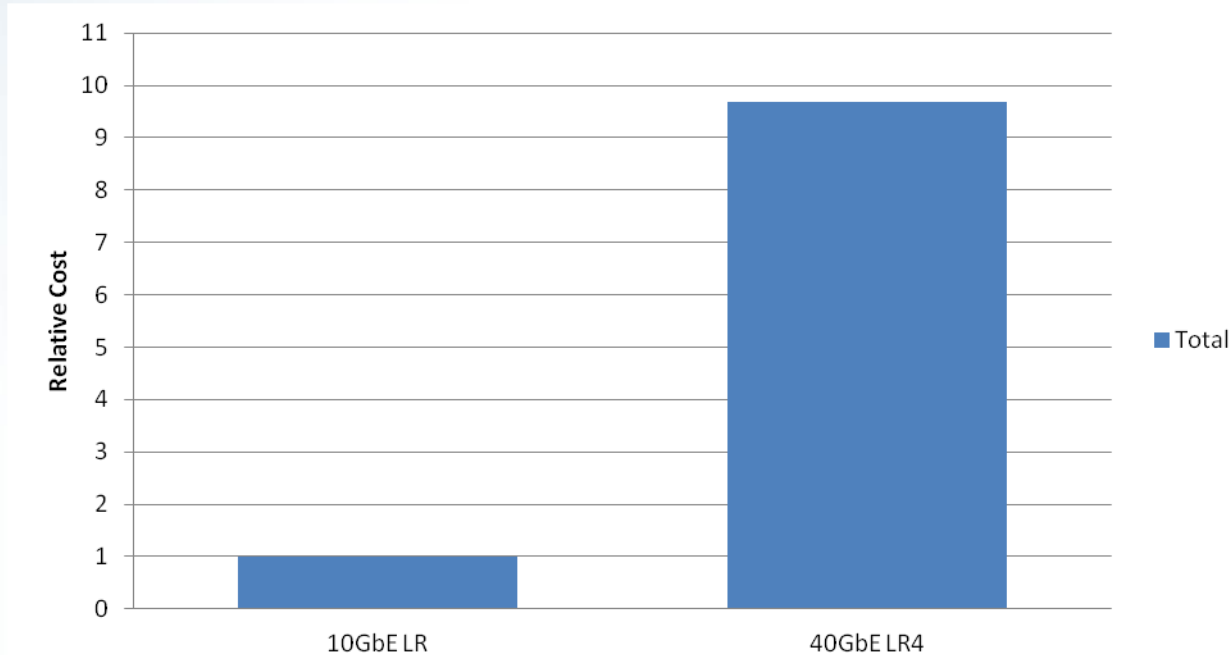
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10G LR vs. 40G LR4 Relative Cost Analysis

Relative Cost Analysis



- **Bottom-up analysis:**

- **Cost of 40G LR4 QSFP+ ~ 9.5x LR SFP+**
- **Dominated by TOSA/ROSA cost**
- **40G LR4 TOSA/ROSA cost ~ 10x 10G LR TOSA/ROSA**

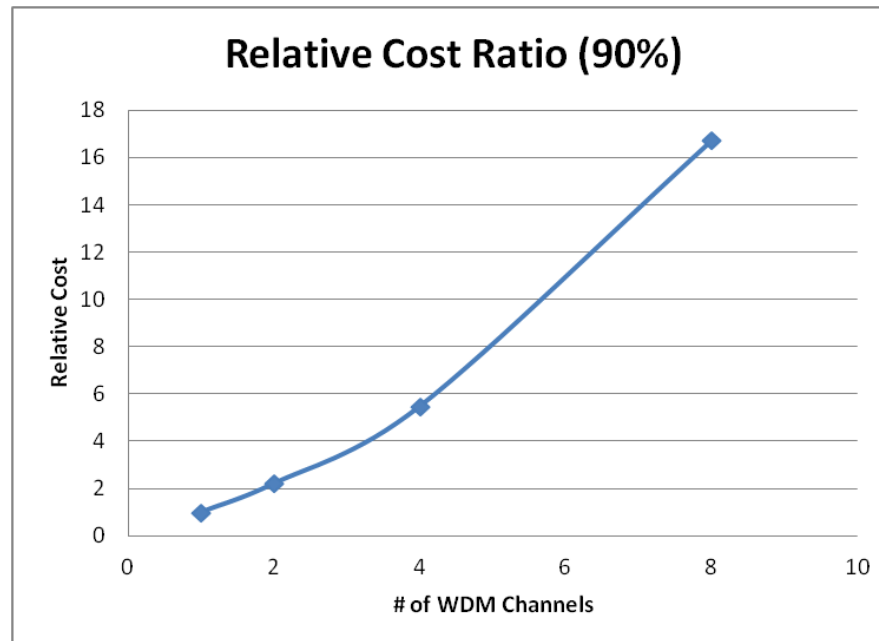
- **Conclusion:**

- **Cost of Multi-channel WDM optics >> single channel Optics**
- **Relative cost per Gbps about 2.4:1**



Multi-Channel WDM Cost Discussion

- **Multi-Channel WDM TOSA and ROSA are based on hybrid integration of discrete laser/modulators with passive WDM optics (PLC, or free space optics)**
 - **Fully integrated array transmitter and receivers will not likely be main-stream mature technology, so NOT analyzed here**
- **Cost premium due to yield loss:**
 - **Yield loss increasing as power of number of channels**





Cost of Cooled vs. Un-cooled Optics

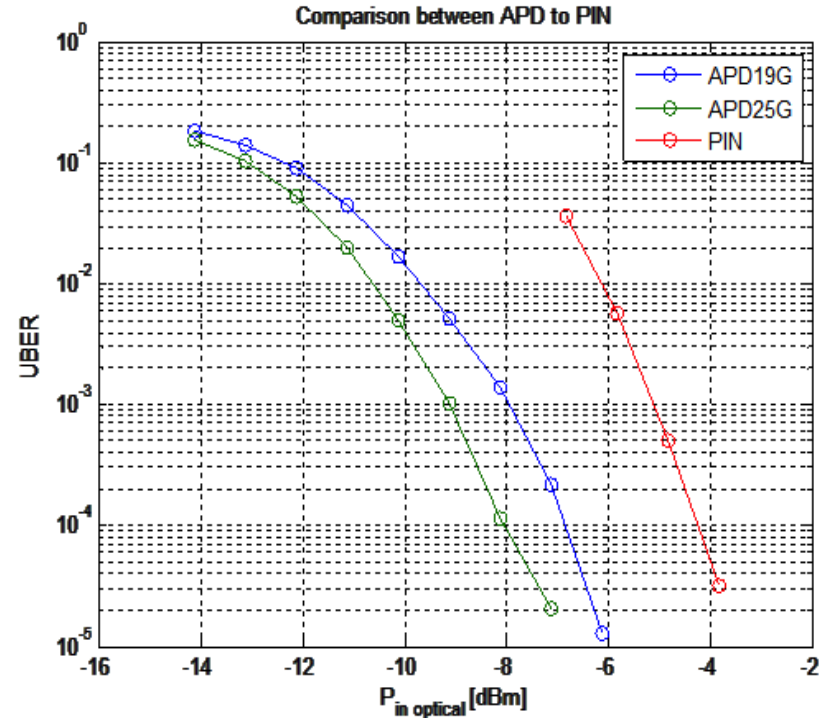
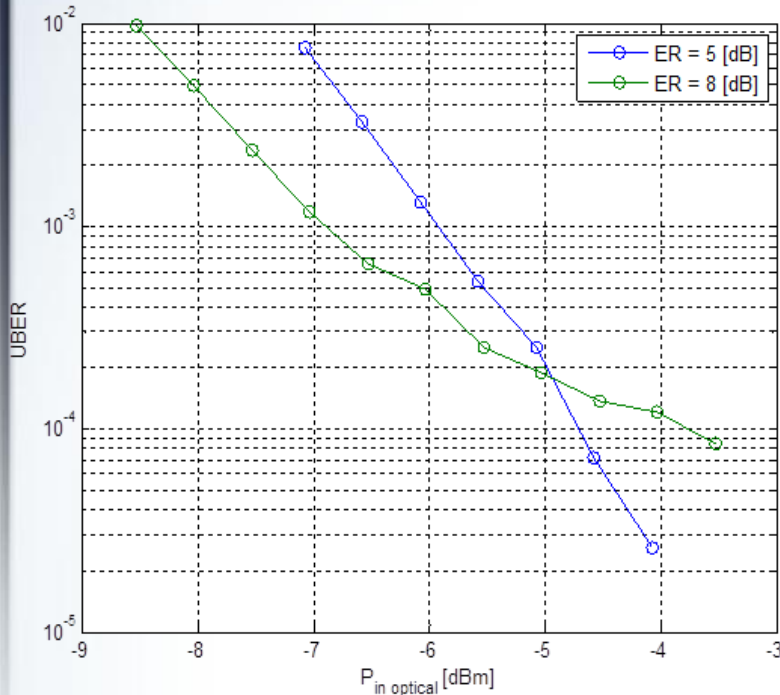
- **Cost reference:**
 - **2.5G**
 - **CWDM (uncooled DML) vs DWDM (Cooled DML)**
 - **TOSA cost ratio ~ 1:5**
 - **10G**
 - **LR (uncooled DML) vs. ER (cooled EML)**
 - **TOSA Cost ratio ~ 1: 4**
- **There is significant cost advantage using uncooled optics vs. Cooled optics**

	Uncooled CWDM	Cooled WDM
4x100G-PAM4	Possible for within 1271nm-1331nm	May or may not be needed
8x50G NRZ	Difficult for 50GBaud: 8Ch. From 1271nm to 1411nm, dispersion @ CD~ up to 100ps/nm	Required to support wavelength within narrow range near 1310nm
8x50G PAM4	Possible for 25GBaud	May or may not be needed



Viability with 25G Tx/Rx for 1x100G PAM4

- Drive lower cost with volume deployed 4x25G Tx/Rx
- Simulation analysis with a RC-MLSE DSP engine (see conroy_3bs_01a_0914.pdf)
- Tx/PIN Rx bandwidth ~ 22GHz; APD BW ~19GHz and 25GHz



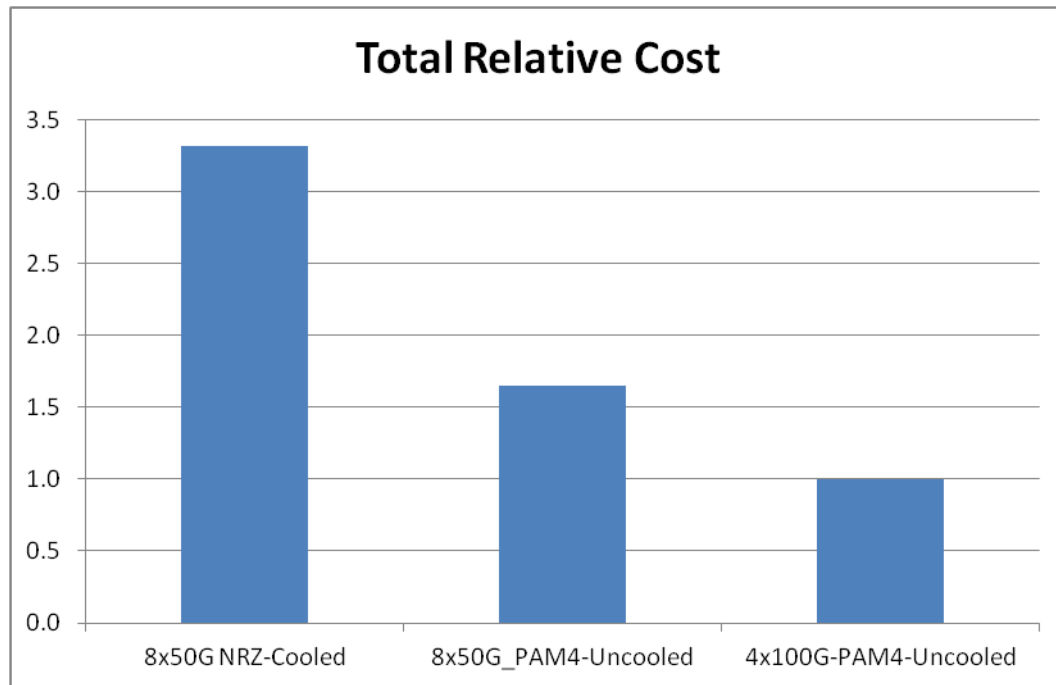
- Results:
 - High ER yields better BER low input power
 - Low ER case has no BER floor down to the range of BER=1E-5
 - APD is promising to provide extra link budget



4x100G-PAM4 vs 8x50G Relative Cost (1)

- **Uncooled CWDM TOSA/ROSA for 4x100G PAM4 and /8x50G PAM4;**
- **Tx/Rx bandwidth ~ 22GHz for PAM4 and ~35GHz for 8x50G NRZ**
- **Higher power DSP assumed for 4x100G PAM4 at slightly higher cost**

	8x50G NRZ-Cooled	8x50G_PAM4- Uncooled	4x100G-PAM4- Uncooled
TOSA	5.3m	2.1m	1.0m
ROSA	2.6n	1.8n	1.0n
Driver	3.0p	2.0p	1.0p
DSP/IC	0.7q	0.7q	1.0q
Total Relative Cost	3.3t	1.7t	1.0t

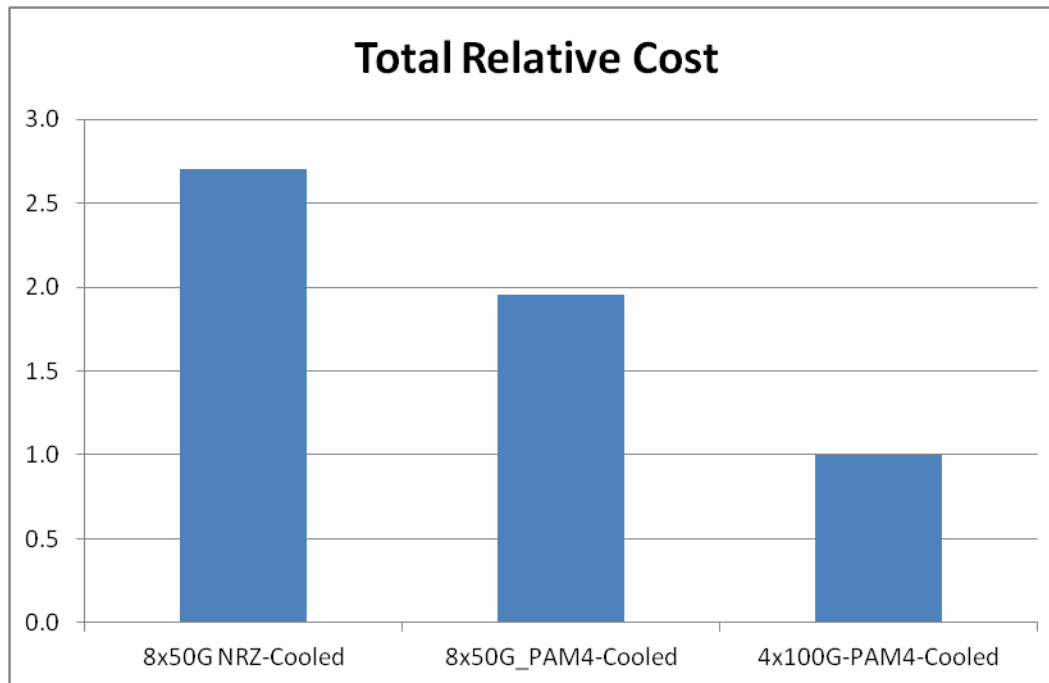




4x100G-PAM4 vs 8x50G Relative Cost (2)

- **Cooled CWDM TOSA/ROSA for 4x100G PAM4 and /8x50G PAM4;**
- **Tx/Rx bandwidth ~ 22GHz for PAM4 and ~35GHz for 8x50G NRZ**

	8x50G NRZ-Cooled	8x50G_PAM4-Cooled	4x100G-PAM4-Cooled
TOSA	3.5m'	2.5m'	1.0m'
ROSA	2.6n'	1.8n'	1.0n'
Driver	3.0p'	2.0p'	1.0p'
DSP/IC	0.7q'	0.7q'	1.0q'
Total Relative Cost	2.7t'	2.0t'	1.0t'





Conclusion

- Provided a relative cost comparison among 4x100G PAM4, 8x50G PAM4/NRZ from a module/IC supplier perspective
- Conclusion: 4x100G-PAM4 offers significant cost advantage vs. 8x50G NRZ or 8x50G PAM4
 - Detail cost model may vary, qualitative conclusion expect to remain



Thank You