OPTI510R: Photonics

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Meinel building R.626
Announcements

- HW #5 is assigned (due April 9)
- April 9th class will be in 305 instead of 307
- April 11th class will be at 2PM instead of 11AM, still in 307
- Final exam May 2
Four-wave-mixing

\[ P = \varepsilon_0 \left( \chi^{(1)} \cdot E + \chi^{(2)} : EE + \chi^{(3)} : EEE + \cdots \right) \quad \text{(Induced polarization)} \]

\[ P_{\text{NL}} = \varepsilon_0 \chi^{(3)} : EEE, \quad \text{(third order nonlinear polarization term)} \]

Consider four optical waves oscillating at frequencies \( \omega_1, \omega_2, \omega_3, \) and \( \omega_4 \) and linearly polarized along the same axis \( x \). The total electric field can be written as:

\[ E = \frac{1}{2} \hat{x} \sum_{j=1}^{4} E_j \exp[i(k_j z - \omega_j t)] + \text{c.c.}, \]

\[ \vec{P}_{\text{NL}} = \frac{1}{2} \hat{x} \sum_{j=1}^{4} P_j \exp[i(k_j z - \omega_j t)] + \text{c.c.}, \]
Four-wave-mixing

We find that $P_j$ ($j = 1$ to 4) consists of a large number of terms involving the products of three electric fields.

For example, $P4$ can be expressed as:

$$
P_4 = \frac{3\varepsilon_0}{4} \chi^{(3)} \left[ |E_4|^2 E_4 + 2(|E_1|^2 + |E_2|^2 + |E_3|^2)E_4 ight.
+ 2E_1E_2E_3 \exp(i\theta_+) + 2E_1E_2E_3^* \exp(i\theta_-) + \cdots],
$$

where $\theta_+$ and $\theta_-$ are defined as

$$
\theta_+ = (k_1 + k_2 + k_3 - k_4)z - (\omega_1 + \omega_2 + \omega_3 - \omega_4)t,
$$

$$
\theta_- = (k_1 + k_2 - k_3 - k_4)z - (\omega_1 + \omega_2 - \omega_3 - \omega_4)t.
$$
There are two types of FWM. The term containing $\theta_+$ corresponds to the case in which three photons transfer their energy to a single photon at the frequency $\omega_4 = \omega_1 + \omega_2 + \omega_3$. This term is responsible for the phenomena such as third-harmonic generation ($\omega_1 = \omega_2 = \omega_3$). In general, it is difficult to satisfy the phase-matching condition for such processes to occur in optical fibers with high efficiencies.

The term containing $\theta$ corresponds to the case in which two photons at frequencies $\omega_1$ and $\omega_2$ are annihilated with simultaneous creation of two photons at frequencies $\omega_3$ and $\omega_4$ such that:

$$\omega_3 + \omega_4 = \omega_1 + \omega_2$$

The phase-matching requirement for this process to occur is:

$$\Delta k = k_3 + k_4 - k_1 - k_2$$
$$= \left( n_3 \omega_3 + n_4 \omega_4 - n_1 \omega_1 - n_2 \omega_2 \right) / c = 0.$$
Four-wave-mixing

FWM efficiency governed by phase mismatch (in a waveguide):

\[ \Delta = \beta(\omega_3) + \beta(\omega_4) - \beta(\omega_1) - \beta(\omega_2) \]

In the degenerate case \((\omega_1 = \omega_2)\), \(\omega_3 = \omega_1 + \Omega\), and \(\omega_4 = \omega_1 - \Omega\)

Expanding \(\beta\) in a Taylor series, \(\Delta = \beta_2 \Omega^2\)

FWM becomes important for WDM systems designed with low dispersion fibers!
Four-wave-mixing

PM PCF(20cm)

90/10 PM OC

Fiber-OPO

Pump in

Output

Ring resonator

Cascaded FWM
FWM-good or bad?

- FWM leads to inter-channel crosstalk in WDM systems
- It can be avoided through dispersion management

On the other hand…

FWM can be used beneficially for:

- Parametric amplification and lasing
- Optical phase conjugation
- Wavelength conversion of WDM channels
- Supercontinuum generation
Major Nonlinear Effects:

- Self-Phase Modulation (SPM)
- Cross-Phase Modulation (XPM)
- Four-Wave Mixing (FWM)
- Stimulated Raman Scattering (SRS)
- Stimulated Brillouin Scattering (SBS)

Origin of Nonlinear Effects in Optical Fibers:

- Ultrafast third-order susceptibility $\chi_3$
M. E. Marhic, *Fiber Optical Parametric Amplifiers, Oscillators and Related Devices* (Cambridge University, 2007)


Passive fiber components

- Fiber spicing and connectorization
- Directional couplers
- WDM couplers
- Isolators
- Tunable filters, resonators, AWG… (homework)
Traditional optics

Optical elements are used to split/combine, filter, focus, amplify, attenuate… light
“Fiberization” in Optics

Ti:sa femtosecond laser

Femtosecond fiber laser
Passive fiber components

- Fiber coupler
- Variable fiber coupler
- WDM
- Isolator
- Attenuator
- Modulator
- Switches
- Pump/signal combiner
- Polarization splitter/combiner
- Collimator
- Fiber delay line
- Polarizer
- Tunable filter
- Circulator
- Faraday rotator mirror
- …
Point-to-point WDM Transmission System
- Building Blocks -

1. **Transmitter Terminal (Tx)**
   - **WDM Mux**
   - **EDFA**
   - **Transmission Fiber**
   - **Dispersion Compensation**
   - **Raman Pump**

2. **Transmission Line**
   - **Point-to-point Link**

3. **Section Span Amplifier Span**

4. **Receiver Terminal (Rx)**
   - **WDM Demux**
   - **EDFA**
   - **Transmission Fiber**
   - **Dispersion Compensation**
   - **Raman Pump**

**Building Blocks**
- SMF or NZDF
Erbium-doped fiber amplifier
Fiber laser

Mode-locked ring fiber laser
Fiber cable construction

Reinforcement needed to protect the fragile glass fiber
Corning® SMF-28® ULL Optical Fiber
With Corning® Ultra-Low Loss Technology
Product Information

Corning® SMF-28® ULL fiber with Corning® ultra-low-loss technology is a G.652-compliant fiber with the lowest attenuation and PMD in the industry, empowering networks to achieve longer spans and extended reach.

**Optical Specifications**

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>Maximum Attenuation (dB/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1310</td>
<td>0.28 – 0.31</td>
</tr>
<tr>
<td>1550</td>
<td>0.17 – 0.18</td>
</tr>
<tr>
<td>1625</td>
<td>0.20 – 0.21</td>
</tr>
</tbody>
</table>

*Maximum specified attenuation value available within the stated range. Alternate attenuation offerings available upon request.*

**Cable Cutoff Wavelength (λ_{ccf})**

\( λ_{ccf} \leq 1260 \text{ nm} \)

**Mode-Field Diameter**

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>MFD (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1310</td>
<td>9.2 ± 0.5</td>
</tr>
<tr>
<td>1550</td>
<td>10.7 ± 0.5</td>
</tr>
</tbody>
</table>

**Attenuation vs. Wavelength**

<table>
<thead>
<tr>
<th>Range (nm)</th>
<th>Ref. λ (nm)</th>
<th>Max. ( α ) Difference (dB/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1285 – 1330</td>
<td>1310</td>
<td>0.03</td>
</tr>
<tr>
<td>1525 – 1575</td>
<td>1550</td>
<td>0.02</td>
</tr>
<tr>
<td>1625</td>
<td>1550</td>
<td>0.03</td>
</tr>
</tbody>
</table>

The attenuation in a given wavelength range does not exceed the attenuation of the reference wavelength (\( λ \)) by more than the value \( α \).

**Dispersion**

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>Dispersion Value (ps/(nm·km))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1550</td>
<td>( \leq 18.0 )</td>
</tr>
<tr>
<td>1625</td>
<td>( \leq 22.0 )</td>
</tr>
</tbody>
</table>

Zero Dispersion Wavelength (\( λ_0 \)): 1300 nm \( \leq λ_0 \) \leq 1324 nm
Zero Dispersion Slope (\( S_0 \)): \( \leq 0.092 \text{ ps/(nm}^2\text{·km)} \)
Fiber connectorization

Fiber optics cable

Before splicing

Fusion splicer

After splicing

Fiber optics connectors
Fiber displacement

![Diagram showing fiber displacement](image)

- **Loss due to radial misalignment (dB)**
- **Radial misalignment / Core diameter**

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Prof. Norwood
Longitudinal displacement

![Graph showing loss due to longitudinal separation with different NA values](image)
Angular deviation

- Loss due to angular deviation [dB]
- Angular deviation $\alpha$ [degrees]
Fiber connectors
Fiber connectors

Insertion losses are generally
<0.2 dB typical
<0.5 dB max

Connectors can have a flat polish or they may have an 8° angle polish which reduces back reflections dramatically (< -60dB return loss) compared to flat polish (< -40dB return loss)
Fiber connectors, FC/PC
Fiber splicing

- Fiber stripping
- Surface cleaning
- Fiber cleaving
- Fiber alignment
- Pre-fusion heating
- Fusing
- Splice evaluation
- Protection, strain relief
  - Heat shrink sleeve
Fiber splicer
Fiber cleaver
Fiber stripper
Fusion splicing
Fiber optic couplers

- Optical couplers either split optical signals into multiple paths or combine multiple signals onto one path.
- The number of input (N) / output (M) ports, (i.e. N x M) characterizes a coupler.
- Fused couplers can be made in any configuration, but they commonly use multiples of two (2 x 2, 4 x 4, 8 x 8, etc.)
Coupler applications

- **Uses**
  - Splitter: (50:50)
  - Taps: (90:10) or (95:05)
  - Combiners

- **Couplers are key components in**
  - Optical amplifiers
  - Fiber lasers
  - Optical switches
  - Mach Zehnder interferometers
  - Fiber-to-the-home networks
  - Optical fiber sensors
The coupling is wavelength dependent. Coupling occurs when the two fibers’ cores are very close to each other. Small changes effect the coupling ratio.

WDM coupler
- 100% of the 1.3 μm light couples to the core of fiber B, and then back to the core of fiber A to emerge at Port C
- 100% of the 1.55 μm light couples to the core of fiber B and emerges at Port D
- Simple coarse WDM filters can be made in this way
Single-mode coupler properties

- Couplers are made by tapering fibers down, thereby making the core very small, resulting in most of the light propagating in the "multimode' cladding in the taper region.

- If the adiabatic coupling regions vary slowly enough, then there is very little loss as the light propagates across the biconical taper.
Fused biconic taper fabrication

- Fabrication of a biconical taper
  - Heat fiber uniformly over a width $w$ to the glass melting point, $T_m$
  - Stretch fiber a distance $L$ on both sides of the heated region

Fiber taper (top) and standard fiber (bottom)
Fused biconic taper fabrication

or

example: experimental set-up

typical parameters

(Bilodeau, et al., JLT, 6, 1476, '8)

Completely automated technology with high throughput

Coupling ratio, excess loss, PDL
Theory for directional couplers

- Four-port devices (two input and two output ports)
- Output can be split in two different directions; hence the name directional couplers
- Can be fabricated using fibers or planar waveguides
- Two waveguides are identical in symmetric couplers
- Evanescent coupling of modes in two closely spaced waveguides
- Overlapping of modes in the central region leads to power transfer
Theory for directional couplers

- Coupled-mode theory commonly used for couplers

- Begin with the Helmholtz equation: \( \nabla^2 \tilde{E} + \tilde{n}^2 k_0^2 \tilde{E} = 0 \)

- \( \tilde{n}(x,y) = n_0 \), everywhere except in the region occupied by two cores

- Approximate solution:
  \[
  \tilde{E}(r, \omega) \approx \hat{e}[\tilde{A}_1(z, \omega)F_1(x,y) + \tilde{A}_2(z, \omega)F_2(x,y)]e^{i\beta z}
  \]

- \( F_m(x,y) \) corresponds to the mode supported by the each waveguide:
  \[
  \frac{\partial^2 F_m}{\partial x^2} + \frac{\partial^2 F_m}{\partial y^2} + \left[ n_m^2(x,y)k_0^2 - \bar{\beta}_m^2 \right] F_m = 0
  \]

- \( A_1 \) and \( A_2 \) vary with \( z \) because of the mode overlap

Credit: Agrawal
Coupled mode equations

- Coupled-mode theory deals with amplitudes $A_1$ and $A_2$

- We substitute assumed solution in Helmholtz equation, multiply by $F_1$ or $F_2$, and integrate over $x$-$y$ plane to obtain:

$$\frac{d\tilde{A}_1}{dz} = i(\beta_1 - \beta)\tilde{A}_1 + i\kappa_{12}\tilde{A}_2,$$

$$\frac{d\tilde{A}_2}{dz} = i(\beta_2 - \beta)\tilde{A}_2 + i\kappa_{21}\tilde{A}_1,$$

- The coupling coefficient is defined as:

$$\kappa_{mp} = \frac{k_0^2}{2\beta} \int \int_{-\infty}^{\infty} (\tilde{n}^2 - n_p^2) F_m^*F_p \, dx \, dy,$$

- Modes are normalized such that:

$$\int \int_{-\infty}^{\infty} |F_m(x,y)|^2 \, dx \, dy = 1$$

Credit: Agrawal
Time-domain coupled mode equations

- Expand $\tilde{\beta}_m(\omega)$ in a Taylor series around the carrier frequency $w_0$ as:

$$\tilde{\beta}_m(\omega) = \beta_{0m} + (\omega - w_0)\beta_{1m} + \frac{1}{2}(\omega - w_0)^2\beta_{2m} + \cdots,$$

- Replace $\omega - w_0$ by $i(\partial / \partial t)$ while taking inverse Fourier transform:

$$\frac{\partial A_1}{\partial z} + \frac{1}{v_{g1}} \frac{\partial A_1}{\partial t} + \frac{i\beta_{21}}{2} \frac{\partial^2 A_1}{\partial t^2} = i\kappa_{12}A_2 + i\delta_aA_1,$$

$$\frac{\partial A_2}{\partial z} + \frac{1}{v_{g2}} \frac{\partial A_2}{\partial t} + \frac{i\beta_{22}}{2} \frac{\partial^2 A_2}{\partial t^2} = i\kappa_{21}A_1 - i\delta_aA_2,$$

where $v_{gm} \equiv 1 / \beta_{1m}$ and

$$\delta_a = \frac{1}{2}(\beta_{01} - \beta_{02}), \quad \beta = \frac{1}{2}(\beta_{01} + \beta_{02})$$

- For a symmetric coupler, $\delta_a = 0$ and $\kappa_{12} = \kappa_{21} \equiv \kappa$

Credit: Agrawal
Consider first the simplest case of a CW beam incident on one of the input ports of a coupler.

Setting time-dependent terms to zero we obtain

\[ \frac{dA_1}{dz} = i\kappa_{12}A_2 + i\delta_a A_1, \quad \frac{dA_2}{dz} = i\kappa_{21}A_1 - i\delta_a A_2. \]

Eliminating \( dA_2/dz \), we obtain a simple equation for \( A_1 \):

\[ \frac{d^2 A_1}{dz^2} + \kappa_e^2 A_1 = 0, \quad \kappa_e = \sqrt{\kappa^2 + \delta_a^2} \quad (\kappa = \sqrt{\kappa_{12}\kappa_{21}}). \]

General solution when \( A_1(0) = A_0 \) and \( A_2(0) = 0 \):

\[ A_1(z) = A_0[\cos(\kappa ez) + i(\delta_a/\kappa_e) \sin(\kappa ez)], \]
\[ A_2(z) = A_0(i\kappa_{21}/\kappa_e) \sin(\kappa ez). \]
Even though $A_2 = 0$ at $z = 0$, some power is transferred to the second core as light propagates inside a coupler.

Power transfer follows a periodic pattern.

Maximum power transfer occurs for $\kappa_e z = m\pi /2$.

Coupling length is defined as $L_c = \pi/(2\kappa_e)$. 
Symmetric couplers

- Maximum power transfer occurs for a symmetric coupler ($\delta_a = 0$)

- General solution for a symmetric coupler of length $L$:

  \[
  A_1(L) = A_1(0)\cos(\kappa L) + iA_2(0)\sin(\kappa L)
  \]

  \[
  A_2(L) = iA_1(0)\sin(\kappa L) + A_2(0)\cos(\kappa L)
  \]

- This solution can be written in a matrix form as

  \[
  \begin{pmatrix}
  A_1(L) \\
  A_2(L)
  \end{pmatrix} =
  \begin{pmatrix}
  \cos(\kappa L) & i\sin(\kappa L) \\
  i\sin(\kappa L) & \cos(\kappa L)
  \end{pmatrix}
  \begin{pmatrix}
  A_1(0) \\
  A_2(0)
  \end{pmatrix}.
  \]

- When $A_2(0) = 0$ (only one beam injected), output fields become

  \[
  A_1(L) = A_1(0)\cos(\kappa L), \quad A_2(L) = iA_2(0)\sin(\kappa L)
  \]

- A coupler acts as a beam splitter; notice $90^\circ$ phase shift for the cross port.
Symmetric couplers

- Simplest application of a fiber coupler is as an optical tap.
- If $\rho$ is close to 1, a small fraction of input power is transferred to the other core.
- Another application consists of dividing input power equally between the two output ports ($\rho = \frac{1}{2}$).
- Coupler length $L$ is chosen such that $\kappa L = \pi/4$ or $L = L_c/2$. Such couplers are referred to as 3-dB couplers.
- Couplers with $L = L_c$ transfer all input power to the cross port.
- By choosing coupler length appropriately, power can be divided between two output ports in an arbitrary manner.
Coupler performance parameters (I)

- **Coupling ratio or splitting ratio:**

\[
CR = \frac{\text{Power from any single output}}{\text{Total power out to all ports}} = \frac{P_t}{P_{T\text{ out}}}
\]

\[
CR = 10 \log_{10} \left( \frac{P_2}{P_1 + P_2} \right) \quad \text{2 x 2 case in dB}
\]

- **Excess loss:**

\[
L_e = \frac{P_{\text{in}}}{P_{T\text{ out}}}
\]

\[
L_e = 10 \log_{10} \left( \frac{P_{\text{in}}}{P_1 + P_2} \right) \quad \text{2 x 2 case in dB}
\]
Coupler performance parameters (II)

➢ **Insertion loss:**

\[
L_i = \frac{\text{Power from any single output}}{\text{Power input}} = \frac{P_t}{P_{in}}
\]

\[
L_i = 10 \log_{10} \frac{P_t}{P_{in}} \quad \text{In dB}
\]

➢ **Isolation or crosstalk:**

\[
L_{iso} = \frac{\text{Input power at one port}}{\text{Reflected power back into other input port}}
\]

\[
L_{iso} = 10 \log_{10} \frac{P_{in}}{P_3} \quad \text{In dB}
\]
Fiber star coupler

Combines power from $N$ inputs and divided them between $N$ outputs

Coupling ratio

$$CR = 10 \log_{10} \frac{1}{N} = 10 \log_{10} N$$

Excess loss

$$L_e = 10 \log_{10} \left( \frac{P_{in}}{N} \sum_{i} \frac{P_{out,i}}{i} \right)$$
Wavelength-dependent couplers

- Wavelength-division multiplexers (WDM) types:
  - 3 port devices (4th port terminated)
  - 1310 / 1550 nm (“classic” WDM technology)
  - 1480 / 1550 nm and 980 / 1550 nm for pumping optical amplifiers
  - 1550 / 1625 nm for network monitoring

- Insertion and rejection:
  - Low loss (< 1 dB) for path wavelength
  - High loss (20 to 50 dB) for other wavelength
Wavelength-dependent couplers

- Fused biconic taper is made and monitored as it is being pulled
- When 1550nm is in the bar state and 1310nm is in the cross state, pulling is stopped - - a coarse WDM filter results
WDM couplers

- Fused Fiber Couplers
  - Low loss (<0.5dB)
  - Small size (35x5.5mm)
  - Low cost (~$200)

- Thin film type WDM
  - Insertion Loss 0.5 ~ 1.0 dB
  - Isolation –20 ~ –30 dB
  - Return Loss –40 dB

- Fused coupler type WDM
  - Insertion Loss < 0.3 dB
  - Isolation –25 ~ –30 dB
  - Return Loss –60 dB
The Singlemode Wavelength Division Multiplexers combine or separate light at different wavelengths. They offer very low insertion loss, low polarization dependence, high isolation and excellent environmental stability. These components have been extensively used in EDFA, CATV, WDM networks and fiber optics instrumentation.

**Specifications**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center Wavelength ((\lambda_c))</td>
<td>nm</td>
<td>980/1550</td>
</tr>
<tr>
<td>Operating Wavelength</td>
<td>nm</td>
<td>(\lambda_c \pm 15)</td>
</tr>
<tr>
<td>Min. Isolation</td>
<td>dB</td>
<td>20</td>
</tr>
<tr>
<td>Max. Insertion Loss</td>
<td>dB</td>
<td>0.15</td>
</tr>
<tr>
<td>Max. Polarization Dependent Loss</td>
<td>dB</td>
<td>0.1</td>
</tr>
<tr>
<td>Thermal Stability</td>
<td>dB/°C</td>
<td>(\leq 0.002)</td>
</tr>
<tr>
<td>Min. Return Loss</td>
<td>dB</td>
<td>60</td>
</tr>
<tr>
<td>Min. Directivity</td>
<td>dB</td>
<td>60</td>
</tr>
<tr>
<td>Max. Optical Power (Continuous Wave)</td>
<td>mW</td>
<td>300</td>
</tr>
<tr>
<td>Operating Temperature</td>
<td>°C</td>
<td>-40 to +75</td>
</tr>
<tr>
<td>Storage Temperature</td>
<td>°C</td>
<td>-40 to +85</td>
</tr>
</tbody>
</table>

*IL is 0.5 dB higher, RL is 5 dB lower for each connector added.
*Test at central wavelength only.
Isolators

- Polarization sensitive isolator
  - Low loss (<0.5dB)
  - Small size (35x5.5mm)
  - Low cost (~$200)

- Polarization insensitive isolator

Diagram showing the principles of operation: Forward and Backward paths with polarization elements such as Faraday crystals and polarizers.
Isolators

The Polarization Insensitive Isolator is designed and manufactured according to Telcordia standard. The unique manufacturing process and optical path epoxy-free design enhance the device high power handling capability. The device is characterized with high performance, high reliability and low cost. It has been widely used in EDFAs, Raman amplifiers, DWDM systems, fiber lasers, transmitters and other fiber optics communication equipments to suppress back reflection and back scattering.

Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Single Stage</th>
<th>Dual Stage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Grade P</td>
<td>Grade A</td>
</tr>
<tr>
<td>Center Wavelength ($\lambda_c$)</td>
<td>nm</td>
<td>1310, 1480 or 1550</td>
<td></td>
</tr>
<tr>
<td>Typ. Peak Isolation</td>
<td>dB</td>
<td>42</td>
<td>40</td>
</tr>
<tr>
<td>Min. Isolation, $\lambda_c \pm 10$ nm, 23 °C, all polarization states</td>
<td>dB</td>
<td>30</td>
<td>29</td>
</tr>
<tr>
<td>Typ. Insertion Loss, $\lambda_c$, 23 °C; all polarization states</td>
<td>dB</td>
<td>0.35</td>
<td>0.5</td>
</tr>
<tr>
<td>Max. Insertion Loss, $\lambda_c \pm 20$ nm, all temperature, all polarization states</td>
<td>dB</td>
<td>0.5</td>
<td>0.7</td>
</tr>
<tr>
<td>Min. Return Loss (Input/Output)</td>
<td>dB</td>
<td>60/55</td>
<td>60/55</td>
</tr>
<tr>
<td>Max. Polarization Dependent Loss, 23 °C</td>
<td>dB</td>
<td>0.05</td>
<td>0.1</td>
</tr>
<tr>
<td>Max. Polarization Mode Dispersion</td>
<td>ps</td>
<td>0.20</td>
<td>0.25</td>
</tr>
<tr>
<td>Max. Optical Power (Continuous Wave)</td>
<td>mW</td>
<td>300</td>
<td></td>
</tr>
<tr>
<td>Max. Tensile Load</td>
<td>N</td>
<td>5</td>
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</tr>
<tr>
<td>Fiber Type</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Operating Temperature</td>
<td>°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Storage Temperature</td>
<td>°C</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*IL is 0.3 dB higher, RL is 5 dB lower for each connector added.*
Questions for Thoughts

What is the new fiber component that you think may be useful to have?

Can we replace all traditional optics with fiber-based components?

How can you turn your experimental setup into fiber-based?

Where are fiber-based components made?

How can you start a successful company providing fiber components and devices?