Optical System Design

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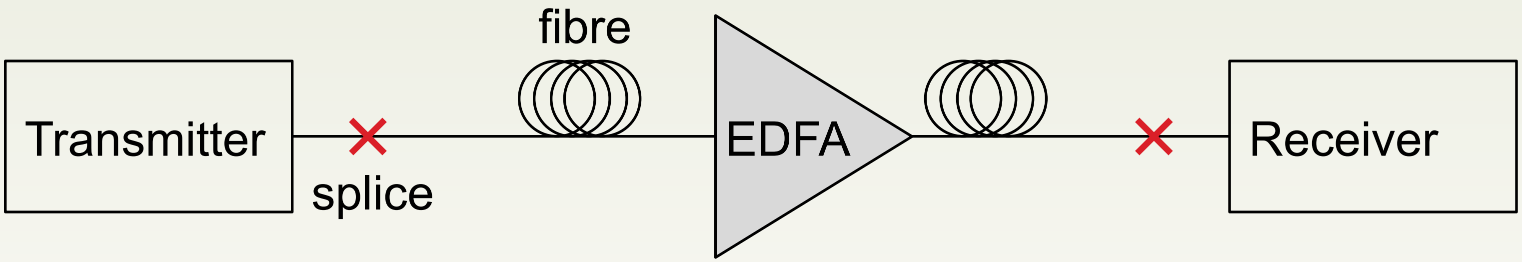
Optical System Design

- What are the main components?
- What are their parameters?
- What are the main impairments?
- How to overcome the impairments?

Keys to simple optical design

- In the next two weeks we will discuss:
  - Limitation due to losses (power budget)
  - Dispersion and its impact on transmission
  - Regenerated system designs
  - Overall design of a link

System Parameters



Transmitter	Splices	Amplifier	Fibre	Receiver

End of Video 1

Power Budget

- Transmitter power is P_t (dBm)
  - May be defined as the maximum output power of the laser, i.e. the peak un-modulated power
  - May also be defined as the time average power when modulated, i.e. the peak is 3dB greater assuming that the laser is modulated with equally probable 1's and 0's

- We must use average i.e. ½ peak

Power Budget

- Receiver sensitivity is P_r (dBm)
  - The receiver sensitivity is defined as the minimum average power required at the receiver to maintain a certain bit error rate (BER). Often today required BERs are $>10^{-12}$ (one error per 10^{12} bits) although often in text books 10^{-9} is still used.
  - Will be specified for a certain wavelength
  - Is dependent on noise power therefore it also depends on the bandwidth, thus the bit rate.

  - Note: If the received power is less than the receiver sensitivity the receiver will still work however the BER will be greater than the specified level.

Power Budget

- Receiver sensitivity is P_r (dBm)
  - Sometimes the receiver sensitivity is also expressed as the number of photons required per '1' bit *M*, which is given by

$$M = \frac{2P_r}{hf_c B}$$

    - where B is the bit rate and f_c is the carrier frequency
- Average power per bit $(P_0+P_1)/2$ for a specific BER

Extinction ratio

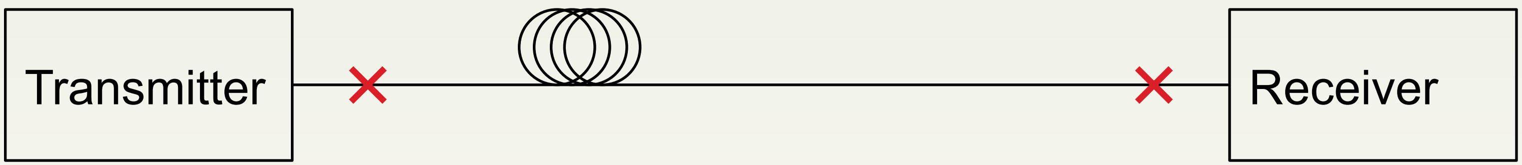
- Often we will assume that $P_0=0$, i.e. a zero bit is characterised by a no light.
- The difference between the amount of light sent when the device is on (one bit), compared to when it is off (zero bit) is often defined as extinction ratio.

- NOTE it is independent of the actual power, and will usually be defined as something like >20dB

Power Budget

- Fibre loss is X dB/km
- System span is L km
- Total splice losses are S dB (assume Ns splices)
- The system operating margin is the difference in dB between the received power (in dBm) and the receiver sensitivity (in dBm)
- Received power is $P_t\text{-}X.L\text{-}S$
- Hence system margin m = $(P_t\text{-}X.L\text{-}S) - P_r$

Power Budget Parameters



Transmitter	Splices	Amplifier	Fibre	Receiver
LED, DFB, DBR, FP Directly or externally modulated Power average or peak Bit rate	Number Loss per splice	None	SMF, DSF, NZ-DSF, DCF Loss/km Dispersion	PD or APD Sensitivity

Loss limited system

- What is the maximum possible system range if the required minimum operating system margin is m?
- Range, $L = (P_t - S - P_r - m)/X$
- Example:
  - Required operating margin, m = 2 dB:
  - If P_t is 0 dBm, S is 1 dB and P_r is -31 dBm in SMF
- Range, **L = 140 km**

- This assumes no significant signal impairment is introduced in the transmission channel

Overcoming loss limitation

- Increase the power from the laser:
  - May induce non-linear effects
- Increase the receiver sensitivity
  - A receiver will always be limited by thermal noise
- Amplify the signal
  - Introduces another component into the system, add noise, distort the signal…

End of Video 2

Dispersion limited system

- Source linewidth and the effect of fibre dispersion limit the attainable transmission distance
- Consider a source linewidth of $\Delta\lambda$, a fibre dispersion of D ps/nm•km and a fibre span of L km
- A pulse transmitted through the fibre will spread in time, proportional to length, with pulse spreading $\boldsymbol{\Delta\tau=\Delta\lambda.D.L}$
- This results in intersymbol, and satisfactory operation requires $\Delta\tau\approx0.3T$, where T is the symbol duration (Bit rate, B=1/T)
- It can be shown that $\Delta\tau\approx0.3T$ equates to a power penalty of 1dB, but is this only a rule of thumb and **must be stated** as an assumption when designing the system

Overcoming Dispersion

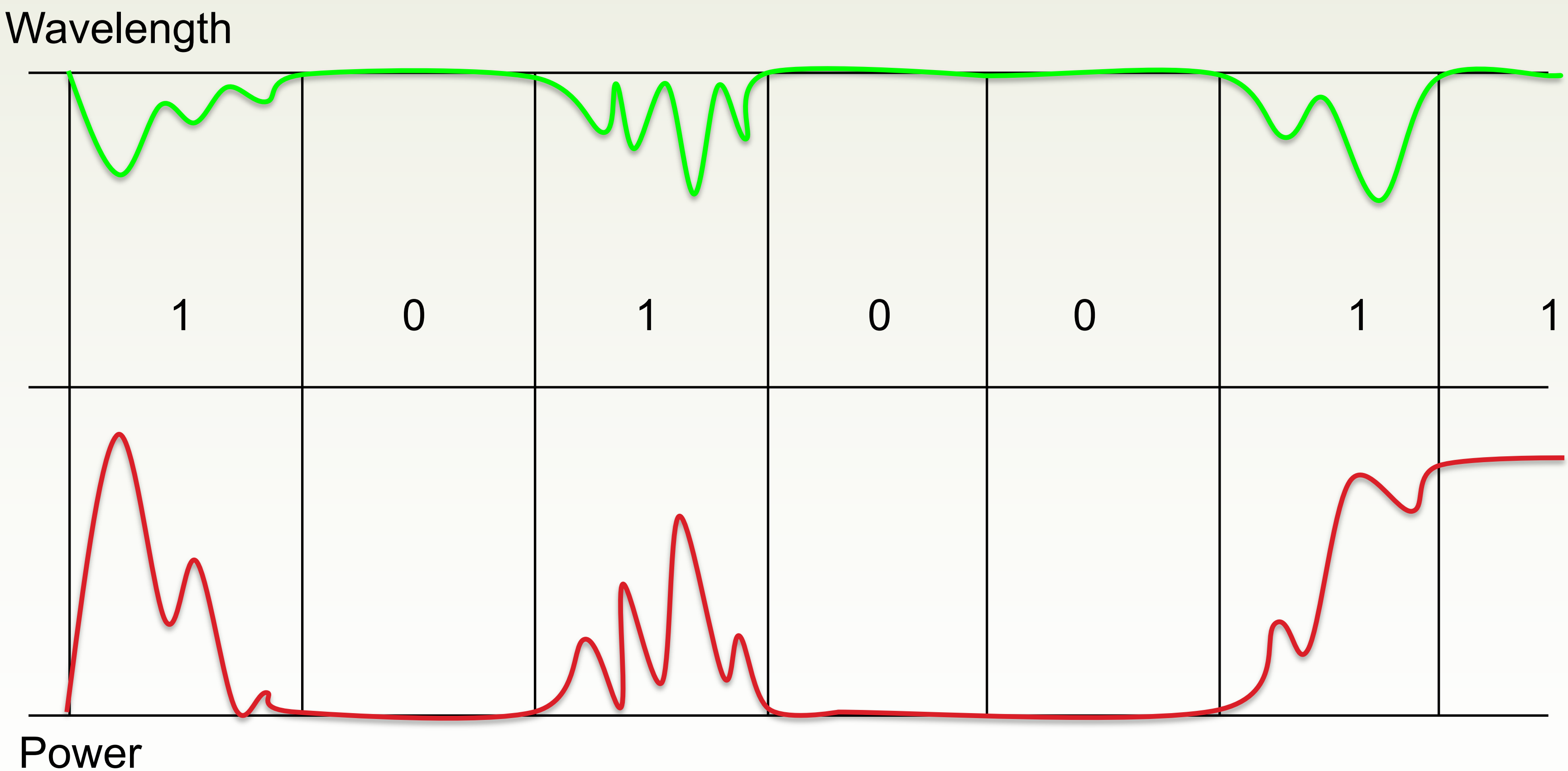
- The equation governing the amount of pulse spread is $\Delta\tau = \Delta\lambda . D . L$
- To increase the dispersion limit we can
  – Decrease the optical linewidth (this depends on the bit rate)
  – Use a laser with a smaller linewidth (usually negligible compared to the modulation induced broadening)
- Decrease D the Fibre dispersion parameter

  –Use different fibre, i.e.Dispersion Shifted
- Decrease L the fibre span
  – Shorter system range, not always practical
- To increase the range we could decrease the bit rate

Chirp Limitations

- The previous analysis applies for a ‘static’ source linewidth
- Direct modulation of a laser diode induces transient wavelength (optical frequency) fluctuations – chirp
- Interaction with the fibre dispersion characteristic leads to transient distortion of the signal which is rather complex in form
- Occurs because dispersion characteristic is not linear with wavelength. As the transient shifts the wavelength we get a change in the level of dispersion

Laser Transient Response



- Output 'on' power ~ 5mW
- 'Patterning' can be seen in the output response
- Peak-peak chirp typically ~ 0.1nm - 0.5 nm

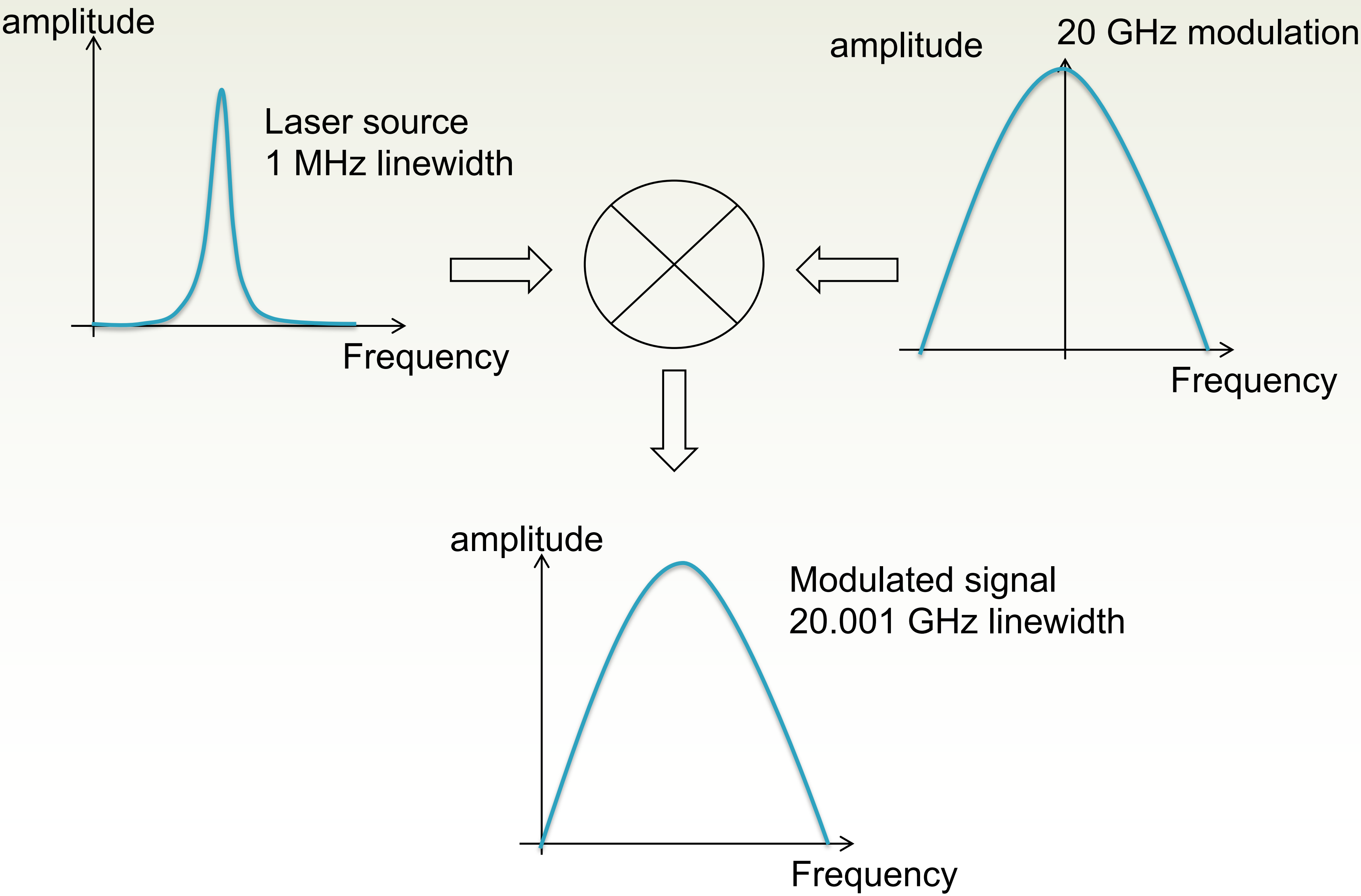
Chirp-Dispersion Interaction

- The laser frequency fluctuation combined with the fibre dispersion has the effect of transiently distorting the time access
- Some portions of the waveform are delayed or advanced relative to the average
- The result is significant pulse distortion
- The distortion is not ALWAYS an impairment - it is possible for pulse compression to occur, which tends to alleviate the penalty due to dispersion
- For sufficiently long distances, though, the effect eventually is always a problem

Modulation-Dispersion Interaction

- A perfect, zero linewidth, source when modulated at bit rate B has spectral width ~ 2B – corresponding to 100% raised cosine filtering
- The information sidebands induced by modulation experience differential delay due to fibre dispersion
- This imposes a transmission rate/length limitiation broadly similar to that noted for finite linewidth sources, even if the source intrinsic linewidth is negligible
- The implications for SMF operating at 1550 nm are indicated in the next few slides

Modulation and linewidth



Implication of modulation

- We said earlier that decreasing the linewidth will increase the dispersion limited range.

- However, because of modulation broadening the linewidth, after a point the inherent laser linewidth becomes insignificant compared to the linewidth broadening from the modulation

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