Analysis of NG-EPON Diplexer Filtering

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Supporters

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Motivation

- The wide US-DS gap in EPON and 10G-EPON is a key enabler of low-cost focusing beam BOSA construction.
  - Loose filter tolerances enable low diplexer filter and assembly costs.
  - US and DS wavelengths far from the transition enable low excess insertion loss
- Having all channels in O-Band has many advantages, but results in much narrower US-DS gaps on the order of 30-50nm.
  - Plans with US-DS in different bands are closer to current low-cost BOSA design.
- Previous contributions have proposed minimum US-DS gaps that are compatible with focusing beam optics in the range of 35-40nm.
  - See Funada_3ca_1_0316, Funada_3ca_1_0516, Huang_3ca_1_0516 and Liu_3ca_2_0516 for examples.
  - If collimated beam optics are needed, BOSA cost increases dramatically (~1.3X not including 25G parts, from liu_3ca_2_0516)
  - What is the additional cost of focusing beam BOSA optics in this range?
  - Even entry-level 25/10G and 25/25G ONUs must pay the higher cost.
- This contribution will review the reasoning behind the 35-40nm cut-off for use of focusing optics and discuss the additional performance, assembly and part costs associated with diplexers for narrow US-DS gap.

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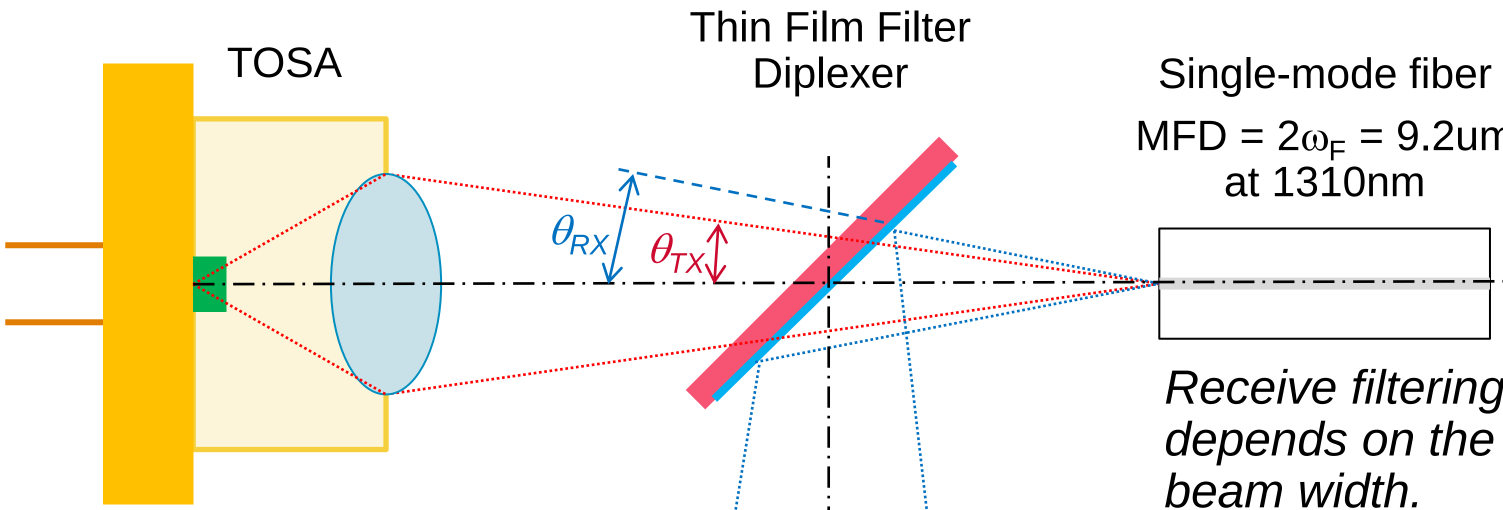
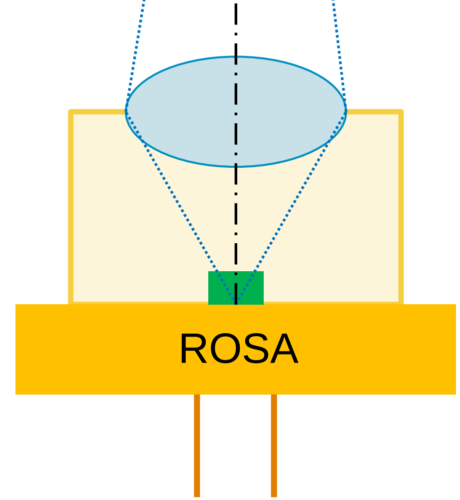
BOSA diplexer optics





Transmit filtering depends on the TOSA beam width.

θ_{TX} depends on choice of optics and working distance, but must be close to θ_F for good coupling to fiber.

For high power TOSA, NA ~ 0.1, or θ_{TX} ~ 5.7º.

Best coupling is when TOSA NA matches fiber NA.

US-DS gap depends on the combination of TX and RX beam characteristics.

Receive filtering depends on the fiber beam width.

θ_{RX} is determined by the NA of the fiber:

$$NA = \sin\theta_F \sim \theta_F$$

$$\theta_F = \theta_{RX} \sim \frac{\lambda}{\pi\omega_F}$$

Fiber beam NA = 0.91, or θ_F ~ 5.2º.

N.B. "Fiber NA" quoted in datasheets is <u>not</u> the same as the NA of the output beam.

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Filter response for diverging beams

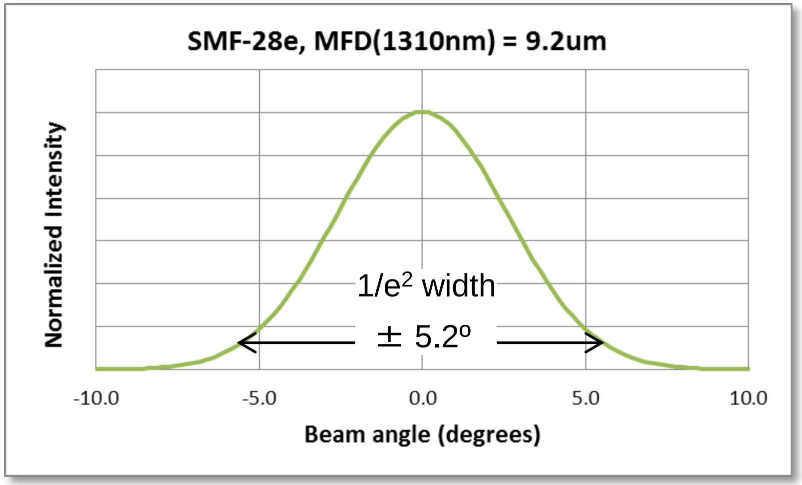
- The diverging beam from the fiber and the converging beam from the TOSA are well-described by Gaussian optics.
- The intensity of a Gaussian beam as a function of angle is:

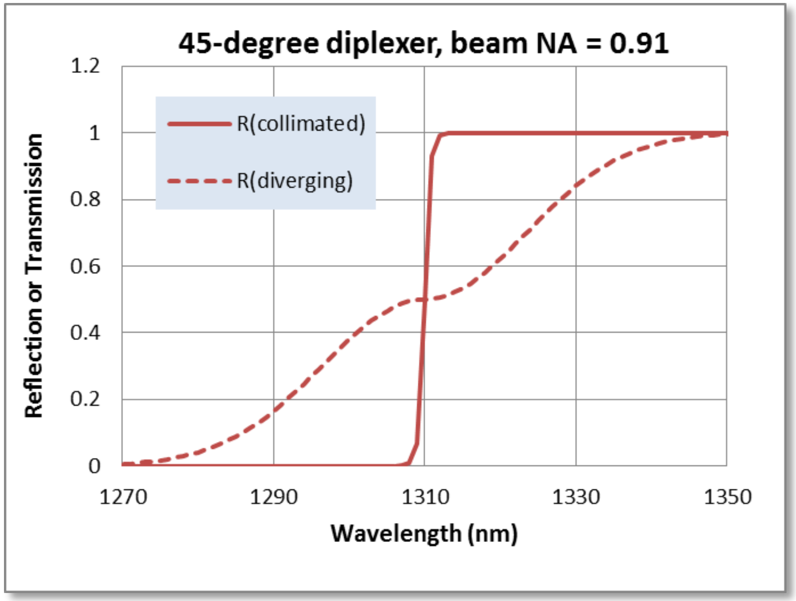
$$I(\theta) = I_0 e^{-2\left(\frac{\pi\omega\theta}{\lambda}\right)^2}$$

- The wavelength shift of an interference filter as a function of angle is given by:

$$\lambda(\theta) = \lambda_0 \sqrt{1 - \left(\frac{\sin\theta}{n_2}\right)^2}$$

- The effect of the diverging beam on the filter response is obtained by integrating over all angles, weighted by the intensity.
- For the SMF beam with MFD = 9.2um, the idealized diplexer transition is broadened from ~4nm to > 50nm.





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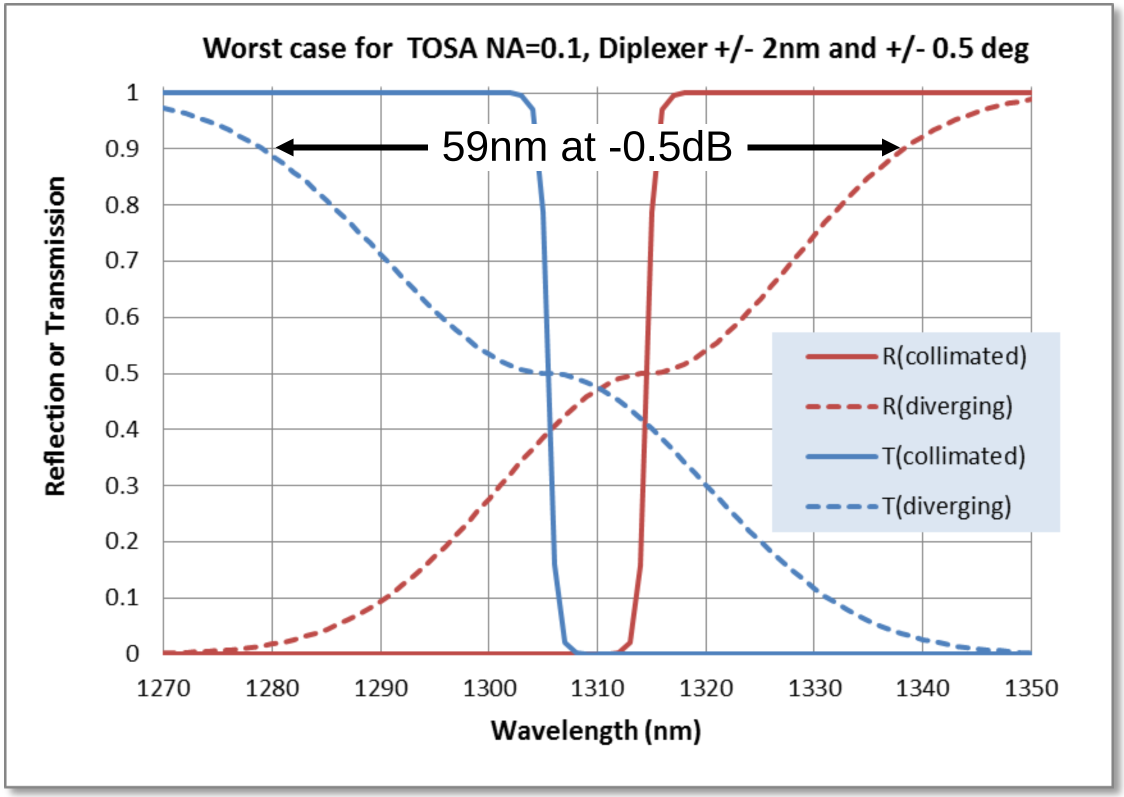
Narrow-gap diplexer analysis

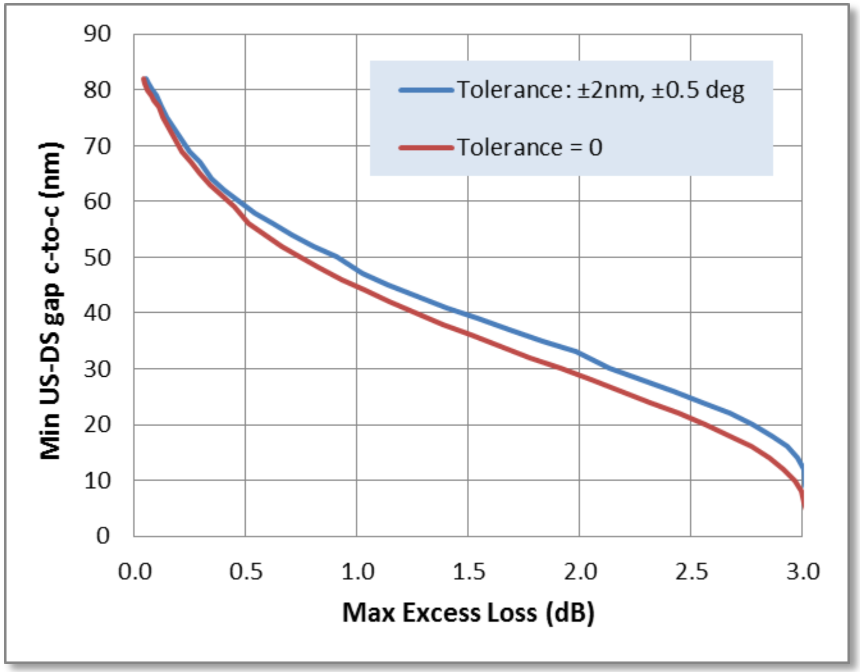
- Typical EPON/GPON BOSA construction
  - TOSA working distance is 6~10mm, with NA ~ 0.1 to 0.2.
  - Diplexer transition band is ~100nm (collimated beam).
  - Diplexer wavelength tolerance is ~ ± 5nm, by sample testing before dicing.
  - Diplexer angle tolerance from housing and assembly ~ ± 0.5º (± 2.6nm).
- Narrow-gap diplexer construction and cost
  - A filter with ~5nm transition width (collimated beam) will require considerably more dielectric layers than a GPON diplexer.
  - Fabrication cost will be higher even before considering yield.
  - Increased testing may be required to insure tighter wavelength tolerance.
  - Assume diplexer wavelength tolerance spec of ± 2nm for narrow gaps.
  - Yield will be lower due to increased complexity and tighter specs.
- Focusing beam TOSA for narrow-gap ONU
  - Use ~10mm working distance with NA = 0.1 for good fiber coupling.
  - Better coupling is possible with NA = 0.09, but longer working distance results.
  - Reducing NA further results in reduced beam cone angle together with increased coupling loss and BOSA length.
  - High power TOSA will require active lens cap alignment to increase coupling and reduce beam pointing error – increased CM infrastructure spending, capping assembly time and cost.

O-band diplexer example



- Worst case for receive path with NA=0.091 is diplexer +2nm and assembly -0.5º.
- Worst case for transmit path with NA=0.1 is diplexer -2nm and assembly +0.5º.
- At 0.5dB max excess loss in either path, minimum US-DS gap is 59nm.
- Assuming ±1nm laser tolerance, minimum center-to-center US-DS gap for 0.5B loss is 61nm.
- For 1dB max excess loss in either path, minimum center-to-center US-DS gap becomes 49nm.

Minimum US-DS gap vs. excess insertion loss



- The plot to the left shows the minimum center-to-center US-DS gap as a function of the maximum excess loss with and without filter tolerances.
- Excess loss does not include filter insertion loss, fiber coupling or other losses.
- Based on this curve, focused beam optics are practical for >60nm gap, with increasing losses for smaller gaps.
- Even with zero tolerances, loss is only reduced by ~0.3dB at 40nm gap.

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Summary

- The analysis presented here for standard single-mode fiber and TOSA with NA=0.1 is more pessimistic than the previously reported cut-off of 35-40nm for use of focusing beam optics.
  - Center-to-center US-DS gap of 61nm results in up to 0.5dB excess loss.
  - Center-to-center US-DS gap of 49nm results in up to 1.0dB excess loss.
- The cost of a focusing beam BOSA with ~60nm US-DS gap will be higher than an equivalent wide gap BOSA for several reasons:
  - A TOSA with > 10mm working distance and active cap lens alignment must be used. Active cap alignment will require additional investment by CMs.
  - The BOSA housing must be longer to contain the low-NA TOSA.
  - A diplexer filter with sharp transition will have more layers and tighter specs, require additional testing and may have lower yield than a filter with wider transition.
  - There will be excess diplexer insertion loss that must be overcome by higher TX power or RX sensitivity, especially for gaps < 50nm.
- Even if they both use focusing beam optics, O-Band ONU diplexer cost will be lower for wavelength plans that have US and DS channels in different bands such as Plans D and E, compared with Plans A, B and C with both US and DS channels in O-band.

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Thank You!