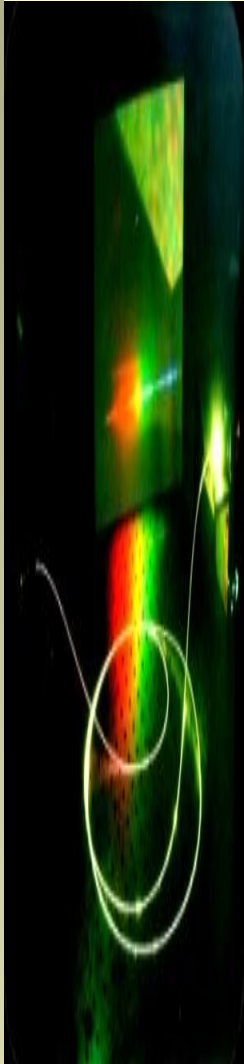


# Optical Fibre Communication Systems

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## Lecture 5 – Optical Amplifier

Professor Z Ghassemlooy

*Optical Communications Research Group*  
The University of Northumbria  
U.K.

# Contents

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- Why the need for optical amplifier?
- Spectra
- Noise
- Types
- Principle of Operation
- Main Parameters
- Applications

# Signal Reshaping and Amplification

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- In long distance communications, whether going through wire, fibre or wave, the signal carrying the information experience:
  - Power loss
  - Pulse broadeningwhich requires amplification and signal reshaping.
- In fibre optics communications, these can be done in two ways:
  - Opto-electronic conversion
  - All optical

# Signal Reshaping and Amplification

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Depending on its nature, a signal can also be regenerated.

- A digital signal is made of 1's and 0's: it is possible to reconstruct the signal and amplify it at the same time.
- An analog signal however, cannot be reconstructed because nobody knows what the original signal looked like.

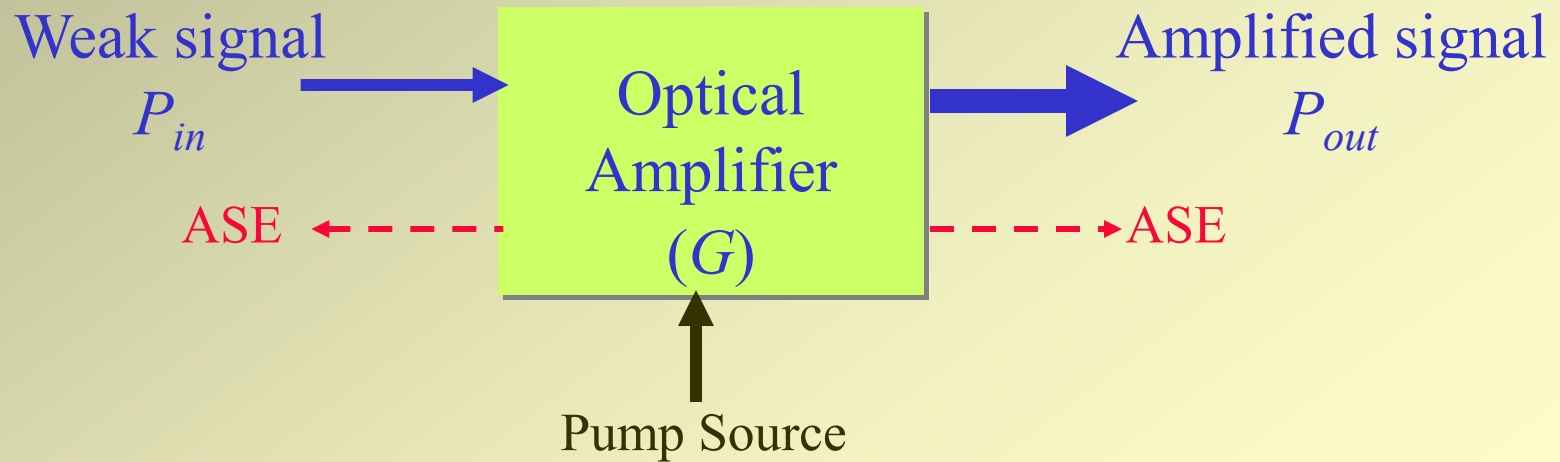
# Why the Need for Optical Amplification?

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- Semiconductor devices can convert an optical signal into an electrical signal, amplify it and reconvert the signal back to an optical signal. However, this procedure has several disadvantages:
  - Costly
  - Require a large number over long distances
  - Noise is introduced after each conversion in analog signals (which cannot be reconstructed)
  - Restriction on bandwidth, wavelengths and type of optical signals being used, due to the electronics
- By amplifying signal in the optical domain many of these disadvantages would disappear!

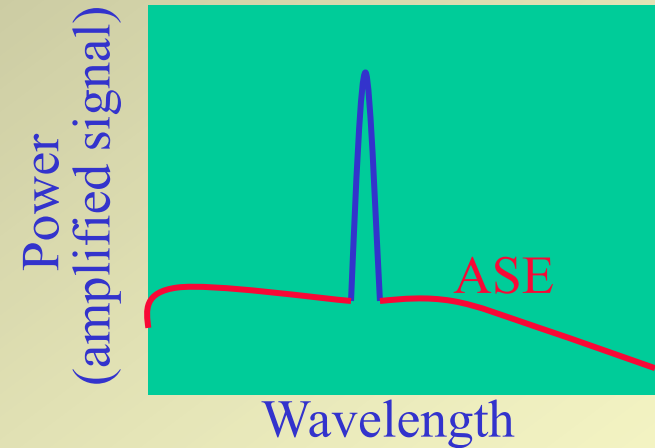
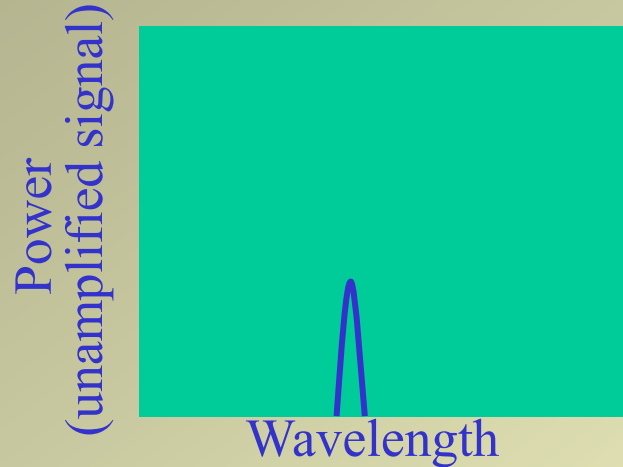
# Optical Amplification

- Amplification gain: Up to a factor of 10,000 (+40 dB)
- In WDM: Several signals within the amplifier's gain ( $G$ ) bandwidth are amplified, but not to the same extent
- It generates its own noise source known as **Amplified Spontaneous Emission (ASE)** noise.

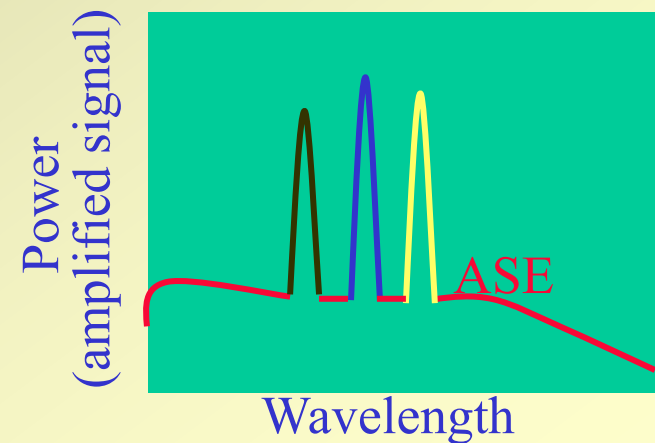
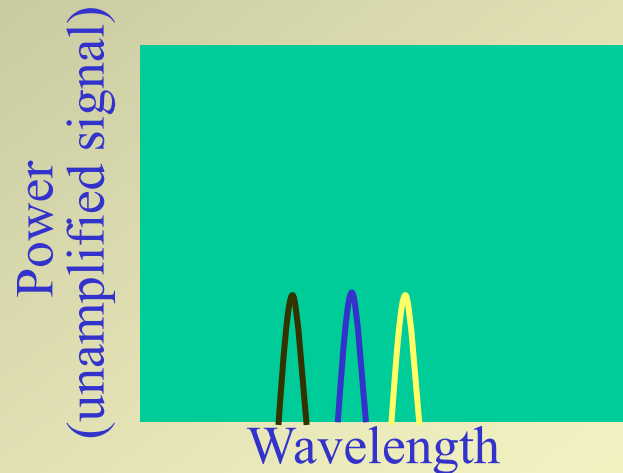


# Optical Amplification - Spectral Characteristics

Single channel



WDM channels



# Optical Amplification - Noise Figure

- Required figure of merit to compare amplifier noise performance
- Defined when the input signal is coherent

$$\text{Noise Figure (NF)} = \frac{\text{Input signal-to-noise ratio (SNR}_i\text{)}}{\text{Output signal-to-noise ratio (SNR}_o\text{)}}$$

- NF is a positive number, nearly always  $> 2$  (I.e. 3 dB)
- Good performance: when  $\text{NF} \sim 3$  dB
- NF is one of a number of factors that determine the overall BER of a network.

# Optical Amplifiers - Types

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There are mainly two types:

- Semiconductor Laser (optical) Amplifier (SLA) (SOA)
- Active-Fibre or Doped-Fibre
  - **Erbium Doped Fibre Amplifier (EDFA)**
  - Fibre Raman Amplifier (FRA)
  - Thulium Doped Fibre Amplifier (TDFA)

# SLA - Principle Operation

- Remember diode lasers?

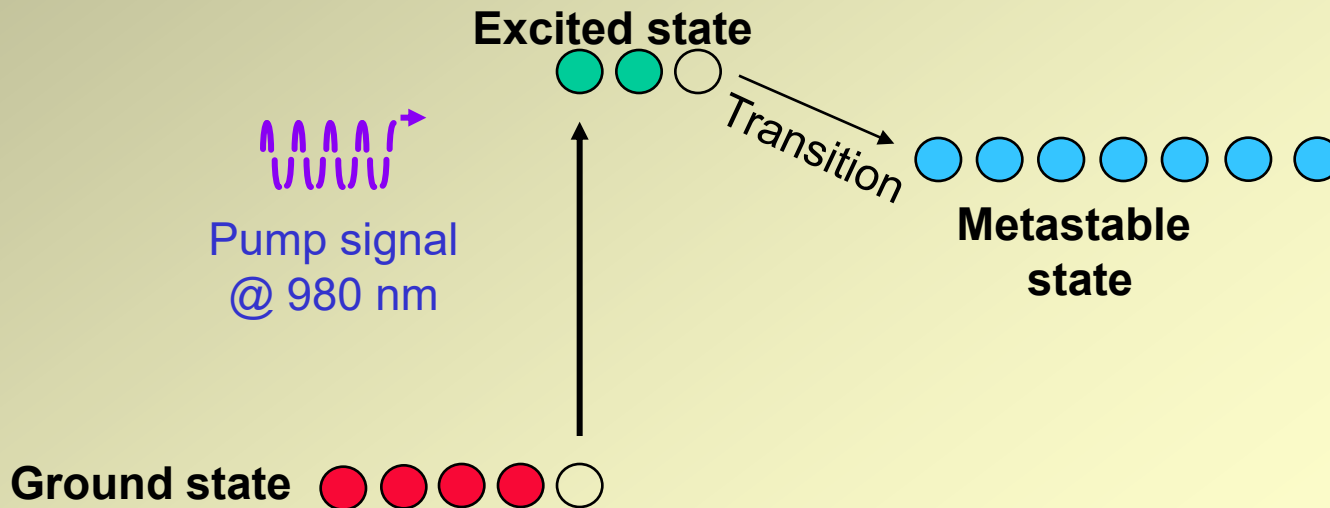
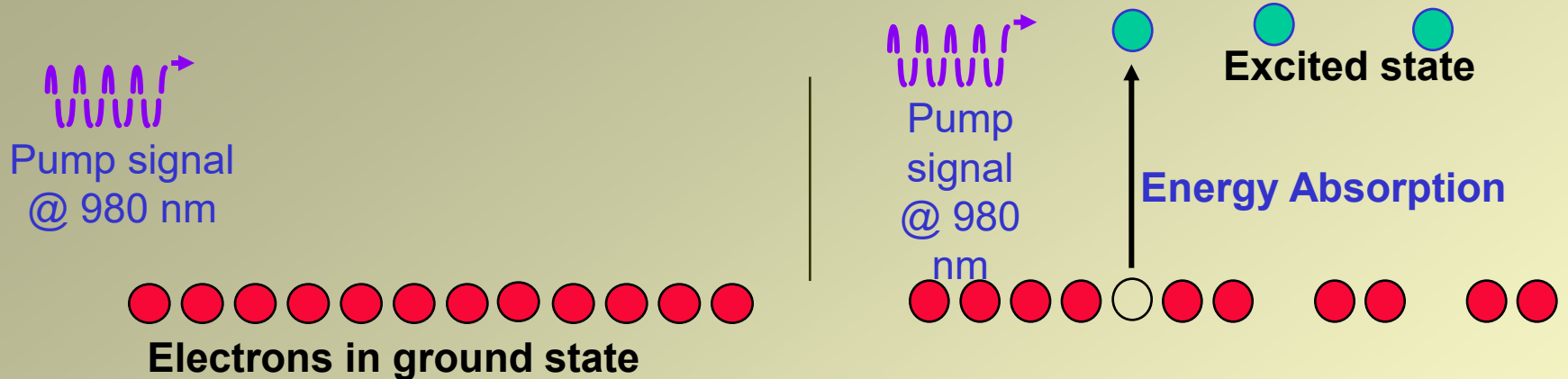
Suppose that the diode laser has no mirrors:

- we get the diode to a population inversion condition
- we inject photons at one end of the diode
- By stimulated emission, the incident signal will be amplified!
  - By stimulated emission, one photon gives rise to another photon: the total is two photons. Each of these two photons can give rise to another photon: the total is then four photons. And it goes on and on...

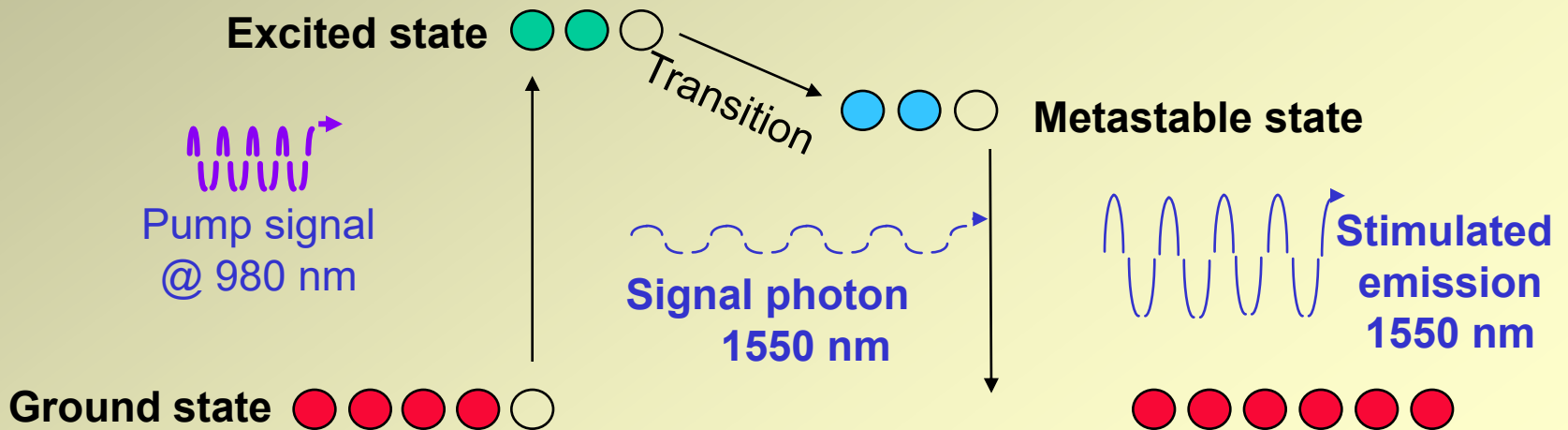
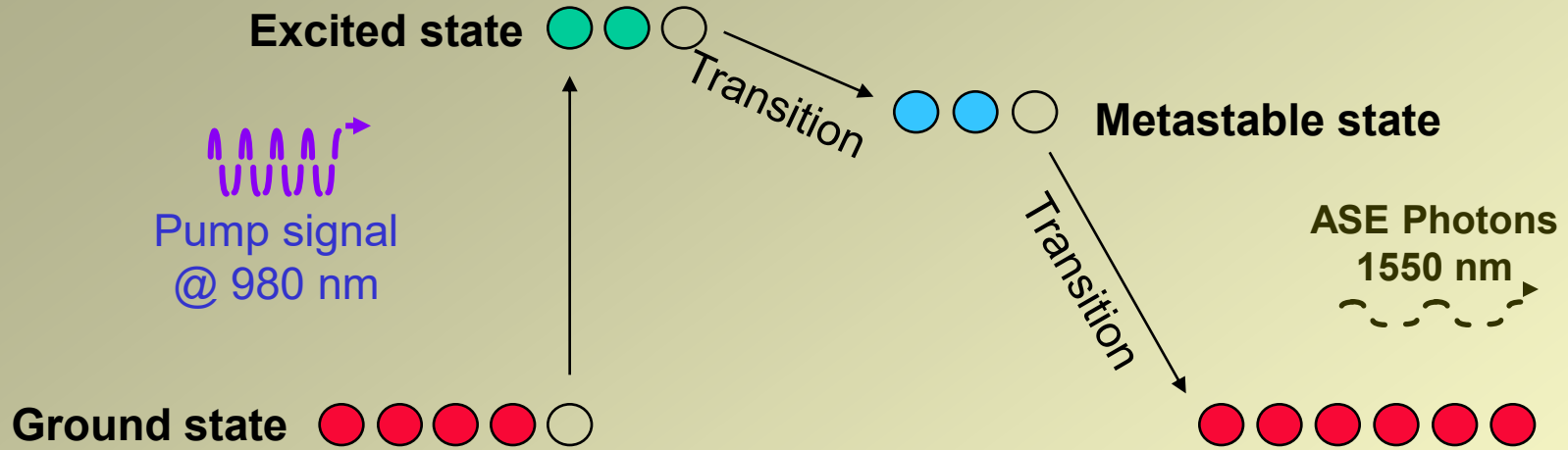
## Problems:

- Poor noise performance: they add a lot of noise to the signal!
- Matching with the fibre is also a problem!
- However, they are small and cheap!

# SLA - Principle Operation



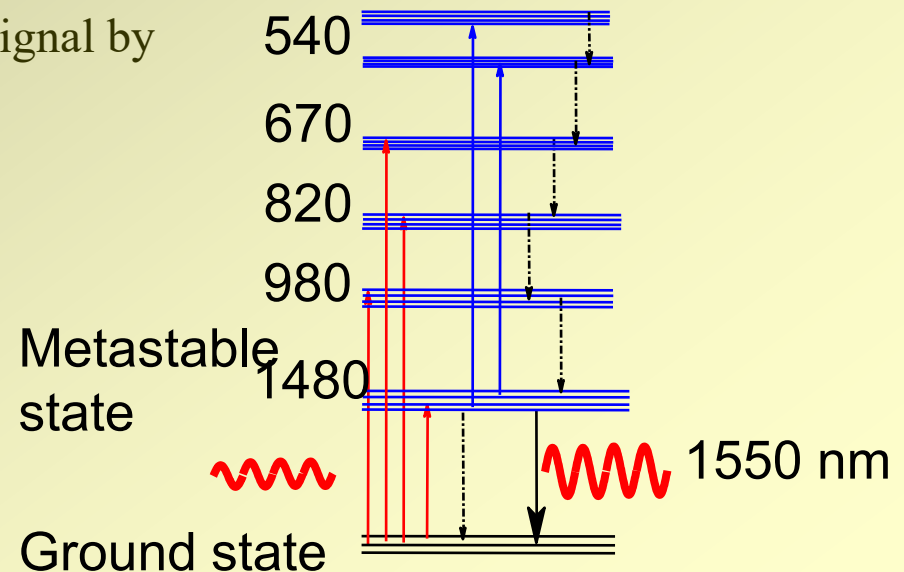
# SLA - Principle Operation



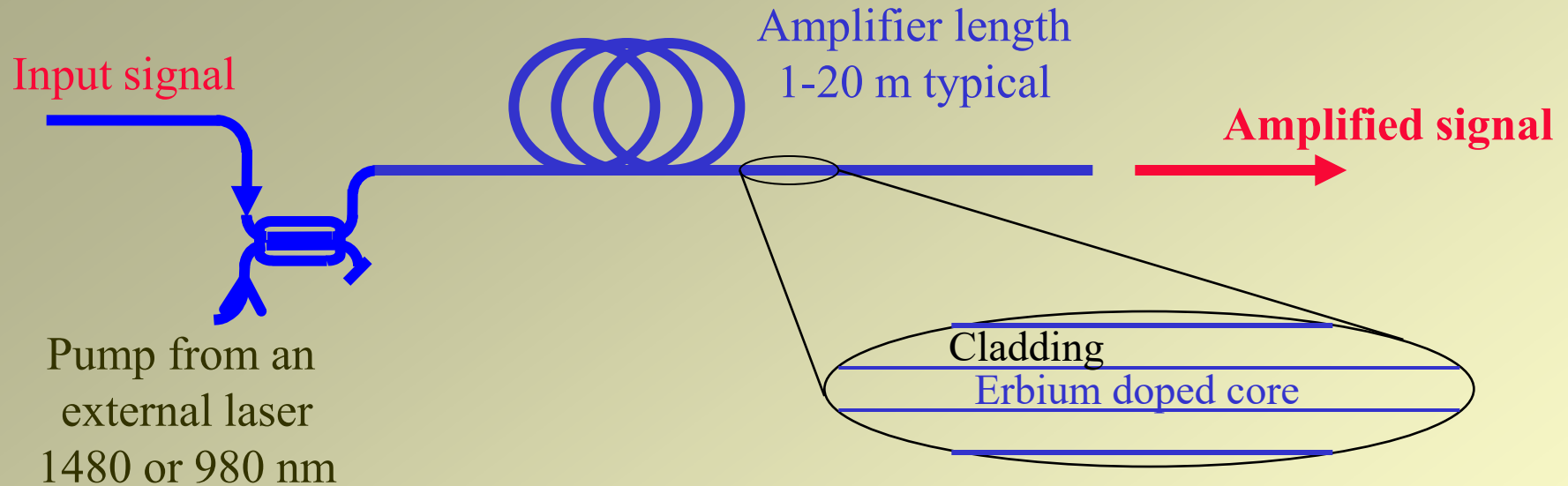
# Erbium Doped Fibre Amplifier (EDFA)

- EDFA is an optical fibre doped with erbium.
  - Erbium is a rare-earth element which has some interesting properties for fibre optics communications.
  - Photons at 1480 or 980 nm activate electrons into a metastable state
  - Electrons falling back emit light at 1550 nm.
  - By one of the most extraordinary coincidences, 1550 nm is a low-loss wavelength region for silica optical fibres.
  - This means that we could amplify a signal by using stimulated emission.

- EDFA is a low noise light amplifier.



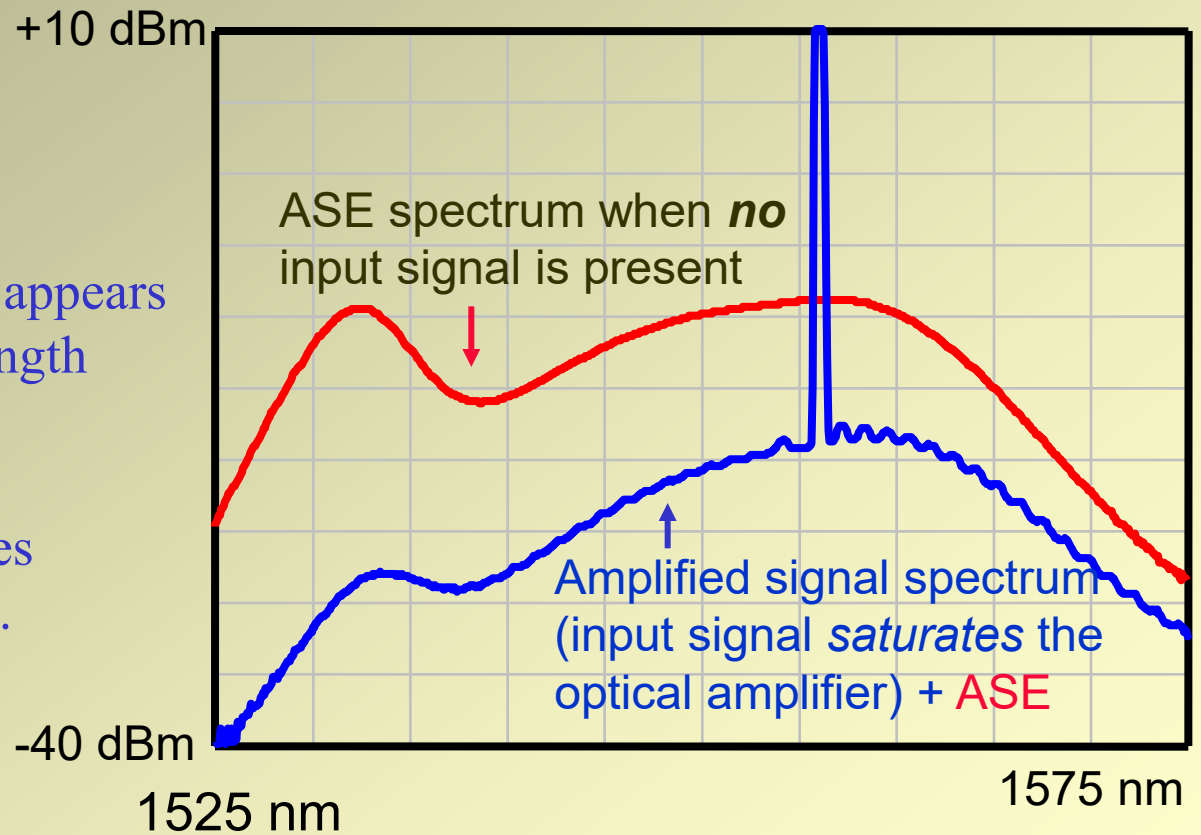
# EDFA - Operating Features



- Available since 1990's:
- **Self-regulating amplifiers:** output power remains more or less constant even if the input power fluctuates significantly
- Output power: 10-23 dBm
- Gain: 30 dB
- Used in terrestrial and submarine links

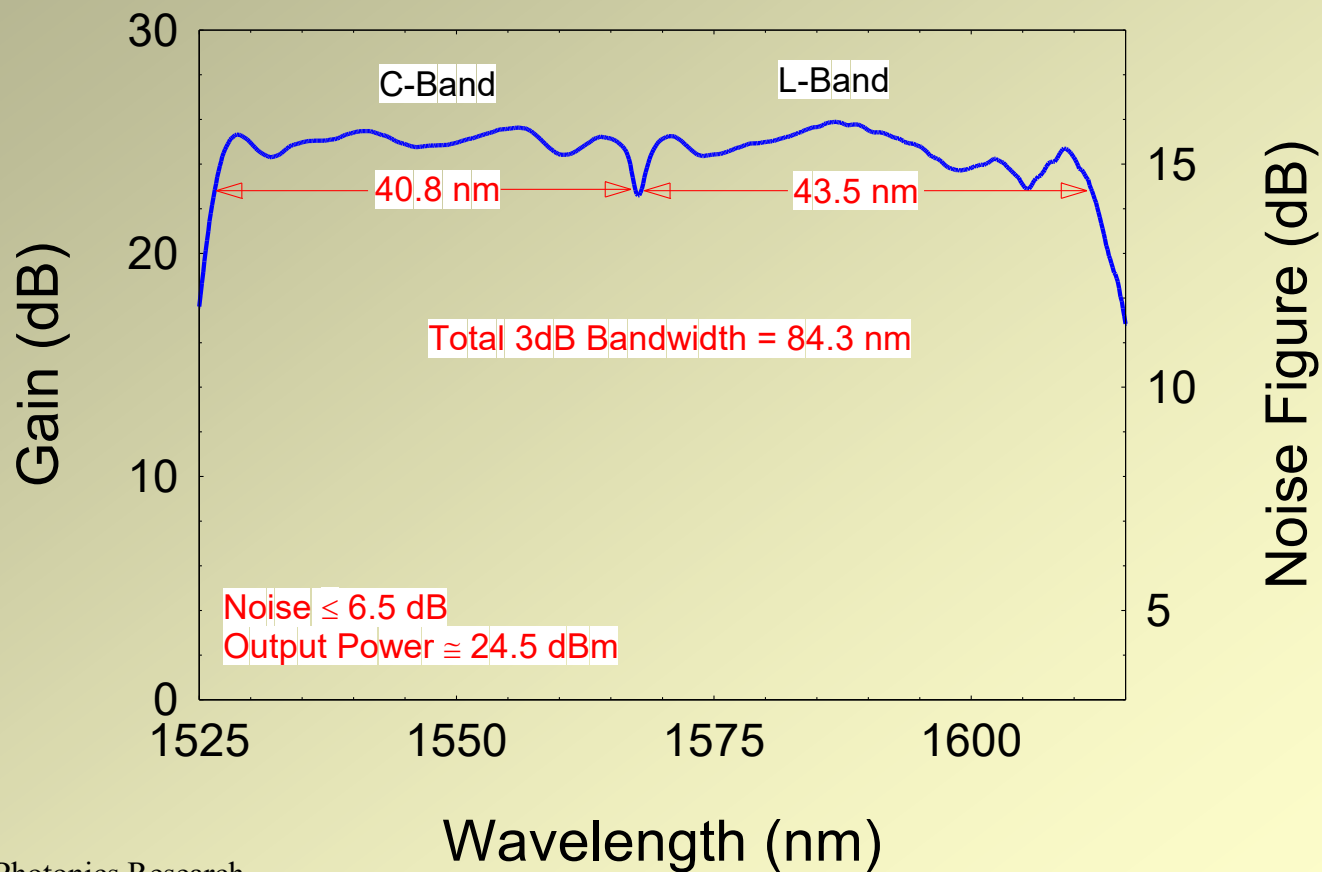
# EDFA – Gain Profile

- Most of the pump power appears at the stimulating wavelength
- Power distribution at the other wavelengths changes with a given input signal.

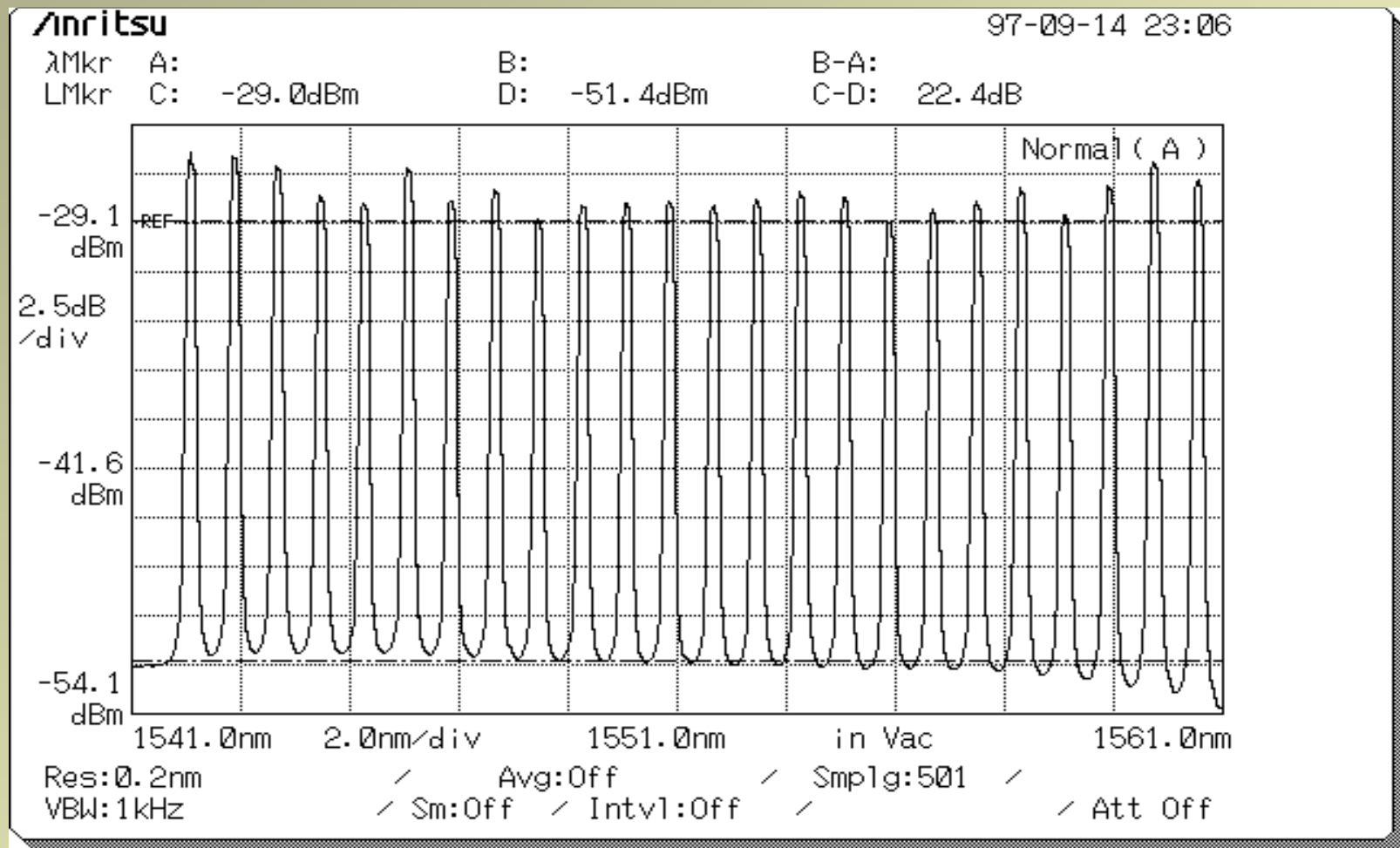


# EDFA – Ultra Wideband

## Ultra-Wideband EDFA



# Optical Amplifiers: Multi-wavelength Amplification



# Optical Amplifier - Main Parameters

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- Gain ( $P_{out}/P_{in}$ )
- Bandwidth
- Gain Saturation
- Polarization Sensibility
- Noise figure ( $SNR_i/SNR_o$ )
- Gain Flatness
- Types
  - Based on stimulated emission (EDFA, PDFFA, SOA)
  - Based on non-linearities (Raman, Brillouin)

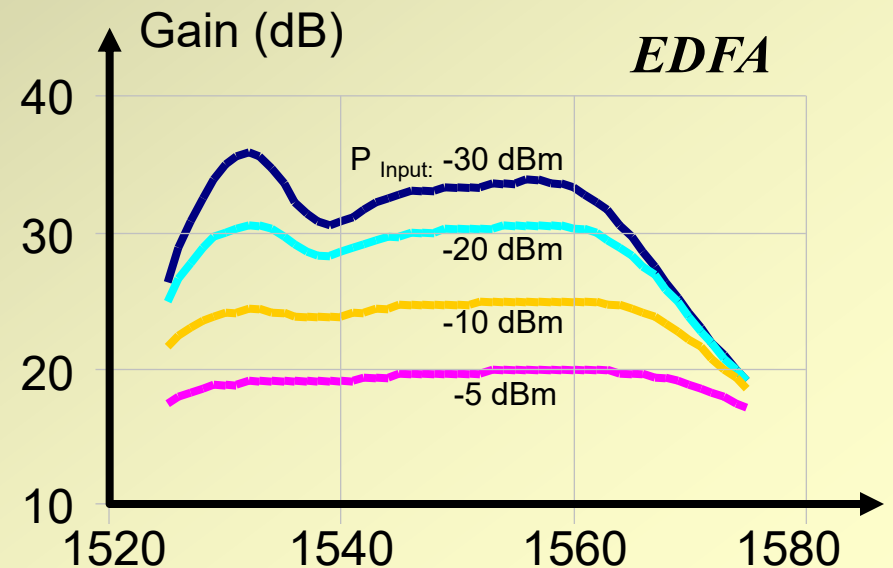
# Optical Amplifier - Optical Gain (G)

- $G = S_{Output} / S_{Input}$  (No noise)
- Input signal dependent:
  - Operating point (saturation) of EDFA strongly depends on power and wavelength of incoming signal

- Gain ↓ as the input power ↑

| $P_{in}$ | Gain  | $P_{out}$ |
|----------|-------|-----------|
| -20 dBm  | 30 dB | +10 dBm   |
| -10 dBm  | 25 dB | +15 dBm   |

Note,  $P_{in}$  changes by a factor of ten then  $P_{out}$  changes only by a factor of three in this power range.



# Optical Amplifier - Optical Gain (G)

- **Gain bandwidth**

- Refers to the range of frequencies or wavelengths over which the amplifier is effective.
- In a network, the gain bandwidth limits the number of wavelengths available for a given channel spacing.

- **Gain efficiency**

- Measures the gain as a function of input power in dB/mW.

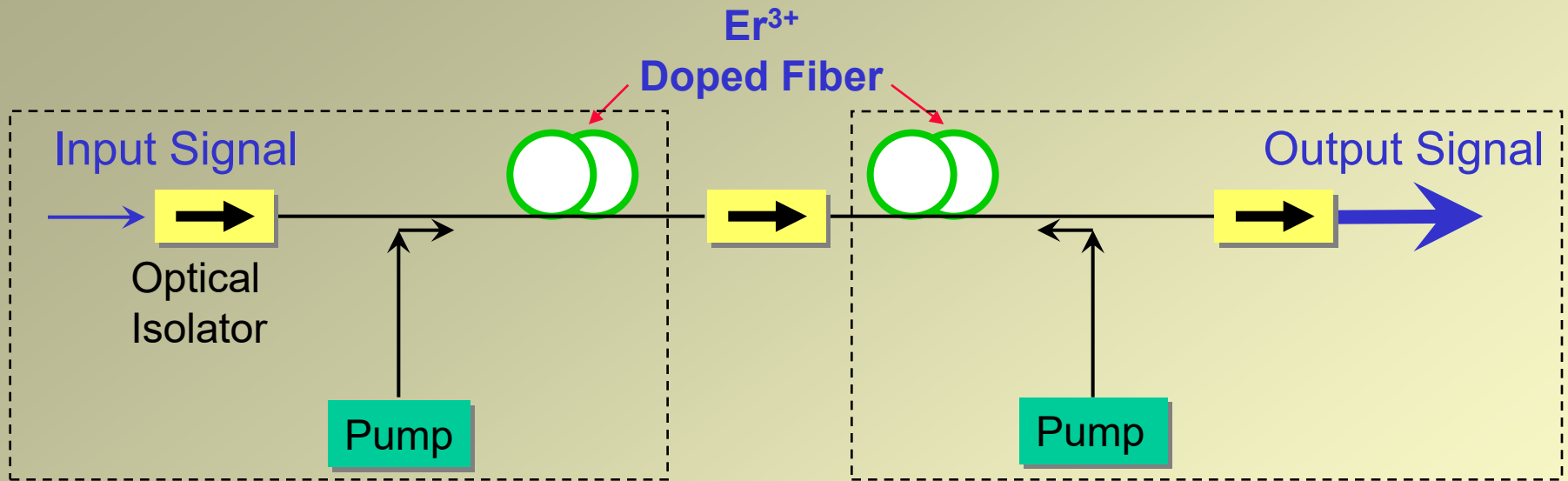
- **Gain saturation**

- Is the value of output power at which the output power no longer increases with an increase in the input power.
- The saturation power is typically defined as the output power at which there is a 3-dB reduction in the ratio of output power to input power (the small-signal gain).

# Optical SNR

- For  $\text{BER} < 10^{-13}$  the following OSNRs are required:
  - $\sim 13$  dB for STM-16 / OC-48 (2.5 Gbps)
  - $\sim 18$  dB for STM-64 / OC-192 (10 Gbps)
- Optical power at the receiver needs to be bigger than receiver sensitivity
- Optical Amplifiers give rise to OSNR degradation (due to the ASE generation and amplification)
  - $\text{Noise Figure} = \text{OSNR}_{\text{in}} / \text{OSNR}_{\text{out}}$
- Therefore for a given OSNR there is only a finite number of amplifiers (that is to say a finite number of spans)
- Thus the need for multi-stage OA design

# Optical Amplifiers: Multi-Stage



1st Active stage co-pumped:  
optimized for low noise figure

2nd stage counter-pumped:  
optimized for high output power

$$NF_{1\text{st}/2\text{nd stage}} = P_{in} - SNR_o \text{ [dB]} - 10 \text{ Log } (hc^2\Delta\lambda / \lambda^3)$$

$$NF_{\text{total}} = NF_1 + NF_2 / G_1$$

# System Performance: OSNR Limitation

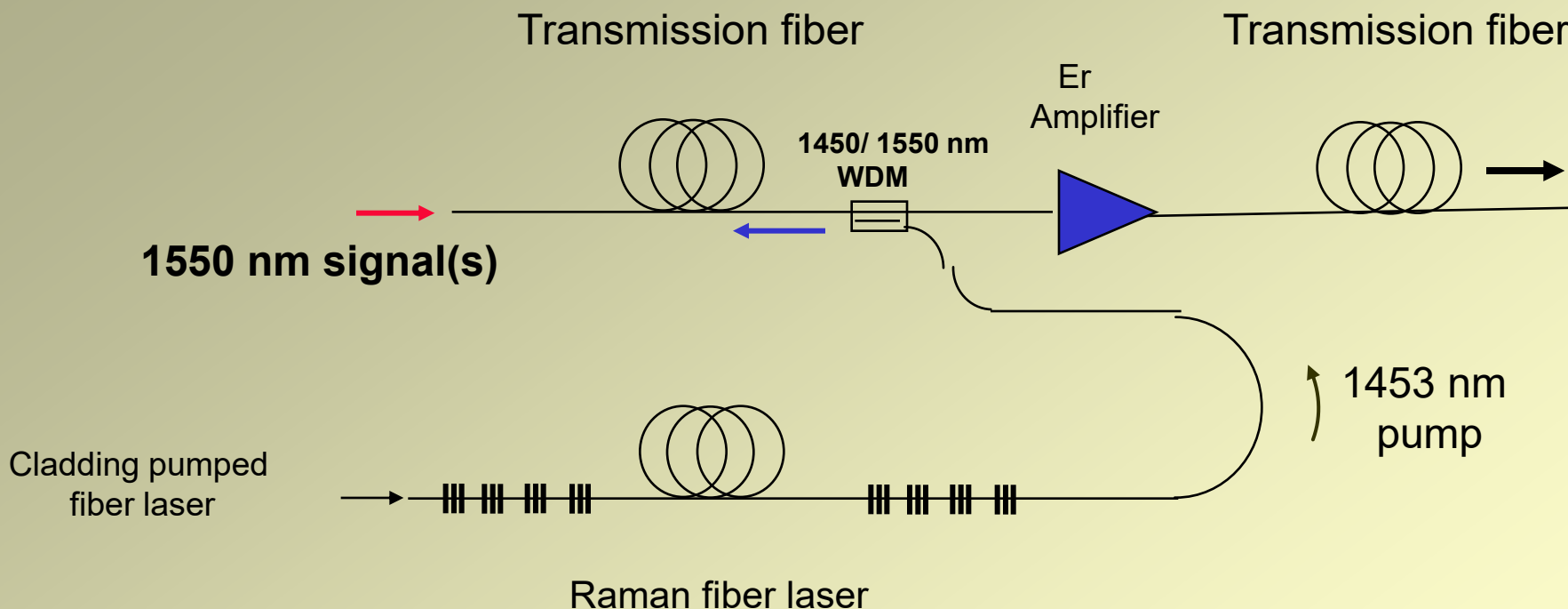
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- 5 Spans x 25 dB
- 32 Chs. @ 2.5Gb/s with 13 dB OSNR
- BER <  $10^{-13}$

## Channel Count / Span Loss Trade-Off:

- 5 spans x 22 dB
- 64 chs @ 2.5Gb/s with 13 dB OSNR
- BER <  $10^{-13}$

# Raman Amplifier



- Offer 5 to 7 dB improvement in system performance
- First application in WDM

P. B. Hansen, et. al. , 22nd Euro. Conf. on Opt. Comm., TuD.1.4 Oslo, Norway (1996).

# Optical Amplifiers - Applications

- In line amplifier
  - 30-70 km
  - To increase transmission link
- Pre-amplifier
  - Low noise
  - To improve receiver sensitivity
- Booster amplifier
  - 17 dBm
  - TV
- LAN booster amplifier

