UNIT-IV

OPTICAL AMPLIFIERS AND NETWORKS

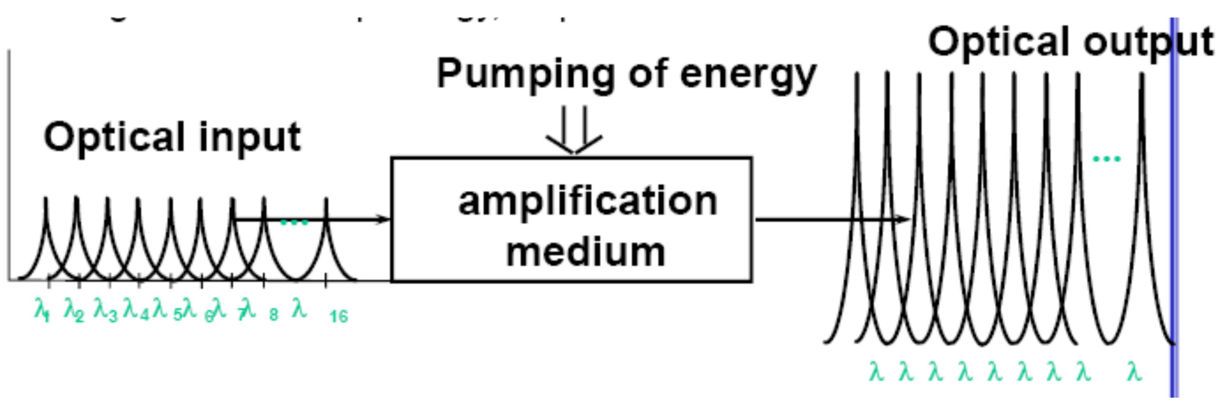
Why Optical Amplifiers?

– Increase transmission distance

- by increasing optical power coupled to transmission fiber(power booster)
- by compensating optical fiber losses(in-line amplifier, remote pump amplifier)
- by improving receiver sensitivity (optical preamplifier)

– Function : Amplification of optical signal without conversion to electrical signal

– Ingredients : Pump energy, amplification medium

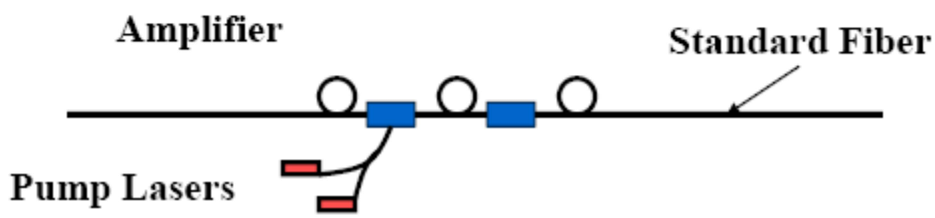


The Need of Optical Amplification:

Why? – Extend distance light signal can travel without regeneration

- **Erbium-Doped Fiber Amplifiers (EDFAs)** – application in long haul. Today's amplifier of choice.

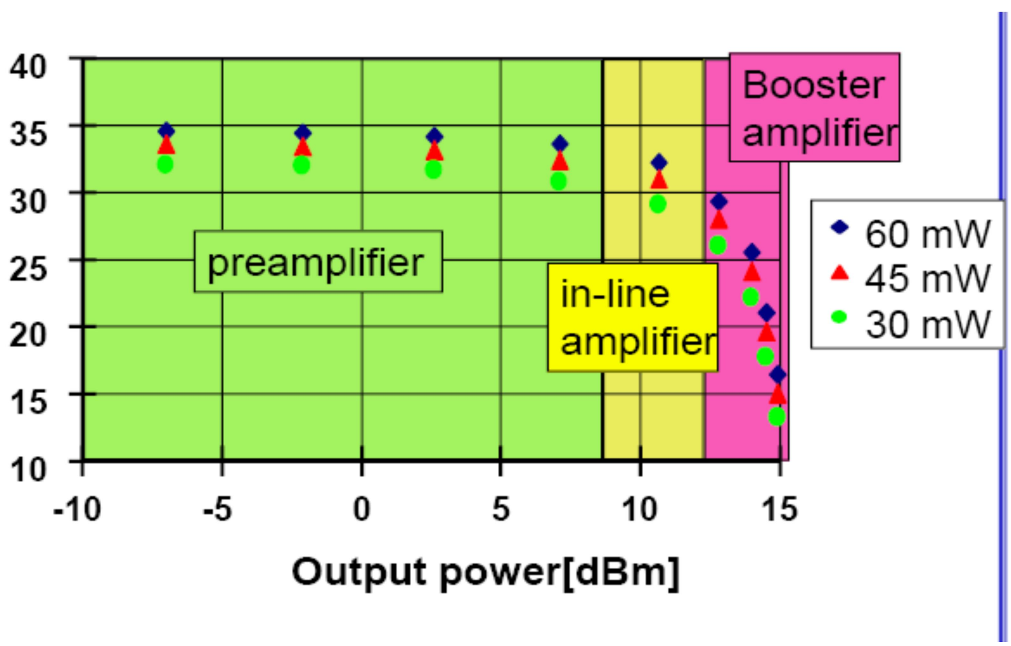
- **Erbium-Doped Waveguide Amplifiers (EDWAs)** – application in metro and access networks
- **Raman Amplifiers** – application in DWDM
- **Semiconductor Optical Amplifiers (SOA)** – not fiber based type, application in metro and access networks



General Application of Optical Amplification:

- In-line amplifier
- Preamplifier
- Power (booster) amplifier
- LAN booster amplifier

Amplifier Operation Points:

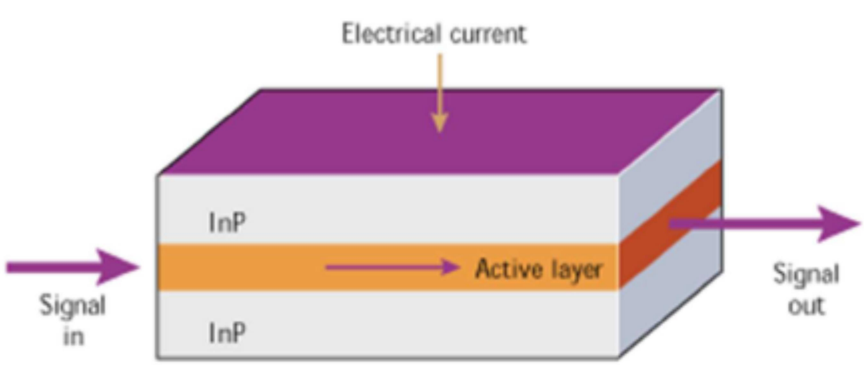


Improvement of System Gain

	Improvement in gain(dB)	Improvement in length(km)	Key technology
Booster amplifier	10 - 15	40 - 60	High efficiency
Preamplifier	5 - 10 (APD) 10 - 15 (PIN)	20 - 40 40- 60	Low noise
In-line amplifier	15 - 30	60 - 120	Low noise Supervisory
Remote pump amplifier	5 - 15	30 - 60	High pumping power

<u>Semiconductor Optical Amplifier (SOA):</u>

- Basically a laser chip without any mirrors
- Metastable state has nanoseconds lifetime
  (-> nonlinearity and crosstalk problems)
- Potential for switches and wavelength converters

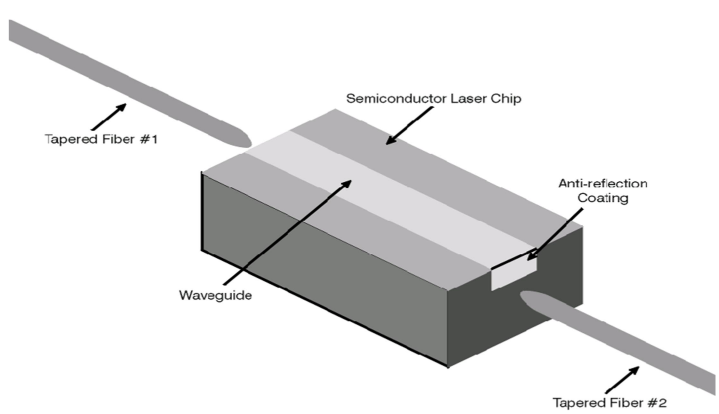


Semiconductor optical amplifiers, like their semiconductor-laser, consist of gain and passive regions. Layers of antireflective coatings prevent light from reflecting back into the circuit while the incoming signal stimulates electrons in the gain region.

Semiconductor optical amplifiers are similar in construction to semiconductor lasers. They consist of a gain (active) section and a passive section constructed of a semiconductor material such as indium phosphide. The main difference is that SOAs are made with layers of antireflection coatings to prevent light from reflecting back into the circuit. Optical gain occurs as excited electrons in the semiconductor material are stimulated by incoming light signals; when current is applied across the p-n junction the process causes the photons to replicate, producing signal gain. The gain medium can be either a bulk or a multiple-quantum-well active layer.

Semiconductor Optical Amplifiers (SOA's)

- Laser diodes without end mirrors
- Fiber attached to both ends
- Amplified version of the optical signal is produced
- Advantage: bidirectional
- Drawbacks
  - High-coupling losses
  - High noise figure



By adjusting the chemical composition of III-V semiconductors (typically Ga In As P) the band gap can be adjusted to give optical gain in the telecommunications windows of interest. The devices are typically 250mm long although devices of up to 1mm have been made. In general the longer devices can achieve higher gain and wider bandwidths.

The optical bandwidth of a semiconductor optical amplifier (SOA) can be as large as 100 nm and the fact that the energy source is a DC electrical current makes these devices look promising as optical amplifiers.

Limitations/Advantages/Applications of SOA:

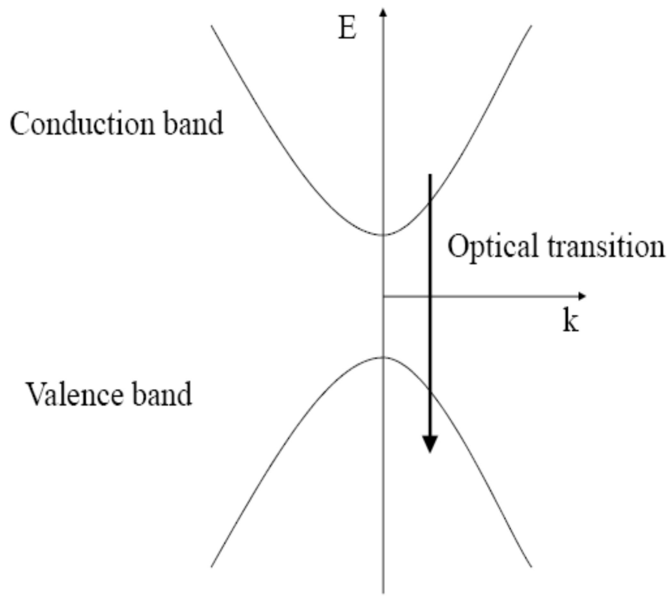
SOAs have severe limitations:

- Insufficient power (only a few mW). This is usually sufficient for single channel operation but in a WDM system you usually want up to a few mW per channel.
- Coupling the input fibre into the chip tends to be very lossy. The amplifier must have additional gain to overcome the loss on the input facet.
- SOAs tend to be noisy.
- They are highly polarisation sensitive.
- They can produce severe crosstalk when multiple optical channels are amplified.

This latter characteristic makes them unusable as amplifiers in WDM systems but gives them the ability to act as wavelength changers and as simple logic gates in optical network systems.

A major advantage of SOAs is that they can be integrated with other components on a single planar substrate. For example, a WDM transmitter device may be constructed including perhaps 10 lasers and a coupler all on the same substrate. In this case an SOA could be integrated into the output to overcome some of the coupling losses.

SOA operation:



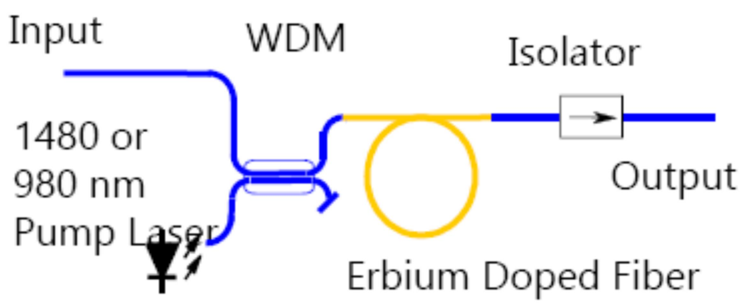
The DC current applied to the device results in electrons being pumped into the (normally empty) conduction band and removed from the (normally full) valence band. This creates the population inversion which is a pre-cursor to optical gain. When signal photons travel through the device they cause stimulated emission to occur when an electron and hole recombine.

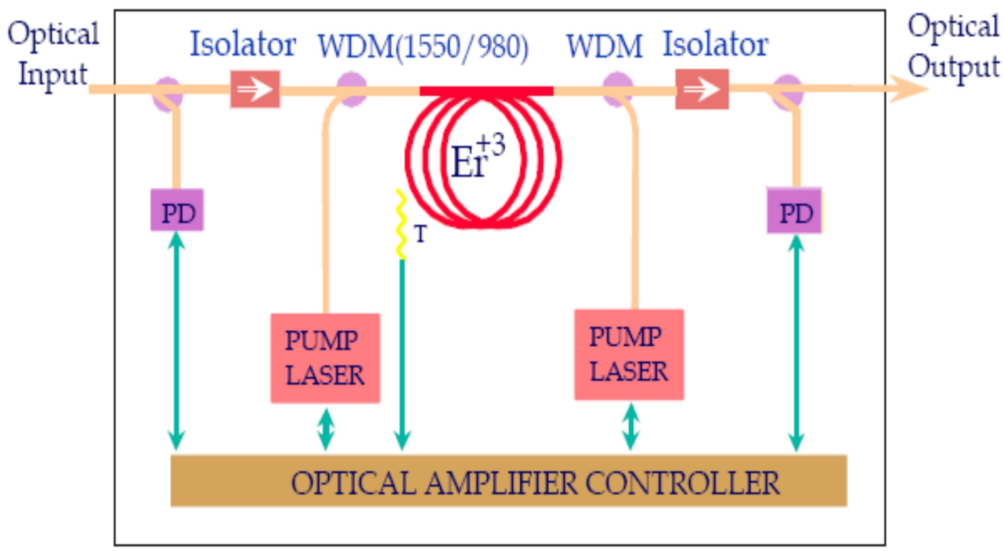
The phase effects in these devices can be quite strong with a gain change of 3dB corresponding to roughly a phase change of p.

Erbium Doped Fiber Amplifiers (EDFA):

Basic EDF Amplifier Design:

- Erbium-doped fiber amplifier (EDFA) most common
  - Commercially available since the early 1990's
  - Works best in the range 1530 to 1565 nm
  - Gain up to 30 dB





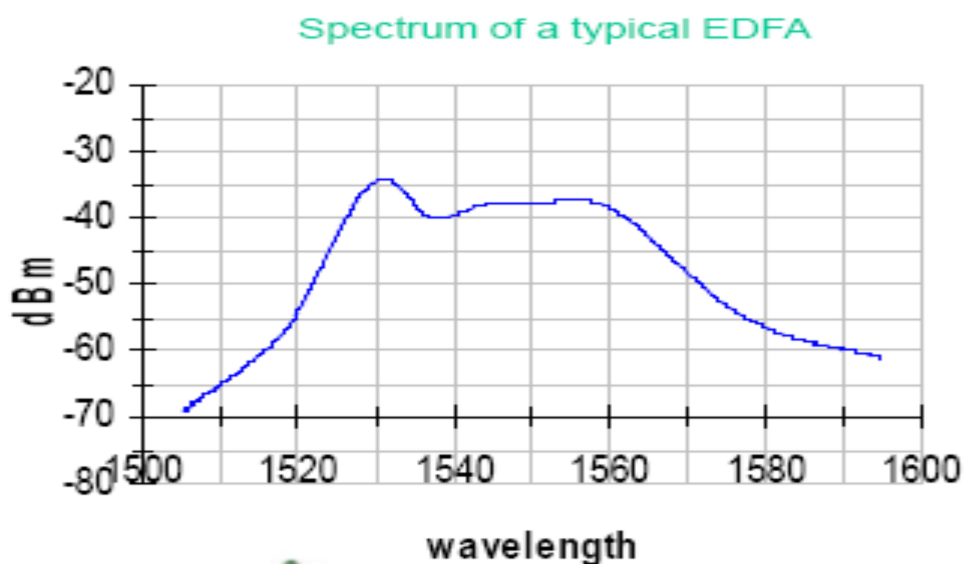
When you actually look at an EDFA block diagram you see the input on the left the output on the right, photo diodes to measure input and output power levels, pump lasers which are used to excite this piece of erbium doped fiber to a higher energy state, and 1550 light is allowed to pass through.

The isolators are used to keep the 980 and 1480 pump wavelengths contained in the fiber but allow 1550nm light to pass through.

Issues of Amplifier Design:

- Optimization
  - maximum efficiency
  - minimum noise figure
  - maximum gain
  - maximum gain flatness/gain peak wavelength

- Dynamic range, operation wavelength
- Gain equalization
- Control circuit
- Monitoring of amplifier performance
- Gain, G (dB)
- $10\log[(P_{Signal\_Out} - P_{ase}) / P_{Signal\_In}]$



- Noise Figure, $F = SNR_{out} / SNR_{in}$
- S-band : 1440 - 1530nm
- C-band : 1530 - 1565nm
- L-band : 1565 - 1625nm

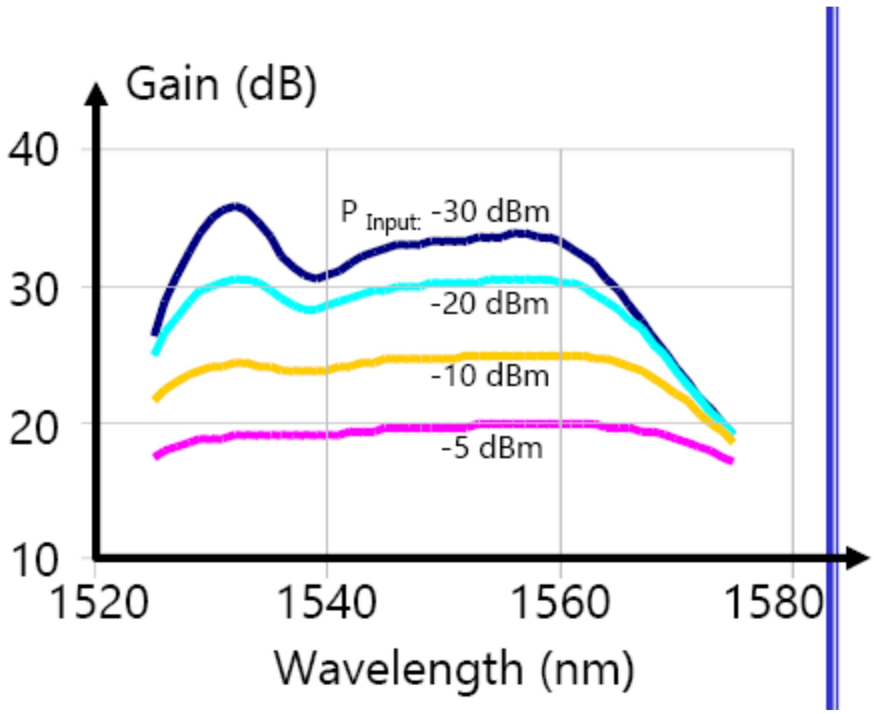
Optical Gain (G):

$G = S_{Output}/S_{Input}$

S_{Output}: output signal (without noise from amplifier)

S_{Input} : input signal

- Input signal dependent
  - Operating point (saturation) of EDFA strongly depends on power and wavelength of incoming signal



Noise Figure (NF):

$NF = P_{ASE} / (h \cdot \nu \cdot G \cdot B_{OSA})$

P_{ASE}: Amplified Spontaneous Emission (ASE) power measured by OSA

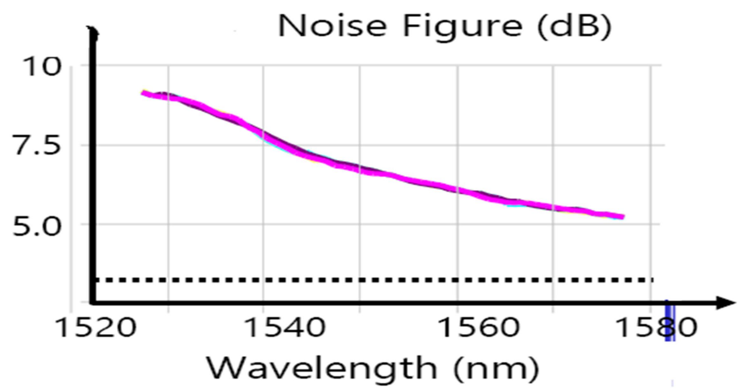
h: Plank's constant

ν: Optical frequency

G: Gain of EDFA

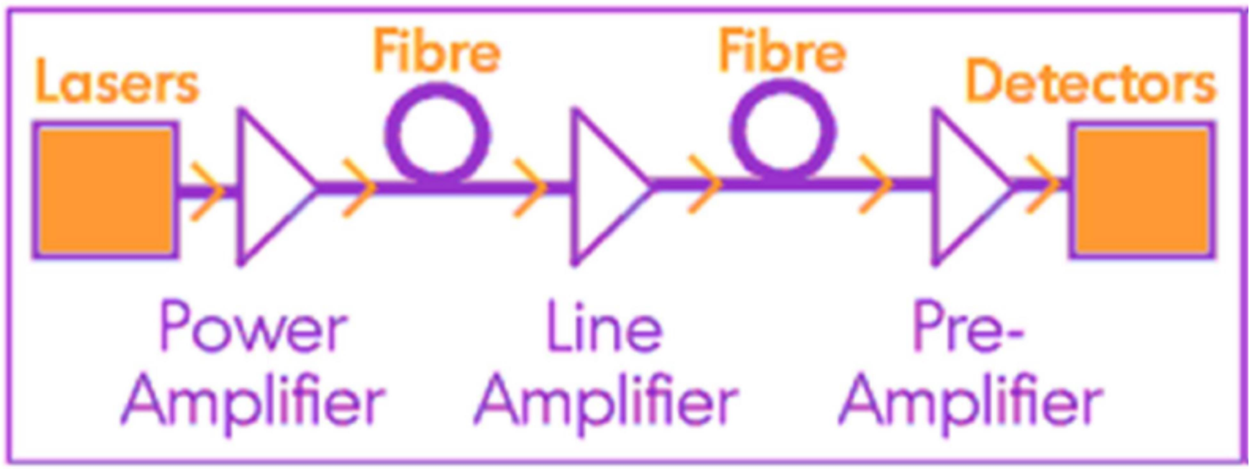
B_{OSA}: Optical bandwidth [Hz] of OSA

- Input signal dependent
  - In a saturated EDFA, the NF depends mostly on the wavelength of the signal
  - Physical limit: 3.0 dB



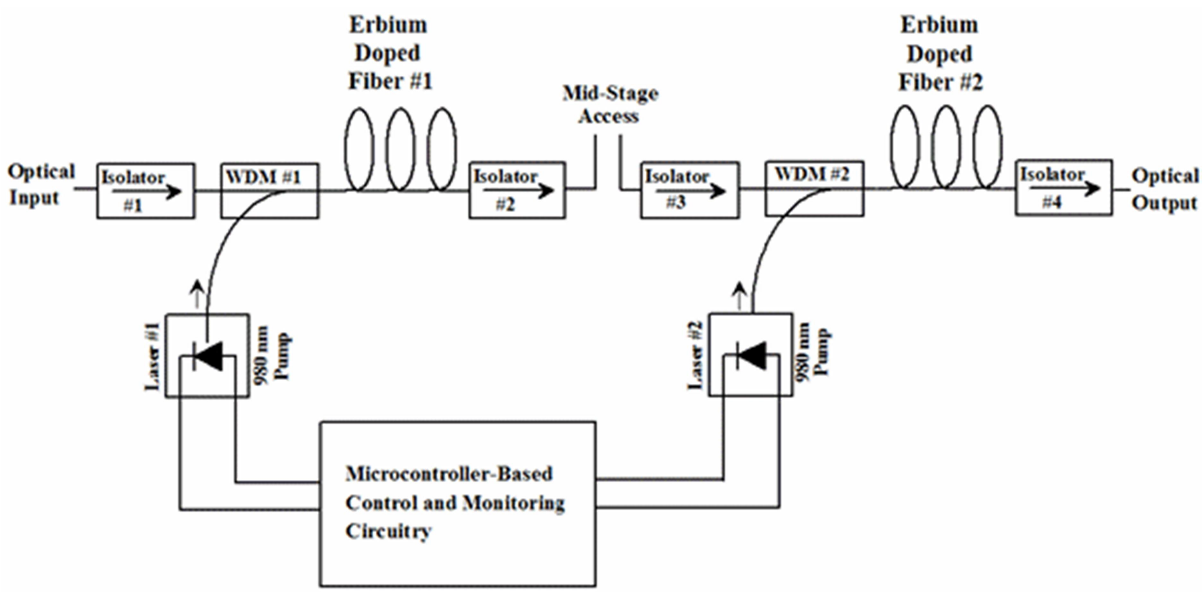
EDFA Categories:

- In-line amplifiers
  - Installed every 30 to 70 km along a link
  - Good noise figure, medium output power
- Power boosters
  - Up to +17 dBm power, amplifies transmitter output
  - Also used in cable TV systems before a star coupler
- Pre-amplifiers
  - Low noise amplifier in front of receiver
- Bi-directional amplifiers
  - An amplifier which work in both ways



Typical Design:

- EDFA with all the options design
  - Coupler #1 is for monitoring input light
  - Coupler #2 is optional and is used for monitoring back reflections. The microcontroller can be set to disable the pump lasers in case the connector on the output has been disconnected. This provides a measure of safety for technicians working with EDFA's.



EDFAs in DWDM Systems:

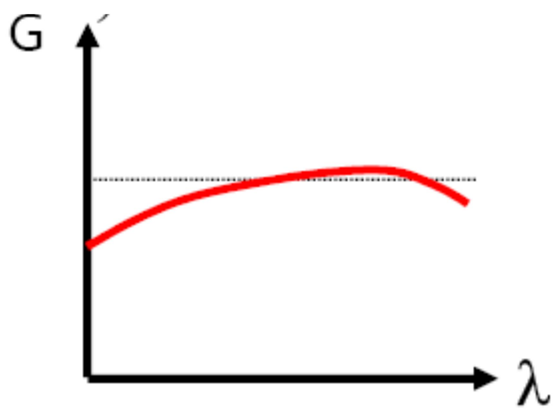
Optical amplifiers in DWDM systems require special considerations because of:

- Gain flatness requirements
- Gain competition
- Nonlinear effects in fibers

Gain versus wavelength:

The gain of optical amplifiers depends on wavelength

Signal-to-noise ratios can degrade below acceptable levels (long links with cascaded amplifiers

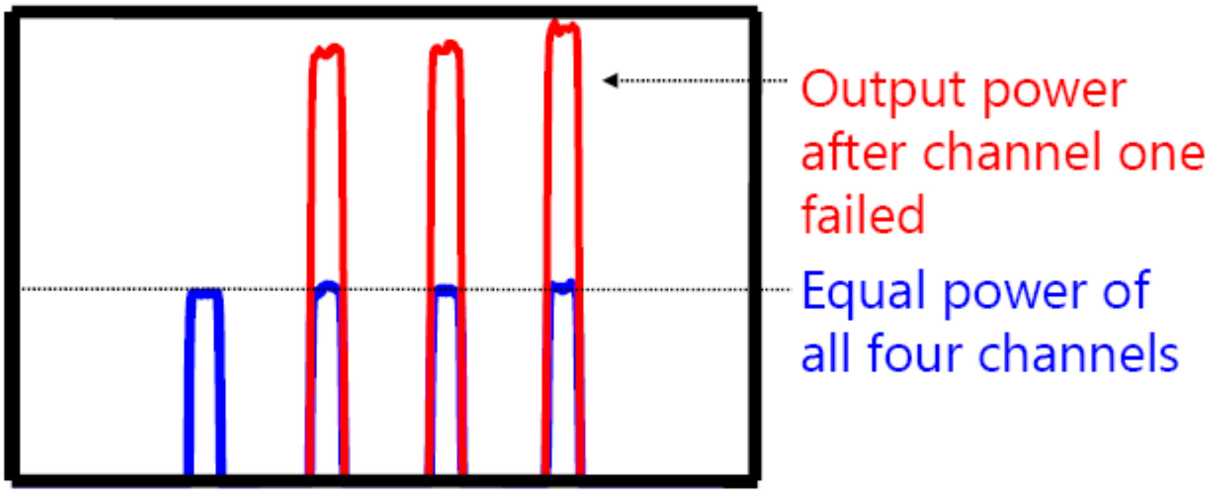


Compensation techniques:

- Signal pre-emphasis
- Gain flattening filters
- Additional doping of amplifier with Fluorides

Total output power of a standard EDFA remains almost constant even if input power fluctuates significantly.

If one channel fails (or is added) then the remaining ones increase (or decrease) their output power.



Output Power Limitations:

- High power densities in SM fiber can cause
  - Stimulated Brillouin scattering (SBS)
  - Stimulated Raman scattering (SRS)
  - Four wave mixing (FWM)
  - Self-phase and cross-phase modulation (SPM, CPM)
- Most designs limit total output power to +17 dBm
  - Available channel power: 50/N mW
    (N = number of channels)

Erbium Doped Waveguide Amplifier (EDWA):

- An erbium-doped waveguide amplifier (EDWA) consists of waveguides embedded in an amorphous erbium-doped glass substrate.
- The erbium atoms provide the glass with gain in the 1,550-nm fibre-optic window.
- The waveguide itself is a localised increase in the glass refractive index.

- Today's manufacturers have several methods available to produce erbium-doped glass waveguides: PECVD and flame hydrolysis deposition, sputtering, ion-exchange, or ion implantation.
- For the manufacture of waveguide amplifiers, the two most advanced methods are ion-exchange and sputtering.

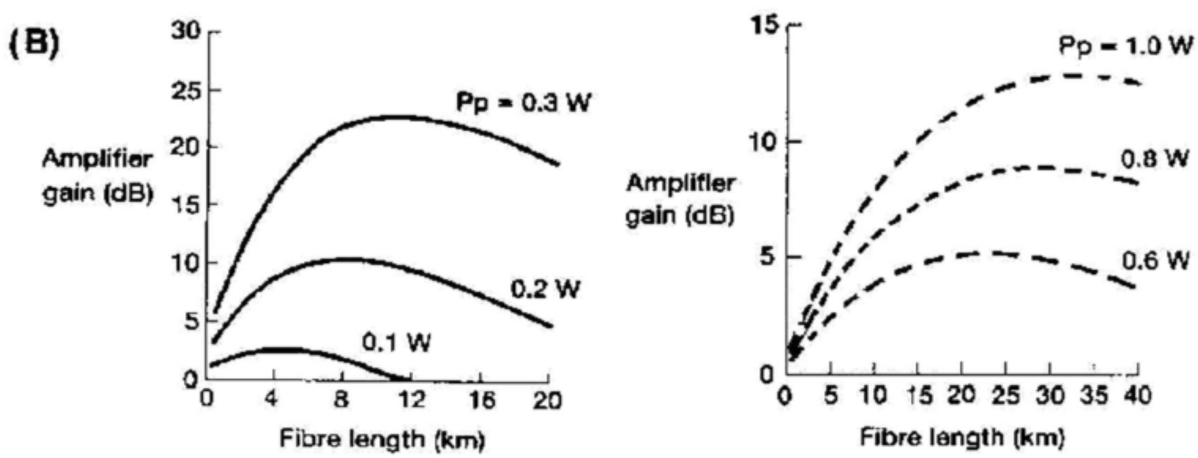
EDWA Advantages:

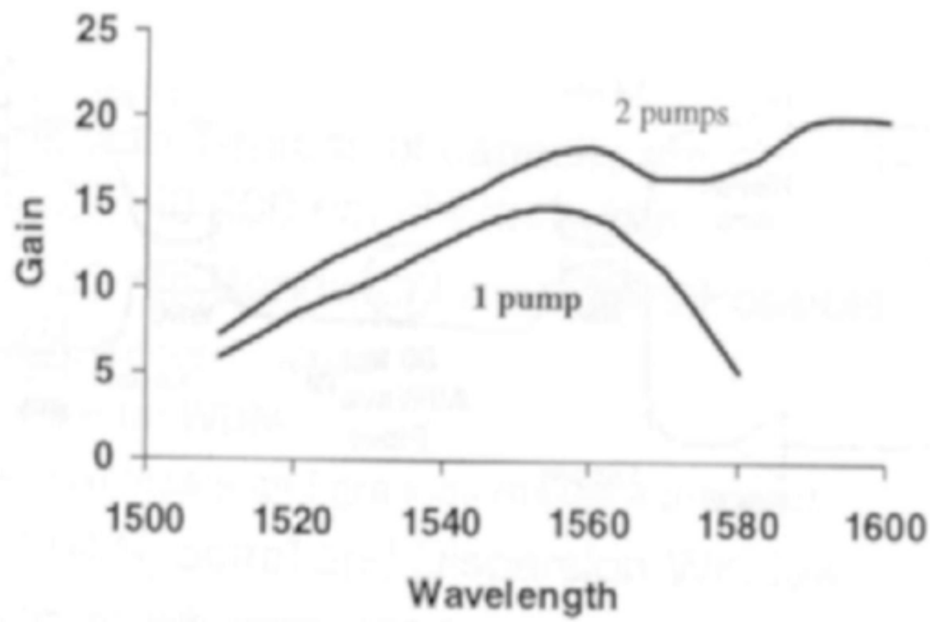
- EDWAs are inherently compact.
- One of the smallest gain block amplifiers to date, featuring 15-dB gain at 1,535 nm, fits in a 130x11x6-mm package.
- EDWAs also offer a better price/performance ratio than comparable EDFAs for access and metro network applications.

<u>Raman Amplifier:</u>

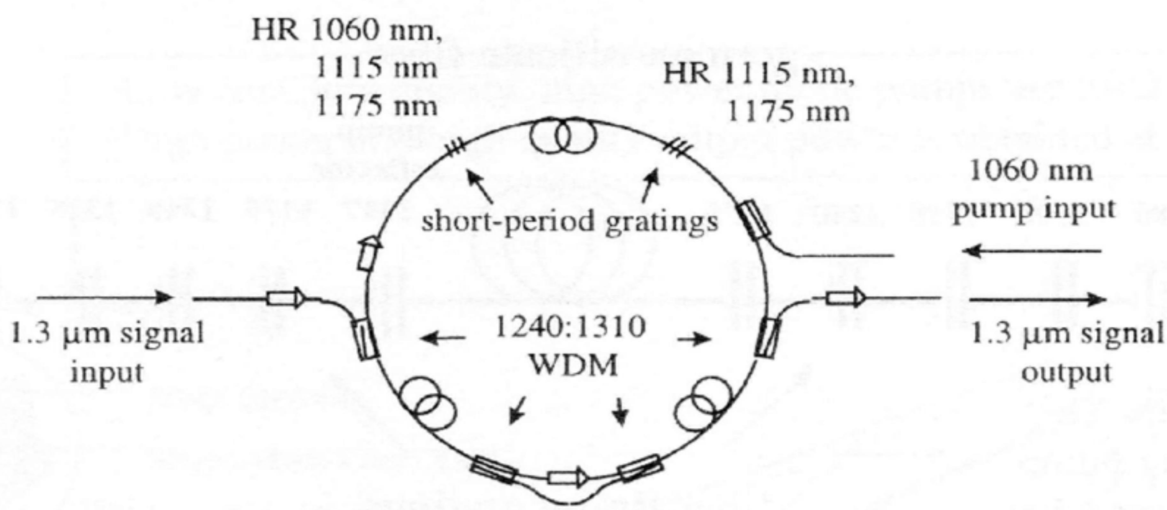
Why do you need it: Amplify signals from 1270 to 1670 nm any optical fiber can serve as the amplifying medium

- Raman process itself provides high-power laser
- Disadvantage: Cross-talk



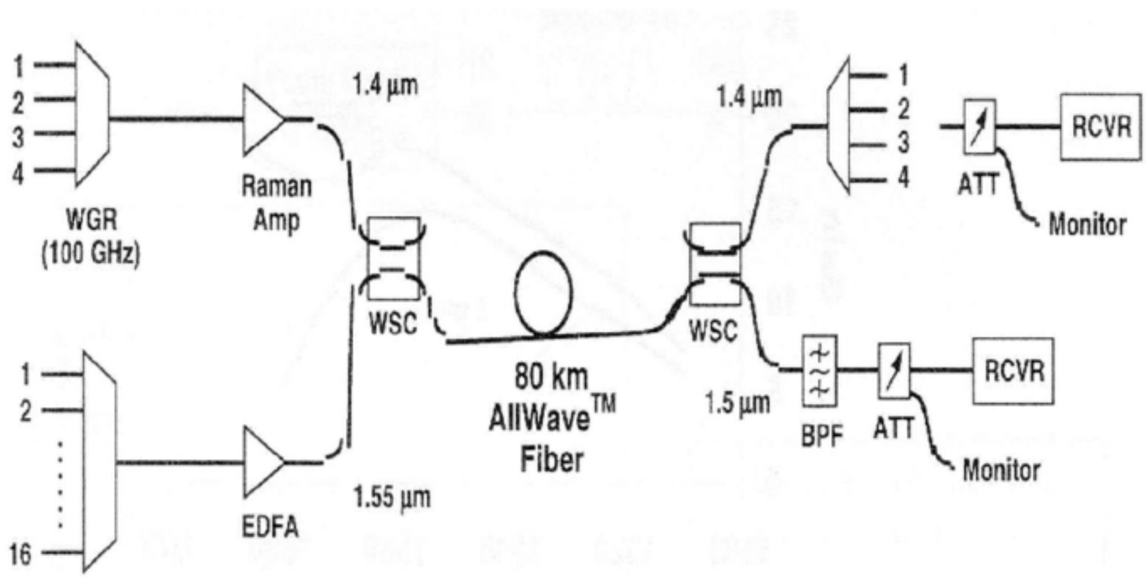


Wide bandwidth Raman amplifier can be realized using multiple pumps



- Multistage Amplifier
- Counter propagating pump

EDFA+Raman:



Advantages:

- ➢ Variable wavelength amplification possible
- ➢ Compatible with installed SM fiber
- ➢ Can be used to "extend" EDFAs
- ➢ Can result in a lower average power over a span, good for lower crosstalk
- ➢ Very broadband operation may be possible

- **Disadvantages**
  - ➢ High pump power requirements, high pump power lasers have only recently arrived
  - ➢ Sophisticated gain control needed
  - ➢ Noise is also an issue

Broadcast and Select WDM Networks:

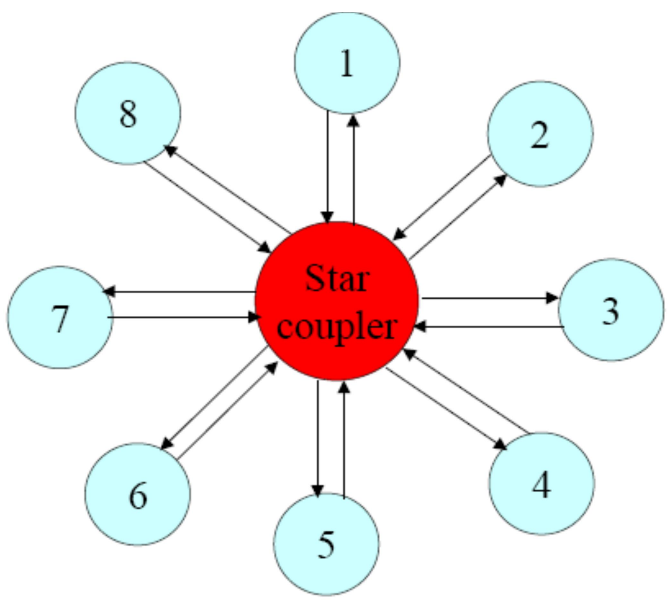
Intended usages are: for high speed LANs and MANs
It can be:
1) Single-hop: no intermediate relaying nodes are used; a transmission of a node on any wavelength of a WDM link can be received by any other node on that same wavelength.
2) Multiple-hop: requires intermediate relaying nodes, usually nodes are assigned channels on which they can transmit and receive, thus to be able to reach all destinations, packets may have to travel through several nodes.
3) Here we are going to investigate Single-hop B&S networks.

Single-Hop B&S Architectures:

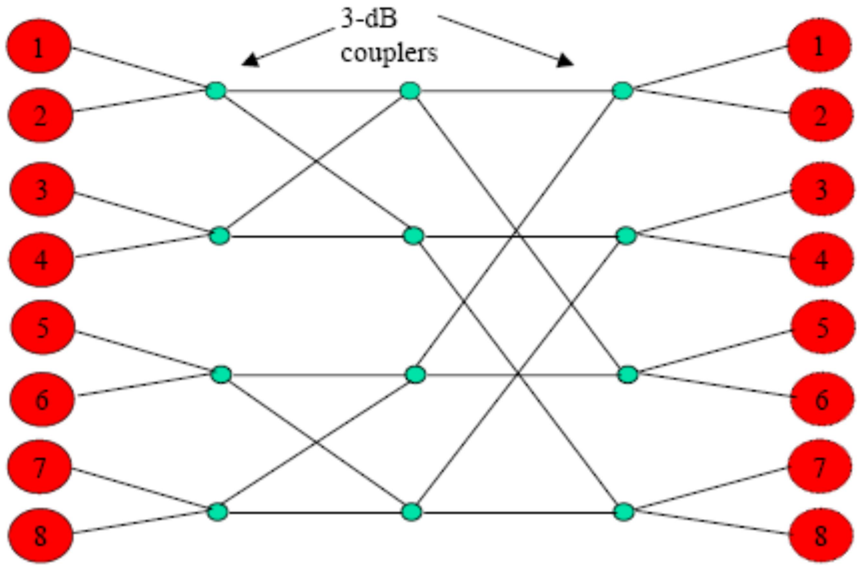
Since there are no intermediate nodes, a significant amount of dynamic coordination is needed.
Typically, each node has a small number of fixed or tunable transmitters (to reduce cost).
For a successful packet transmission the destination should have a receiver available at the given Wavelength, the source is transmitting on for the entire packet duration.

The two main topologies/techniques for Single-hop B&S are:
(1)Star topology with an N*N passive star coupler
(2) Folded bus with 2N couplers

N*N Passive Star Coupler:

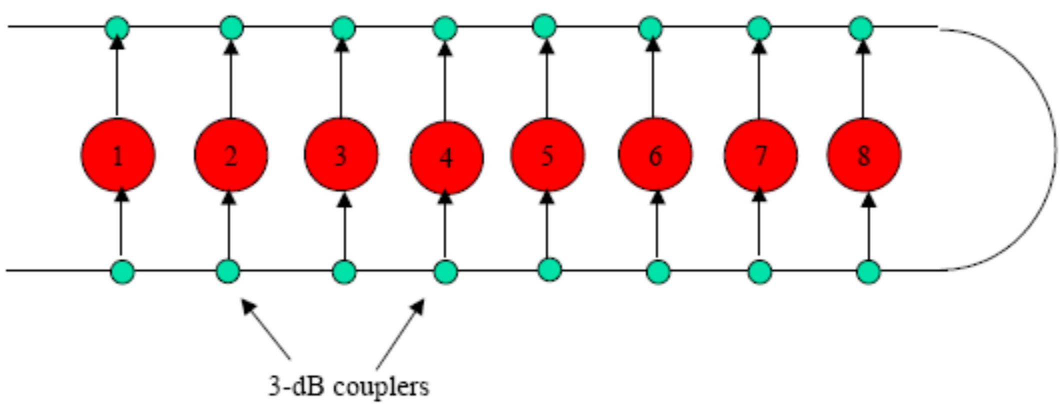


A passive star coupler can be realized with N/2*log2N pcs. Of 2x2 couplers



Each signal passes through exactly log2N couplers, thus the loss is uniform for all nodes (assuming that there is no insertion and other losses, each signal experiences 3dB*log2N loss). The coupler is a passive element, so no external power is required to establish such a hub.

Folded Bus Topology:



Folded Bus Properties:

- Loss is not uniform for all nodes
- For a while these topologies were not seriously considered but with the wide availability of EDFAs the became feasible again.
- Calculation of loss is rather non-trivial, but with some simplification the worst case loss is 3dB*N.

Single-Hop Systems:

Since nodes are contending with each other for the bandwidth, single-hop systems can be subdivided into two categories:
1. Pre-transmission coordination systems
2. No pre-transmission coordination systems

Pre-transmission coordination:

- A wavelength is dedicated as a control channel.
- This control channel is contended for by the nodes to advertise a broadcast to a destination on one of the data channels.
- Nodes (or idle nodes) are required to monitor the data channel for reception to "ensure" That the advertised transmission is received by the intended destination.

No Pre-transmission coordination systems:

- No control channel exists.
- Transmission rights are either pre-assigned (no-contention) or a subset of channels is Pre-assigned to every node to transmit and receive on with contention.
- Intuitively, pre-transmission coordination systems are the better choice (although a lot Of prototype systems use no coordination).

Classifying B&S Systems:

According to the employed receivers and transmitters the following classification can be given:

- FT-FR (Fixed Transmitter – Fixed receiver)
- TT-FR (Tunable Transmitter – Fixed receiver)
- FT-TR (Fixed Transmitter – Tunable receiver)
- TT-TR (Tunable Transmitter – Tunable receiver)