Low-Cost Wide Wavelength Division Multiplexing (WWDM) for 10 Gb Ethernet

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Outline

WWDM for the LAN -
- Introduction/Motivation
- SX Results at HP Labs
- LX Results/Plans

WWDM DFB Source Study
- Introduction/Motivation
- Results

Conclusions/Challenges
High-Speed Local Area Networks

- 62.5/125 Multimode fiber used for premises (<500m)
- Single mode fiber used for campus LANs (up to ~10km)
- Gigabit Ethernet (1.25 Gbaud) is being widely deployed
- Need already exists for higher data rates in LANs

→ Low cost solutions needed for 10 Gb/s LANs
Potential Solutions for 10 Gb

- Parallel Optics
- Multilevel modulation schemes
- Serial TDM
- WWDM
12.5 Gbd Serial TDM  (Assuming 8B/10B encoding)

CHALLENGES:

- Will only go ~ 50 meters on conventional 62.5-µm MM fiber
- Temperature control may be required
- High side mode suppression/low parasitic capacitance laser required
- Relaxation Oscillations ⇒ high laser drive ⇒ poor extinction ratio
- RIN due to reflections may not allow 12.5 Gbd w/out isolation
- Si may not be feasible for optoelectronic ICs (GaAs or SiGe required)
- 10 Gb/s SERDES required
- Significant jitter issues
Parallel Optics

CHALLENGES:

• Higher cost of fiber ribbon cable limits cost effectiveness at long (km) distances.

• Current ribbon connector cost quite high

• SX solutions (VCSEL based) have eye-safety/power budget constraints

• LX solutions (FP edge emitter based) have MMF launch issues which are not easily addressed in ribbon fiber form factor.
WWDM for the LAN

Advantages

- Longer Distances on MMF or SMF
- Slower, Silicon Electronics
- Unisolated, Uncooled Lasers
- Slower detectors → Larger Detector Areas
- Lower-speed packaging
Possible Configurations -

HP Labs SpectraLAN Project -

A. **Short Wavelength** (eg. 820, 835, 850, 865 nm)
   
   VCSEL based Tx / GaAs PIN based Rx
   
   Multimode Fiber: 4x1.25 Gbd = 5 Gbd over 220 m of 62.5-μm Fiber
   
   4x2.5 Gbd = 10 Gbd over 110 m of 62.5-μm Fiber

B. **Long Wavelength** (eg. 1280, 1300, 1320, 1340 nm)
   
   DFB based Tx / InGaAs PIN based Rx
   
   Multimode Fiber: 4x3.125 Gbd = 12.5 Gbd over ~300 m of 62.5-μm Fiber
   
   Singlemode Fiber: 4x3.125 Gbd = 12.5 Gbd over ~10 km of SMF
Short-wavelength (SX) SpectraLAN Modules

Lab Prototype

1.25 Gbd per channel

After 300m 62.5-µm Fiber

2.5 Gbd per channel

After 100m 62.5-µm Fiber
Advantages of 1300-nm

I.  Bandwidth-Distance Product
    2.5 Gb/s in 62.5-µm MMF:  110 m @850nm
                        300 m @1300nm

II. Power Budget
    ~ 7.8 dB advantage over 850 nm (6 dB eye safety, 1.8 dB
    from lower photon energy)

III. Single Mode Fiber Compatibility
    850-nm sources are incompatible with standard SMF

IV. Supply Voltage
    Lower bandgap means lower forward voltage on lasers
# SpectraLAN™- LX Piece Parts

<table>
<thead>
<tr>
<th><strong>Data</strong></th>
<th>4 duplex channels, 3.125 Gbd/channel</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fiber</strong></td>
<td>Dual use SMF/MMF</td>
</tr>
<tr>
<td><strong>Package</strong></td>
<td>MTRJ duplex connector, BGA surface mount</td>
</tr>
<tr>
<td><strong>Sources</strong></td>
<td>Uncooled, unisolated DFB lasers</td>
</tr>
<tr>
<td><strong>Wvlngth</strong></td>
<td>1280, 1300, 1320, 1340 nm</td>
</tr>
<tr>
<td><strong>MUX</strong></td>
<td>4-to-1 silica waveguide combiner</td>
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<tr>
<td><strong>Detectors</strong></td>
<td>InGaAs PIN photodiode array</td>
</tr>
<tr>
<td><strong>DEMUX</strong></td>
<td>Compact injection molded plastic</td>
</tr>
<tr>
<td><strong>ICs</strong></td>
<td>4-channel TX; 4-channel RX (Si)</td>
</tr>
</tbody>
</table>
**Goal** -

- Experimentally verify that DFBs with low SMSR and no isolator have:
  - $\text{RIN} < -117 \text{ dB/Hz}$
  - $\text{BER} < 10^{-12}$
  - Small mode-partition noise power penalty (6 km SMF)

- Examine RIN and corresponding BER at high ambient temperature
Measurements

- Sample set of 21 DFB lasers
- Measurements performed on each laser:
  - L-I-V (Light Power-Current-Voltage) - To establish appropriate drive level for remaining tests.
  - Optical spectrum - To establish the SMSR
    * CW
    * with 2.488 GBd modulation
  - Relative intensity noise (RIN)
    * after short SMF patchcord
    * with 3-dB coupler and receiver on one arm
    * at elevated ambient temperature
  - Received Eye Diagrams
    * back-to-back
    * after 6 km SMF
  - Bit Error Rate (BER)
    * back-to-back
    * after 6 km SMF

Note: Performed BER and Eye Measurements at 2.488 GBd due to RCVR
WWDM DFB Source Study - Conclusions

- 1300-nm DFBs with no specification on SMSR and no isolator suitable for WWDM
- Measured RIN < -125 dB/Hz over all SMSR
- Measured RIN < -118 dB/Hz @ 70° C ambient
- Measured PP < 1 dB due to MPN over 6 km SMF
- Measured BER < 10^{-12} over 6 km SMF
- BER results improved with waveguide combiner
- Total PP < 2 dB over 6 km SMF
WWDM - Advantages/Challenges

* Essentially Current DFB/ Gb Ethernet LX technology
  - All component, IC technology currently available
  - Cost model is believable

* Riskier Aspects of technology well in hand
  - Large (and growing) experience base with multi-Gb/multi-channel ICs (multi-year parallel optics effort)
  - Precision die attach is in production at HP

* Database of DFB source measurements which indicate that uncooled, unisolated lasers with no SMSR spec will be suitable for WWDM.
WWDM - Advantages/Challenges

* 4-chip PDA not proven in production ---> potential cost factor

* Power variation between channels over temperature needs to be investigated/verified

* Electrical/thermal crosstalk at 3.125 Gbd needs to be investigated/verified