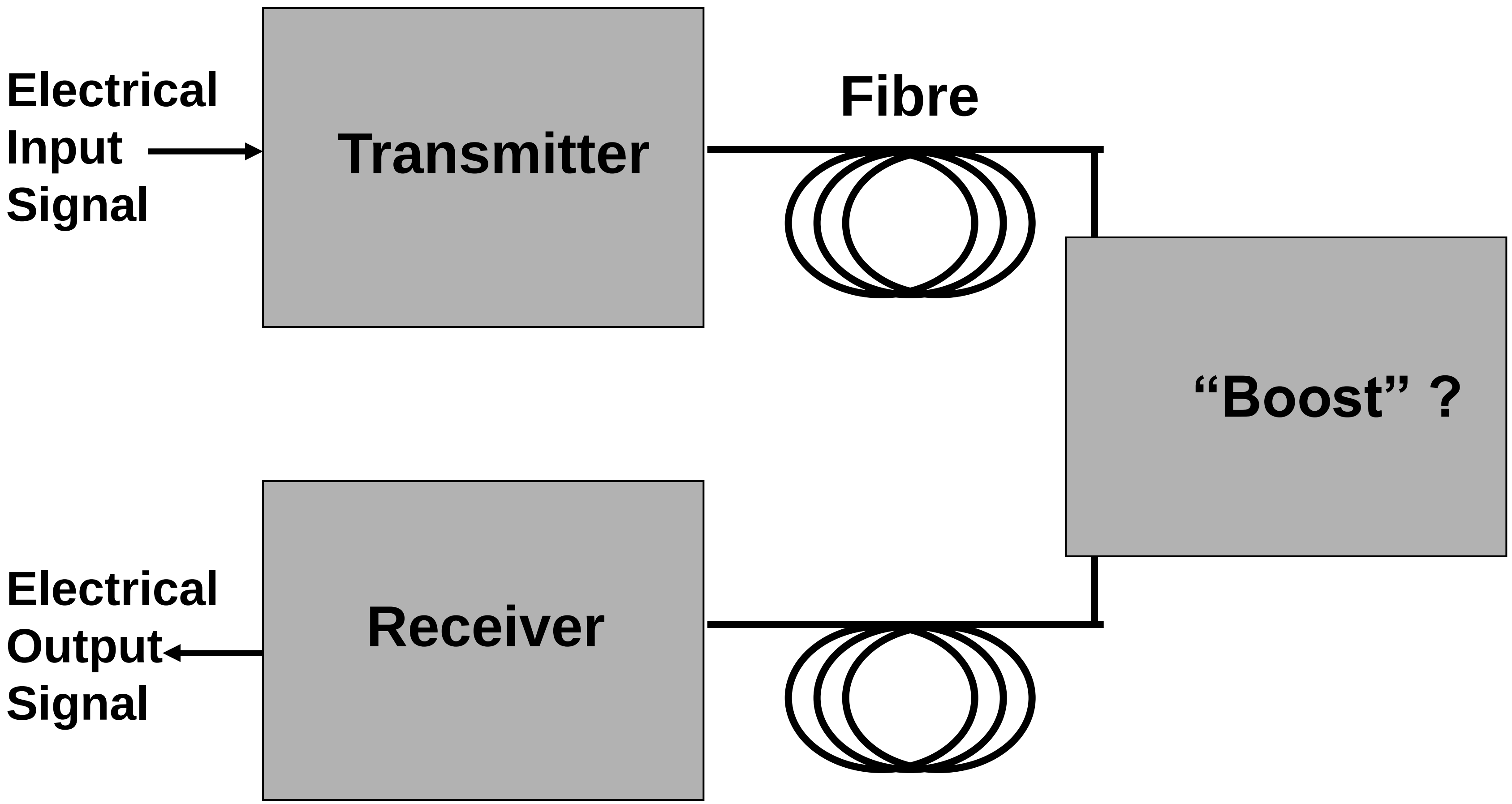
AMPLIFICATION

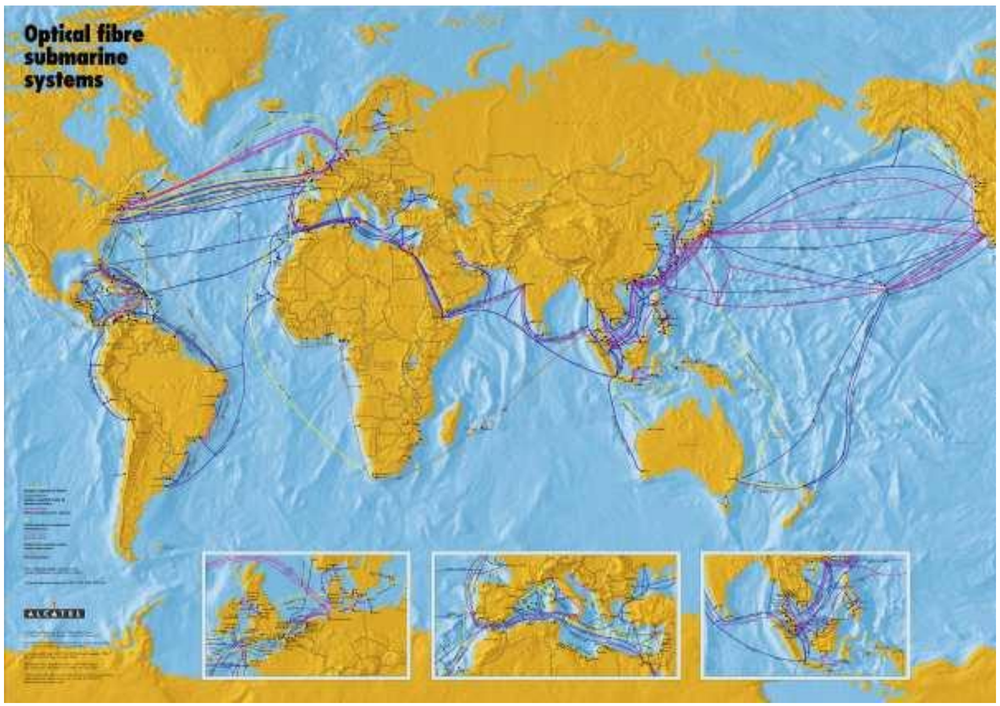
Minimum Average Power and receiver Q

Requirement for “Boosting” the signal
Regeneration
Amplification
Erbium and EDFAs
 Gain saturation
 Cross talk
Semi-conductor Optical Amplifiers

Optical Fibre System



Transmission over a Long Distance



$\sim 10^4$ km between Transmitter and Receiver

0.2dB/km $\sim 2\times10^3$ dB

Require periodic “boost” to signal

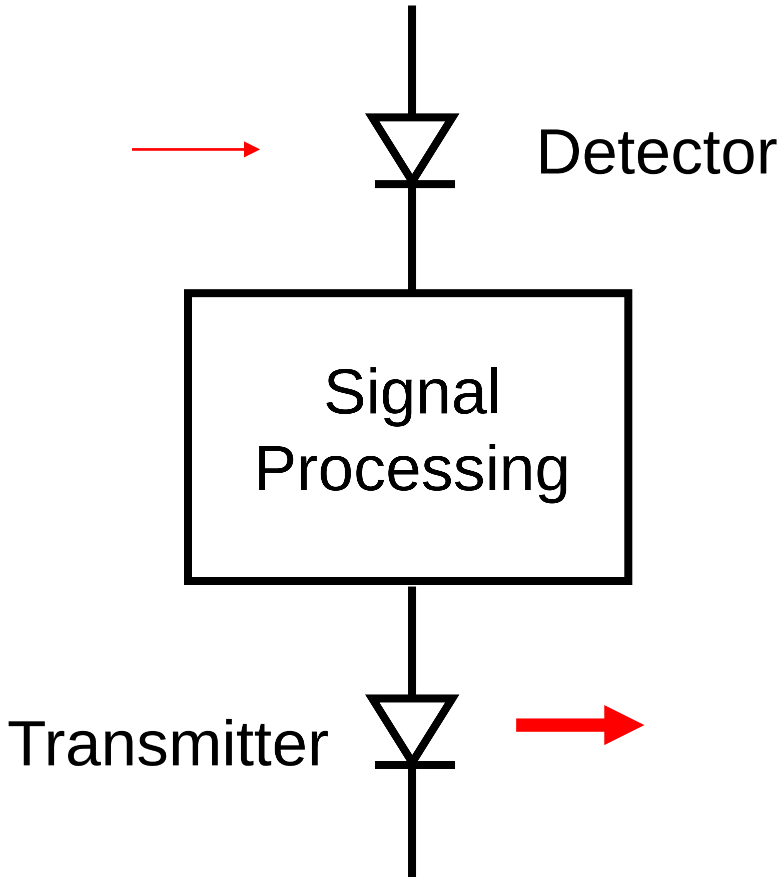
Must do this in a simple robust manner – manufacturer must guarantee will work for 25 years

Optical Amplifiers

When setting up an optical link a power budget is set up and repeaters (amplifiers) added when path loss exceeds the available power margin.

Amplifiers are of two types – doped-fibre amplifiers (DFAs) and semiconductor optical amplifiers (SOAs).

Repeaters/Regenerators



Complex circuitry – 10s of GHz

Signal processing requires a specific signal type – internal clock, etc

Many failure modes

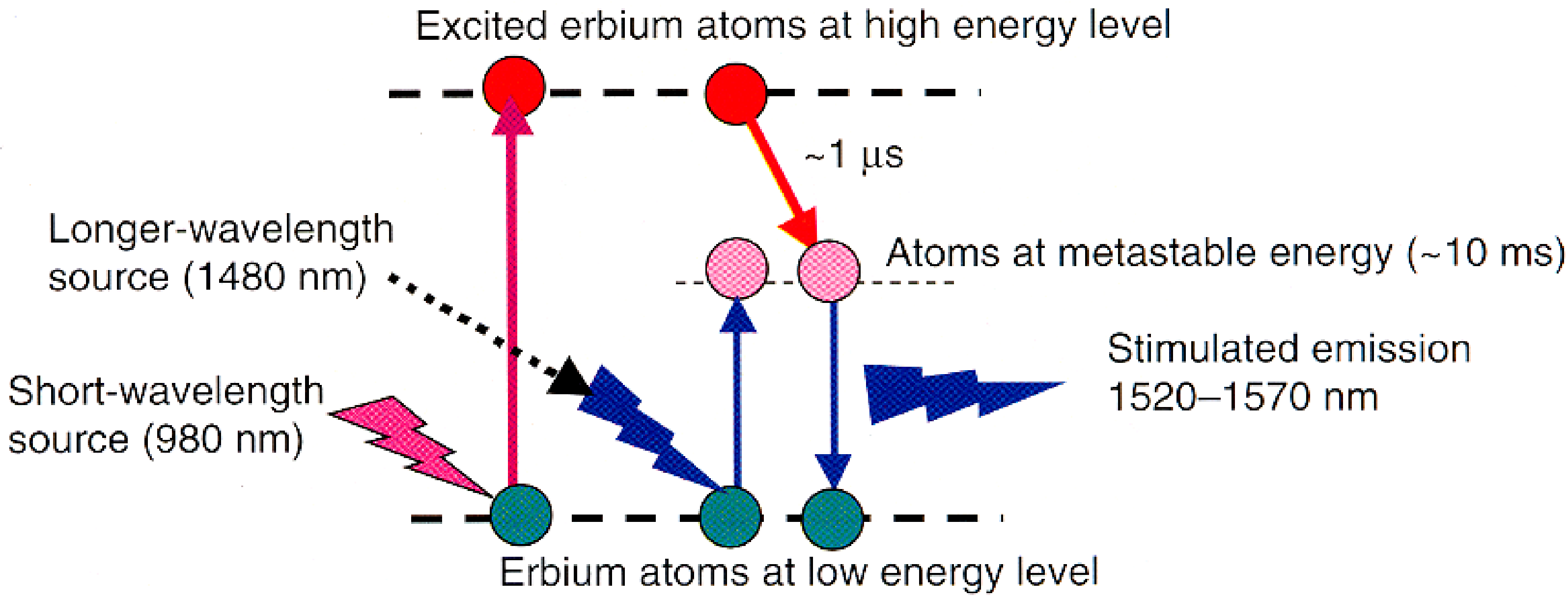
Need to qualify all components for 25 years operation

Too risky…

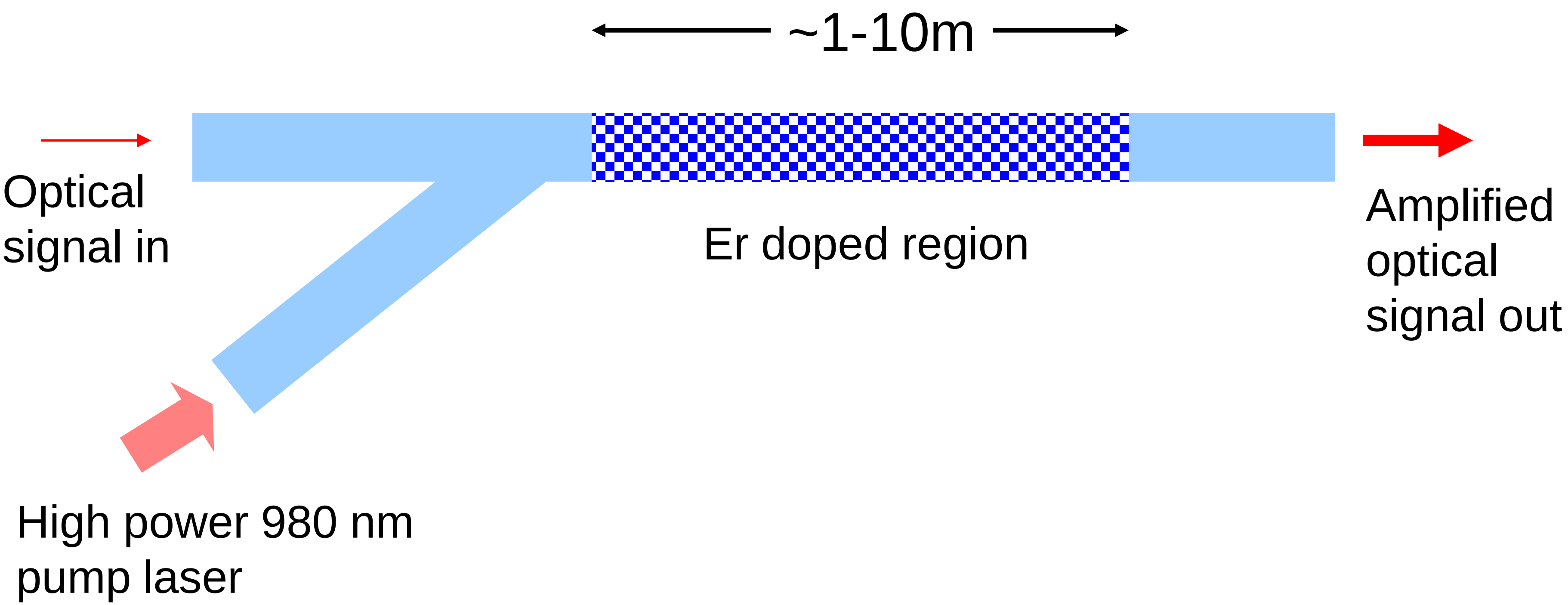
Erbium

Erbium has an optical transition at ~1.55 um – pump at 980nm or 1480nm

1480nm gives more noise



Erbium Doped Fibre Amplifier (EDFA)



Pump laser can travel in same or opposite direction as pulse to be amplified

EDFA cont.

- A length of optical fibre doped with erbium (Er) – 10 to 30 m
- - Y coupler (3dB) allows Er region to be pumped with a semiconductor laser (usually 980nm)
- Absorption of 980nm photon by Er^{3+} ion results in the excitation of electrons within the electronic levels of the ion.
- The electron occupies a short-lived state before relaxing to a long-lived energy level.
- The relaxation from this level to the ground state results in the emission of a photon at 1550nm
- Due to inhomogenaities a broad band (=/-20nm) emission is possible.
- If excitation is sufficiently strong a population inversion is possible – in such a case a signal photon is highly likely to trigger the stimulated emission of a photon amplifying the signal.

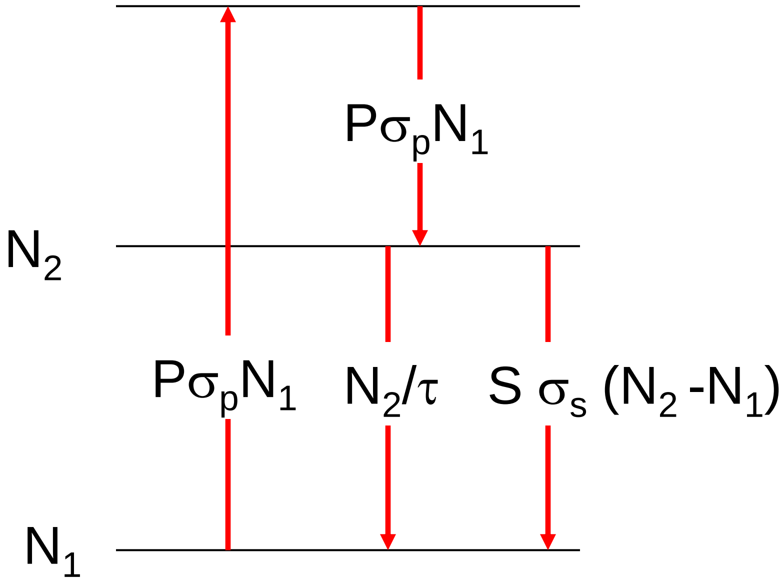
<u>Dual pumped EDFA</u>

Distribution of excited Er ions more even

Get more gain 30dB but also more noise

If one pump laser fails – still get some gain

EDFA – Rate Equations



Pump excites some Er atoms from N_1 to N_2 via short lived state

Er atoms in state 2 decay via spontaneous emission or by stimulated emission due to signal

N_1 and N_2 are volume densities of Er atoms in the ground (1) and excited (2) states - Volume density of Er atoms $N = N_1 + N_2$

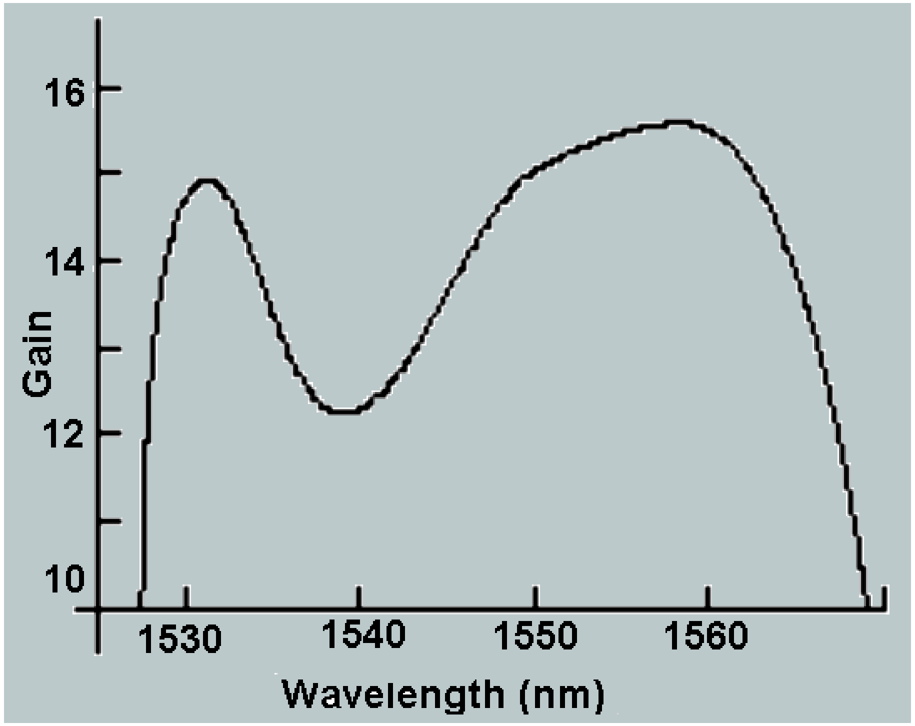
P = pump power
S = incident signal power
σ_p = optical cross section for absorbing pump
σ_s = optical cross section for stimulated emission due to signal
τ = spontaneous emission decay time
Gain = $G = 1 + \sigma_s (N_2 - N_1)$

EDFA – Conclusions from Rate Equations

No signal and strong pump – obtain population inversion

Introduce signal – get gain

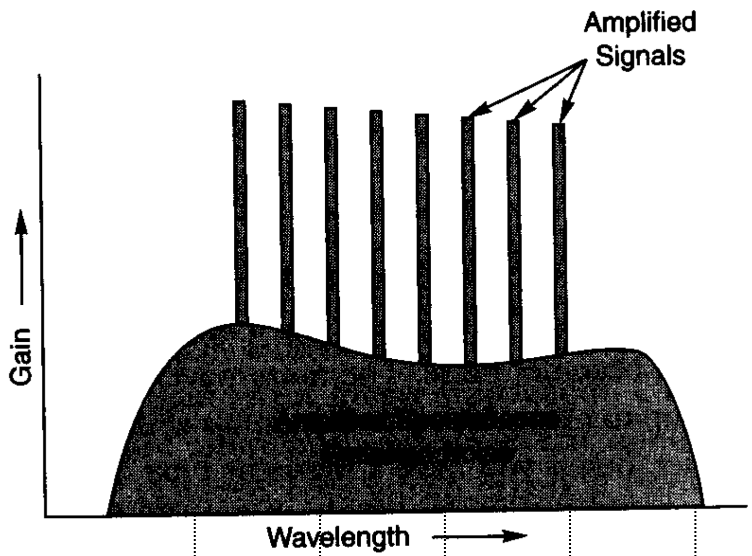
As we increase signal strength, deplete level N_2 and gain saturates as system cannot keep up – **Gain Saturation**



For maximum gain – need large concentration of Er atoms, high pump power

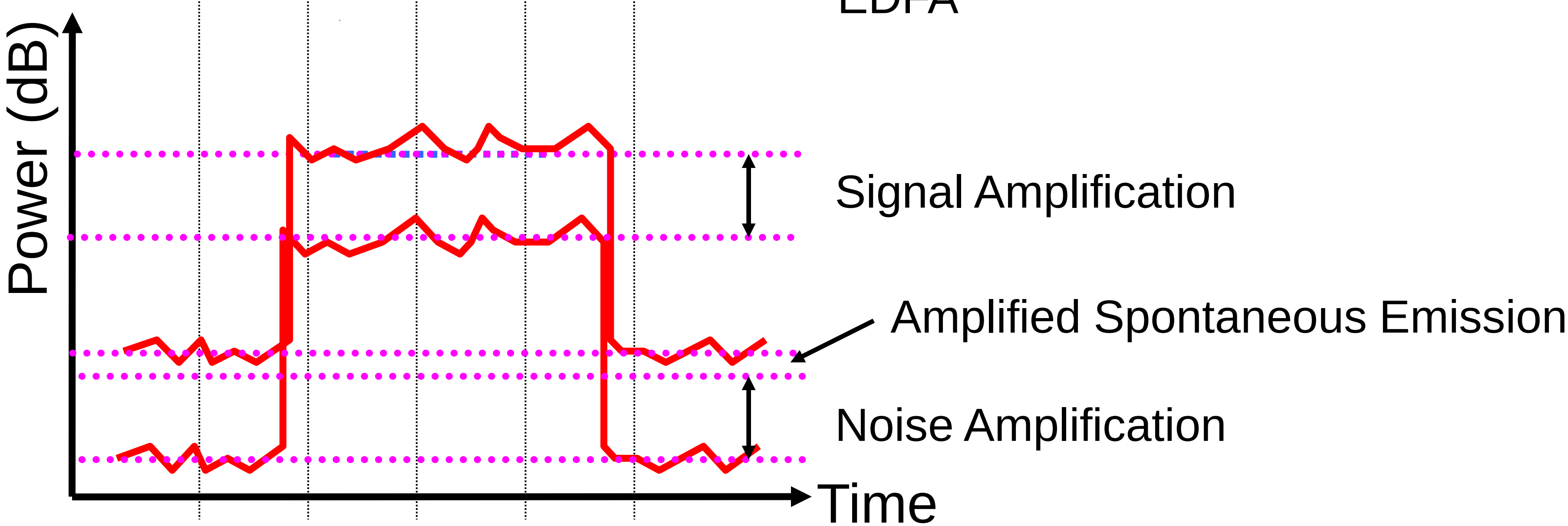
Max gain ~ 30dB/EDFA

EDFA – Noise



EDFAs amplify noise input with signal

Also generate background noise – amplified spontaneous emission
Spontaneous emission which is waveguided will be amplified in EDFA



Pros and Cons of EDFAs

Pros

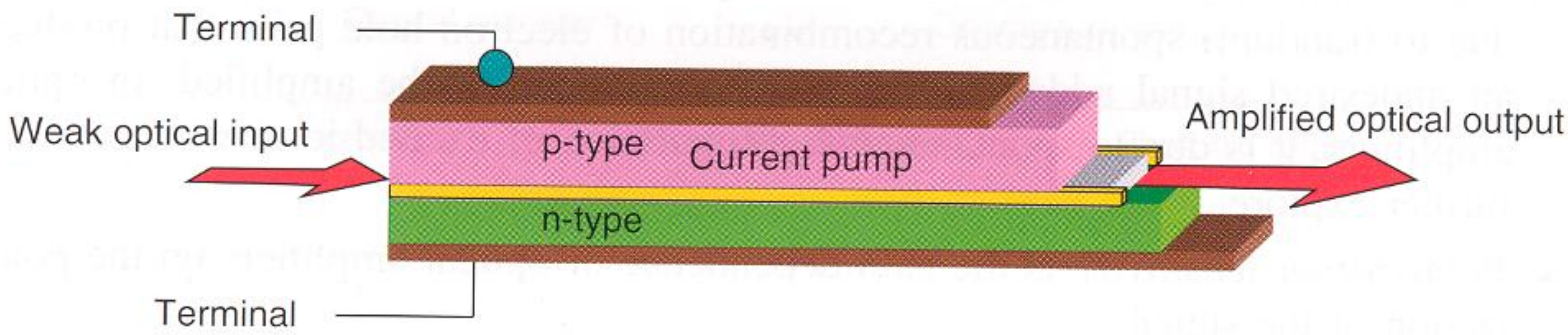
Simple! Just need high reliability high power pump laser
Not tied to a particular data type
Excellent for WDM applications
Can be used as pre-amplifiers before a detector, power booster after a transmitter or amplifier mid-way between transmitter and receiver

Cons

Doesn't help with dispersion
Adds noise - ASE
Crosstalk

Semiconductor Optical Amplifiers (SOAs)

Based on FP Laser but non-reflecting ends – broad amplification



Polarisation Dependent – optical E-fields polarised vertically or horizontally see different gains

Coupling losses large

Integration possible

Summary

The average receiver power can be determined for a p-i-n diode by making suitable approximations.

Due to dispersion and loss within a fibre it is necessary along a fibre link to regenerate the signal from time-to-time.

A regenerator consists of a detector, electronics, and a transmitter which will resend an input signal - this must be tied to a specific data type though

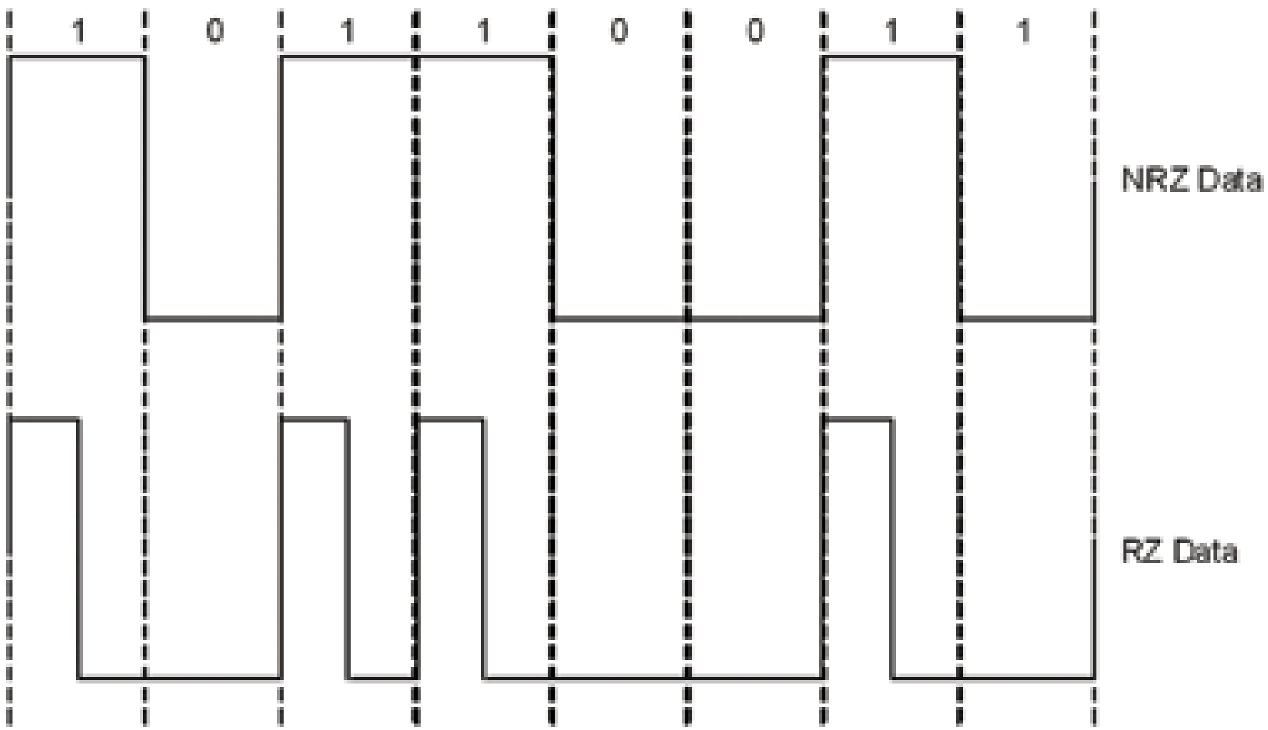
An amplifier increases the optical signal strength (the signal remains in the time domain)   Due to it's atomic shell structure optically pumped erbium doped fibres provide this amplification

Compared to a regenerator, EDFAs are attractive due to their simple, robust design, that they are not tied to a particular data type, are useful for WDM applications, but the don't help with dispersion, add noise (amplified spontaneous emission), and can suffer from crosstalk

Return to zero RZ and non return to zero NRZ pulses

- As *NRZ* data signals have a larger duty cycle, the peak power of an *NRZ pulse* is lower than that of RZ *pulse* at the same level of average optical power.
- Now average launch power = half peak power for a NRZ pulse stream - since probability of a 1 or 0 is equal and 0 and 1 are uncorrelated.
- Hence peak power = 2 x average power

Illustration of ideal NRZ and RZ signals.



Worked Example – Optical fibre system

An optical fibre link operating at 1300 nm transmits a train of pulses in NRZ format with a 1:1 mark space ratio. The optical receiver needs at least 2000 photons to detect 1 bit accurately. The optical fibre loss is 1.5 dB/km. What is the maximum possible length of the fibre link for a 0.5Gb/s lightwave system designed to transmit 0dBm of average power?

The energy of 1 photon $E = 6.6 \times 10^{-34} c/\lambda$ J.

Solution

$E = hv = hc/\lambda$

At 1300 nm Energy of 1 photon = $6.6 \times 10^{-34} \times 3\times10^{8}/1300\times10^{-9} = 1.53 \times 10^{-19}$ J

Need 2000 photons to detect 1 bit at 0.5Gb/s

Need a peak received power of $1.53 \times 10^{-19} \times 2000 \times 500 \times 10^{6} = 1.53 \times 10^{-7}$ W

Average power = peak power/2 = 0.76×10^{-7} = -71 dBW = -41 dBm

Launch power = 0 dBm

Assuming no margin have 41 dB available in power budget as a loss in fibre

Loss = 1.5dB/km, hence fibre length = 41/1.5 = 27.3 km.