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NG-PON2 Optical Components Update
Agenda

• NG-PON2 Optical Challenges
  – ONU Optics Challenges
  – OLT Optics Challenges

• NG-PON2 Solutions for Optics
  – ONU Optics
    – Discrete Optics Approaches
    – Photonic Integrated Optics Approaches
  – OLT Optics
    – Discrete Optics Approaches
    – Photonic Integrated Optics Approaches
ONU Optical Challenges
High ONU Transmit Power and Dispersion

• To avoid optical amplifiers, higher Tx power is needed from the ONU
  – +4dBm to +9dBm Transmit Power required (for Type A system)
  – Relatively easy to achieve with DMLs (Direct Modulated Laser), but they have a large dispersion penalty for 10Gbps Upstream rates
  – EMLs (Externally Modulated Lasers) have a low dispersion penalty but cannot achieve +4dBm minimum power
Spectral Excursion

- Maximum Spectral Excursion in Burst Mode Operation
  - ONU wavelength must be contained in a 40 GHz window
- Unlike point to point optics, PON upstream operates in burst mode
  - ONU laser must go from completely off to on in 128 ns
  - Inrush of current causes 25 GHz to 40 GHz spectral shift

Finisar: Yasuhiro Matsui – “Short Term Spectral Excursion (STSE) Mitigation” – Sept 8th, 2014
ONU Tuning Speed

• Switching Speeds for Wavelength Tuning
  – TWDM-PON ONU Optics must be able to tune across a minimum of 4 wavelengths
  – Three Classes of Switching Times
    • Class 1: < 10 μs
    • Class 2: 10 μs to 25 ms
    • Class 3: 25 ms to 1 sec
  – Service Restoration through Wavelength Mobility
    • Must be < 50ms
    • Therefore Class 2 wavelength switching is needed
ONU Optical Echoes

- Reflections in the fiber ODN can cause an ONU burst echo to land on another ONU burst
  - If wavelengths coincide interference occurs
  - Current ONU Reflectance
    - 6dB
    - Needs to be better to avoid problem
OLT Optical Challenges
NG-PON2 Optical Budgets

• Most Popular Budget Classes
  – Class N1 – 20km + 64-way split
  – Class N2 or E1 – 20km + 128-way split

<table>
<thead>
<tr>
<th></th>
<th>Class N1</th>
<th>Class N2</th>
<th>Class E1</th>
<th>Class E2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum optical path loss</td>
<td>14 dB</td>
<td>16 dB</td>
<td>18 dB</td>
<td>20 dB</td>
</tr>
<tr>
<td>Maximum optical path loss</td>
<td>29 dB</td>
<td>31 dB</td>
<td>33 dB</td>
<td>35 dB</td>
</tr>
<tr>
<td>Maximum differential optical path loss</td>
<td></td>
<td></td>
<td>15 dB</td>
<td></td>
</tr>
</tbody>
</table>

• OLT Receiver Sensitivity is most challenging
OLT Receiver Sensitivity

- APDs are most common and popular OLT receiver
  - NG-PON2 adds loss of the Wavelength Multiplexer
  - Additional power penalties for Out of Channel and Out of Band noise and Echoes
  - Consequence: *Typical APD receivers cannot meet any of the optical budget requirements, including the smallest one, N1*
OLT Transmit Power

- EMLs are typically used at OLT due to DML Dispersion Penalty
  - Due to penalties and WM losses EMLs cannot meet required transmit power for any of the budgets, N1, N2, E1 or E2
ONU Solutions for Optics Challenges
ONU Discrete Optics Solutions – EML + SOA

- Transmit Power Solution
  - EML is ideal laser from optical dispersion standpoint but power is too low
    - Solution: Follow EML with SOA (Semiconductor Optical Amplifier)
    - Can be two discrete parts or two components on one chip
- Spectral Excursion Solution
  - The SOA may also be used as an optical shutter
    - Shutter opens when laser is stable
- Disadvantages:
  - High power consumption and high cost
ONU Discrete Optics Solutions – DML with reduced ER

- DMLs normally have too much chirp for use in 10Gbps TWDM-PON optics over 20km
  - With 6dB ER, BER < 10^{-3} not possible for needed sensitivity
  - Power penalty = too high
  - Reducing DML Extinction Ratio (ER) reduces chirp
  - Transmit power of DML is increased according to new Tx vs ER table proposed for G.989.2 amendment 2 to compensate for reduced ER
ONU Discrete Optics Solutions – DML with reduced ER

• Calix and other contributions determined worst case degradation with decreased ER (extinction ratio)
• Goal: No performance degradation at the OLT receiver
  • Allows use of directly modulated lasers (DML)
  • Laser must compensate with higher minimum transmit power
  • Targeted for G.989.2 amd 2

![Graph showing extinction ratio vs. mean launch optical power](image-url)
ONU Discrete Optics Solution – 10G Down, 2.5G Up

- Consider 10G/2.5G Asymmetrical Line Rate and Class 3 Tuning for Residential Services
  - Dispersion issues with DMLs Mitigated
  - Higher power of DML can be used for Type A ONUs
  - No need to reduce ER and increase Tx power
  - Slower tuning allows use of simple conventional temperature control
  - Spectral excursion less problematic

Result
- Viable TWDM-PON vendors triple or quadruple
- Costs significantly reduced
- Can coexist with 10G/10G Business ONUs via dual burst rate OLT
ONU Discrete Optics Solution – Consider Fixed Wavelength?

- Fixed wavelength does not directly address the challenges except obviously the tuning time challenge.
- Fixing the TWDM-PON ONU wavelengths does lead to secondary improvements:
  - Laser no longer heated to high temperatures to tune to all 4 channels, EMLs can now achieve Type A transmit power levels.
  - Receiver becomes identical in simplicity to other 10G receiver technologies and costs (like XGS-PON).
- Disadvantage:
  - Wavelength mobility advantages such as software upgrade and wavelength protection eliminated.
  - Need to stock ‘Wavelength SKUs’.
Discrete Optics Solution for Tuning – DBR (Distributed Bragg Reflector) Laser

- DBR Laser can tune in nanoseconds
  - Spectral Excursion can be reduced to 5GHz
- DBR is also capable of meeting Class 2 and even Class 1 Tuning Times
- Disadvantage: Currently very expensive

Finisar: Yasuhiro Matsui – “Short Term Spectral Excursion (STSE) Mitigation” – Sept 8th, 2014
Discrete Optics Solution for Tuning – Low Thermal Mass

- Thermal Tuning is commonly used
  - Large thermal mass and low impedance = Slow tuning times
- Solution:
  - Reduce Thermal Mass
  - Increase Thermal Impedance
  - Air-Gap Suspended Waveguide
- Result:
  - < 0.3 milliseconds tuning
- Note: Same principal of low thermal mass and high thermal impedance works for receiver filter tuning

“Narrow Linewidth Tunable Semiconductor Laser”, Yasuhiro Matsui et al, IPRM 2016 Invited Paper
NG-PON2 Optical Solution – ONU Optical Echoes

- Reducing Reflection at ONU
  - Calculations show that if reflections are < -32dB, the problem of echoes is mitigated
  - Calix survey shows vendors are able to achieve < -32dB reflectance
  - Cost increase zero or minimal
  - June - Geneva Plenary G.989.2 amendment 2
Photonic Integrated Circuits – Tunable PICs Solution

- Multiple optical components can be integrated onto one substrate
  - Additional components solve technical challenges
    - SOA to increase Tx power and act as shutter
    - External tunable Tx filter improves out of band noise
    - External modulator reduces dispersion penalty
    - SOA at Rx to increase sensitivity
    - Fast thermal tuning with low thermal mass = Class 2 switching speed
  - Cost stays low due to integration
- Disadvantage:
  - High upfront costs
  - Time to develop process
Photonic Integrated Circuits – Fixed PICs Solution

- Concept: Modified 4 lane 25Gbps = 100Gbps Ethernet Transceiver
  - Borrow from 100 Gbps PIC technology – parallel transmitters and receivers
    - Four lasers on one substrate are similar in cost to one laser
    - Laser Wavelength Switching in few nanoseconds, just turn on desired laser
    - Four lasers on one substrate are similar in cost to one laser
    - Receiver Wavelength Switching instantaneous
    - External modulator reduces dispersion penalty
    - SOA at Tx to boost power
    - SOA at Rx to increase sensitivity
      - Cost stays low due to integration
- Disadvantage:
  - High development costs and long lead time for process development
- *Same technique can be used for 20-40Gbps Bonded ONU*
OLT Solutions for Optics Challenges
OLT Solution – Receiver Sensitivity Approaches

• State-of-Art APDs and TIAs (Trans-Impedance Amplifier) for N1 Class
  – Closed 1dB gap for N1 link budget
• For Link Budgets N2 → E2
  – SOA in receiver, can achieve -32 to -34dBm
  – Quasi-Coherent Receiver, can achieve -34dBm
  – Also allows use of Type B ONUs
    • OK for EMLs

Sensitivity with ASE, SOA, WM and APD

-40 -35 -30 -25 -20 -15
2 4 6 8 10
ER (dB)

Sensitivity at BER = 1e-3

No ASE
ASE = 32 dB
ASE = 30 dB
ASE = 28 dB
ASE = 26 dB
ASE = 24 dB
OLT Optical Solution – Transmit Power

• EMLs are typically used at OLT due to DML Dispersion Penalty
  – Due to penalties and WM losses EMLs cannot meet required transmit power for any of the budgets, N1, N2, E1 or E2
• Solution: SOA in OLT Transmitter
  – Can achieve N1, N2 and possibly E1
Extended Budget Solution: Active Wavelength Multiplexer

- Allows relaxed requirements on ONUs and OLTs
  - Boost upstream and downstream power by using optical amplifiers in the Wavelength Multiplexer → Active WM
  - Allows lower power Type B ONU optics, reducing cost
- Disadvantages
  - Additional active device to monitor and manage
  - Requires additional reliable power supply
  - Requires increased rack space
  - Adds cost (may be offset by lower ONU cost)
  - Optical Amplifier failure brings down entire ODN (can be managed with redundant amplifiers and optical switch, but adds more cost)
Conclusions

• NG-PON2 is a very powerful and flexible new PON standard
  – With some of the power and flexibility came optical challenges to be overcome
• But…optical component vendors have brought forth a wide variety of approaches to meet the challenges
  – This bodes well for meeting the challenges with possibly multiple solutions
    • High sensitivity OLT allows Type B ONU EML for 10G/10G
    • Use of 10G/2.5G ONU allows DML for lower cost and more vendors
    • PICs have promise for long term
  – Will one solution ‘win’ over time?
  – …….stay “tuned”!