Contents

- Connectors + Optical Splice
- Attenuators
- Coupler
- Splitter
- Filters
- Fibre Brag Grating
- Optical Isolator
- Circulators
- Optical Add/Drop
- Multiplexer & Demultiplexer
Connectors

A mechanical or optical device that provides a demountable connection between two fibers or a fiber and a source or detector.
Connectors - *contd.*

**Type:** SC, FC, ST, MU, SMA

- Favored with single-mode fibre
- Multimode fibre (50/125um) and (62.5/125um)
- Loss 0.15 - 0.3 dB
- Return loss 55 dB (SMF), 25 dB (MMF)

Single fibre connector

---

Prof. Z Ghassemlooy
Connectors - contd.

- Single-mode fiber
- Multi-mode fiber (50/125)
- Multi-mode fiber (62.5/125)
- Low insertion loss & reflection

MT-RJ Patch Cord

MT-RJ Fan-out Cord
Optical Splices

• Mechanical
  – Ends of two pieces of fiber are cleaned and stripped, then carefully butted together and aligned using a mechanical assembly. A gel is used at the point of contact to reduce light reflection and keep the splice loss at a minimum. The ends of the fiber are held together by friction or compression, and the splice assembly features a locking mechanism so that the fibers remained aligned.

• Fusion
  – Involves actually melting (fusing) together the ends of two pieces of fiber. The result is a continuous fiber without a break.

Both are capable of splice losses in the range of 0.15 dB (3%) to 0.1 dB (2%).
Attenuators

**Singlemode Variable Attenuator**
- Repeatable, variable attenuation from 2 to 40dB
- <-70dB reflectance (unconnectorized)
- Polarization insensitive
- Low modal noise
- Long-term reliability
Attenuators - *contd.*

- Bandpass 1310/1550nm
- FC, SC, ST, and D4 styles
- Wavelength independent
- Polarization insensitive
- Low modal noise
Optical Couplers

- Optic couplers either split optical signals into multiple paths or combine multiple signals on one path.
- The number of input (N)/ output (M) ports, (i.e. N x M size) 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

• Uses
  – Splitter: (50:50)
  – Taps: (90:10) or (95:05)
  – Combiners

• An important issue:
  – two output differ $\pi/2$ in phase

• Applications:
  – Optical Switches,
  – Mach Zehnder Interferometers,
  – Optical amplifiers,
  – passive star couplers, ...
Coupler Configuration

\[
P_1 \rightarrow \lambda_1 \rightarrow \lambda_3 \rightarrow P_3
\]

\[
P_1 \rightarrow \lambda_1 \rightarrow \lambda_2 \rightarrow \lambda_3 \rightarrow P_3
\]

\[
P_1 \rightarrow \lambda_1 \rightarrow \lambda_2 \rightarrow \ldots \lambda_n \rightarrow P_3
\]
Coupler - Integrated Waveguide

Directional Coupler

\[ P_2 = P_0 \sin^2 kz \]
\[ P_1 = P_0 - P_2 = P_0 \cos^2 kz \]
\[ k = \text{coupling coefficient} = (m + 1)\pi/2 \]
**Coupler - Integrated Waveguide Directional Coupler**

- A directional coupler

- Different performance couplers can be made by varying the length, size for specific wavelength.
Coupler - Performance Parameters

- Coupling ratio or splitting ratio

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

In dB
\[
CR = 10 \log_{10} \left( \frac{P_2}{P_1 + P_2} \right)
\]

For 2 x 2 coupler

- Excess Loss

\[
L_e = \frac{\text{Input power} \, P_i}{\text{Total output power} \, P_{T-out}}
\]

\[
L_e = 10 \log_{10} \left( \frac{P_0}{P_1 + P_2} \right)
\]
Coupler - Performance Parameters

• Insertion Loss

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

• Isolation Loss or Crosstalk

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

In dB

\[ L_{iso} = 10 \log_{10} \left( \frac{P_0}{P_3} \right) \]
Generic 2X2 Guided-Wave Coupler

There are altogether eight possible ways (two ways) for the light to travel.

where \( \mathbf{b} = \mathbf{S} \mathbf{a} \)

\[
\mathbf{b} = \begin{bmatrix} b_1 \\ b_2 \end{bmatrix}, \quad \mathbf{a} = \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}, \quad \text{and} \quad \mathbf{S} = \begin{bmatrix} s_{11} & s_{12} \\ s_{21} & s_{22} \end{bmatrix}
\]
Generic 2X2 Guided-Wave Coupler

Assume: Fraction \((1- \varepsilon)\) of power in the input port 1 appears at output port 1, and the remaining power \(\varepsilon\) at the output port 2.

\[
S = \begin{bmatrix}
\sqrt{1-\varepsilon} & j\sqrt{\varepsilon} \\
\sqrt{\varepsilon} & \sqrt{1-\varepsilon}
\end{bmatrix}
\]

If \(\varepsilon = 0.5\), and input signal defined in terms of field intensity \(E_i\), then

\[
\begin{bmatrix}
E_{o,1} \\
E_{o,2}
\end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix}
1 \\
j
\end{bmatrix} \begin{bmatrix}
E_{i,1} \\
E_{i,2}
\end{bmatrix}
\]

Let \(E_{o,2} = 0\), thus in term of optical power

\[
P_{o,1} = E_{o,1}E_{o,1}^* = \frac{1}{2} E^2_{i,1} = \frac{1}{2} P_0
\]

\[
P_{o,2} = E_{o,2}E_{o,2}^* = \frac{1}{2} E^2_{i,1} = \frac{1}{2} P_0
\]

Half the input power appears at each output.
Tree and Branch Coupler

Coupling ratio; 1:1 or 1: \( n \),
where \( n \) is some fraction
Fibre Star Coupler

Combines power from \( N \) inputs and divided them between \( M \) outputs

\[
CR = -10 \log_{10} \left( \frac{1}{N} \right) = 10 \log_{10} N
\]

Excess loss

\[
L_e = 10 \log_{10} \left( \frac{P_{in}}{\sum_{i} P_{out,i}} \right)
\]

Power at any one output

\[
P_{o,i} = \frac{1}{n} (P_1 + P_2 + \ldots + P_N)
\]
Star Coupler - 8 X 8

Star couplers are optical couplers with more than four ports.

No of 3 dB coupler \( N_{c-3dB} = \frac{N}{2} \log_2 N \)
• If a fraction of power traversing each 3 dB coupler = $F_p$, where $0 < F_p < 1$.

• Power lost within the coupler = $1 - F_p$.

Excess loss

$$L_e = -10 \log_{10} \left( F_p^{\log_2 N} \right)$$

Coupling ratio (splitting loss)

$$CR = -10 \log_{10} \left( \frac{1}{N} \right) = 10 \log_{10} N$$

Total loss = splitting loss + excess loss

$$L_T = 10 \left( 1 - 3.322 \log_{10} F \right) \log_{10} N$$
Reflection Star Couplers
Y- Couplers

Y-junctions are 1 x 2 couplers and are a key element in networking.
## Coupler - Characteristics

<table>
<thead>
<tr>
<th>Design class</th>
<th>No. of port</th>
<th>CR</th>
<th>Le (dB)</th>
<th>Isolation directivity (-dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 x 2 Single mode</td>
<td>2</td>
<td>0.1-0.5</td>
<td>0.07-1.0</td>
<td>40 to 55</td>
</tr>
<tr>
<td>2 x 2 Multimode</td>
<td>2</td>
<td>0.5</td>
<td>1-2</td>
<td>35 to 40</td>
</tr>
<tr>
<td>N x N Star</td>
<td>3-32</td>
<td>0.33-0.03</td>
<td>0.5-8.0</td>
<td></td>
</tr>
</tbody>
</table>
Splitters

- The simplest couplers are fiber optic splitters.
- They possess at least three ports but may have more than 32 for more complex devices.
- Popular splitting ratios include 50%-50%, 90%-10%, 95%-5% and 99%-1%; however, almost any custom value can be achieved.
- Excess loss: assures that the total output is never as high as the input. It hinders the performance. All couplers and splitters share this parameter.
- They are symmetrical. For instance, if the same coupler injected 50 µW into the 10% output leg, only 5 µW would reach the common port.
Coupler + Splitter - Applications

• Local monitoring of a light source output (usually for control purposes).
• Distributing a common signal to several locations simultaneously.
• Making a linear, tapped fiber optic bus. Here, each splitter would be a 95%-5% device that allows a small portion of the energy to be tapped while the bulk of the energy continues down the main trunk.
Optical Filters

• **Passband**
  - Insertion loss
  - Ripple
  - Wavelengths (peak, center, edges)
  - Bandwidths (0.5 dB, 3 dB, ..)
  - Polarization dependence

• **Stopband**
  - Crosstalk rejection
  - Bandwidths
  - (20 dB, 40 dB, ..)

Agilent Tech. LW Div.
Filters - Thin-film Cavities

- Alternating dielectric thin-film layers with different refractive index
- Multiple reflections cause constructive & destructive interference
- Variety of filter shapes and bandwidths (0.1 to 10 nm)
- Insertion loss 0.2 - 2 dB, stopband rejection 30 - 50 dB

Agilent Tech. LW Div.
Fiber Bragg Gratings (FBG)

- A Bragg grating is a periodic refractive index variation written along the fibre (single-mode) core using high power UV radiation.

- If the optical period is $l_0 / 2$, the grating reflects wavelength $l_0$ selectively, very useful in filtering communication channels in or out.

\[ \lambda = 2 n \Lambda_{\text{Bragg}} \]
Fiber Brag Gratings (FBG) - *contd.*

- **Regular interval pattern:** reflective at *one* wavelength
  - Notch filter, add / drop multiplexer (see later)
  \[ \lambda \]

- Increasing intervals: “chirped” FBG compensation for chromatic dispersion
- Different wavelengths are reflected at different points of the Chirped FBG because of the variation in Grating Pitch.
- Different Wavelengths are travelling different paths and the slower can catch-up the quicker.

---

IN  

OUT

1-meter long FBG

Prof. Z Ghassemlooy
Optical Isolators

- Only allows transmission in one direction through it. **Main application:** To protect lasers and optical amplifiers from returning reflected light, which can cause instabilities.

- **Insertion loss:**
  - Low loss (0.2 to 2 dB) in forward direction
  - High loss in reverse direction:
    - 20 to 40 dB single stage, 40 to 80 dB dual stage

- **Return loss:**
  - More than 60 dB without connectors
Principle of operation

- Horizontal polarisation
- Vertical polarisation
- Linear polarisation
Optical Circulators

• Based on optical crystal technology similar to isolators
  – Insertion loss 0.3 to 1.5 dB, isolation 20 to 40 dB

• Typical configuration: 3 port device
  – Port 1 -> Port 2
  – Port 2 -> Port 3
  – Port 3 -> Port 1

Agilent Tech. LW Div.
Dispersion Compensation using Chirped FBG and Circulator

- FBG is linearly chirped, i.e. the period of the grating varies linearly with position. This makes the grating to reflect different wavelengths at different points along its length. Therefore, introducing different delay.
- In a standard fibre. Chromatic dispersion introduces larger delay for lower frequency (high wavelength) components of a pulse.
- Chirped FBG introduces larger delay for the higher frequency components, thus compensating for the dispersion effect (i.e. compressing the pulse)
Add - Drop Multiplexers

• Circulator with FBG

• Dielectric thin-film filter design
Multiplexers (MUX) / Demultiplexers (DEMUX)

- Key component of wavelength-division multiplexing (WDM) technology
- Types of technologies
  - Cascaded dielectric filters
  - Cascaded FBGs
  - Phased arrays (see later)
- Low crosstalk is essential for demultiplexing
Array Waveguide Grating (AWG)

Object plane

FPR

Free Propagation Region (normally a lens)

Image plane

Rows .. translate into .. columns

- N X N demultiplexer
- 1 X N demultiplexer!

Agilent Tech. LW Div.

Prof. Z Ghassemlooy
AWG - contd.

- Each \( \lambda \) experience a different phase shift because of different lengths of waveguide.
- Phase shifts wavelength are dependent.
- Thus, different channels focus to different output WG, on exit.
- N-input and N-output fibres
- Single input: wavelength demultiplexer!

- 1990s - First developed
- 1999 - Commercially available
- No. of channels: 250 to 1000 @ spacing of 10 GHz.
MUX - DeMUX - Performance

MUX

• Judged by the insertion loss/channel

DeMUX

• Sensitivity to polarisation
• Crosstalk (< -20 dB)
Next Lectures

- Optical amplifier
- Optical Switches