

Optical System Design

Prof Cyril Renaud
c.renaud@ucl.ac.uk

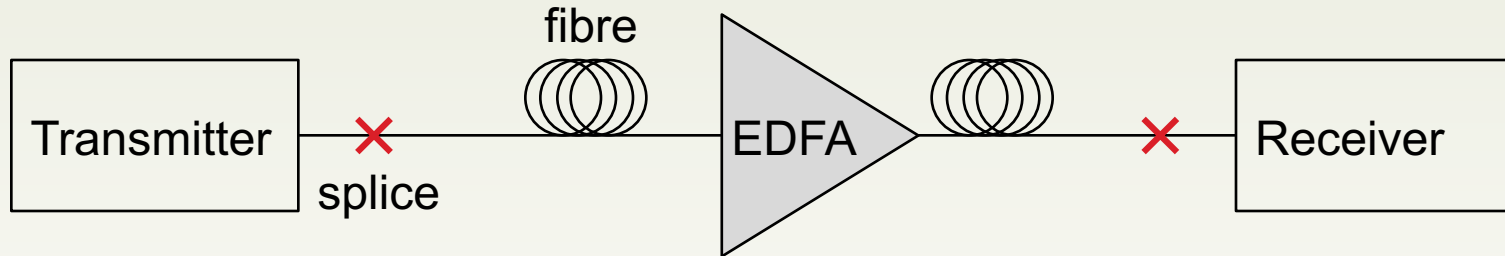
Optical System Design

- 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. $\frac{1}{2}$ 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

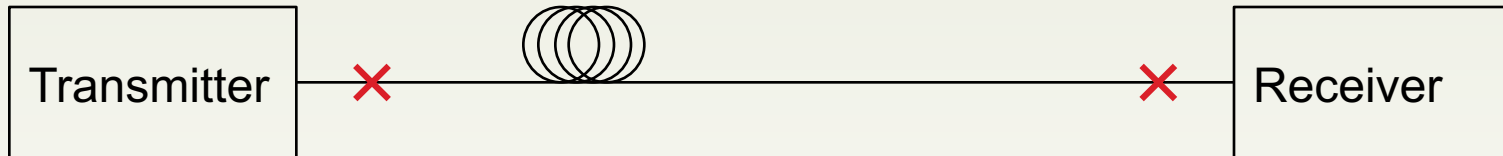
- Often we will assume that $P_0=0$, i.e. a zero bit is characterised by a no light.
- The difference between the amount of light sent when the device is on (one bit), compared to when it is off (zero bit) is often defined as extinction ratio.
- NOTE it is independent of the actual power, and will usually be defined as something like $>20\text{dB}$

Power Budget

- Fibre loss is X dB/km
- System span is L km
- Total splice losses are S dB (assume N_s 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 $P_t - X \cdot L - S$
- Hence system margin $m = (P_t - X \cdot L - S) - P_r$

Splice loss: fusion splicing is a technique to join two fibers ends. Optical power loss at the splicing point is known as splice loss.

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 $\Delta\tau = \Delta\lambda \cdot D \cdot L$
- This results in intersymbol, and satisfactory operation requires $\Delta\tau \approx 0.3T$, where T is the symbol duration (Bit rate, $B = 1/T$)
- It can be shown that $\Delta\tau \approx 0.3T$ 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

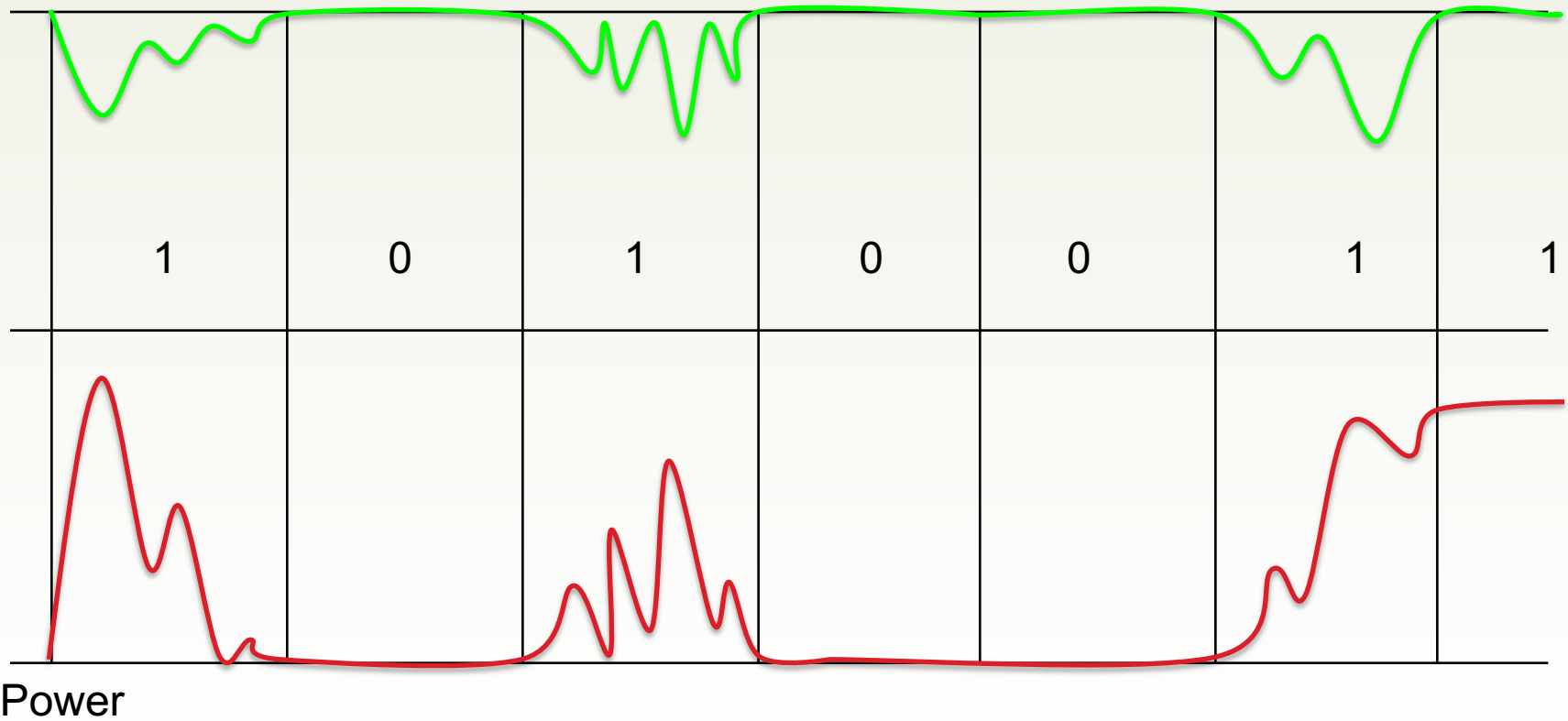
- The equation governing the amount of pulse spread is $\Delta\tau = \Delta\lambda \cdot D \cdot L$
- To increase the dispersion limit we can
 - Decrease the optical linewidth (this depends on the bit rate)
 - Use a laser with a smaller linewidth (usually negligible compared to the modulation induced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

Wavelength



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

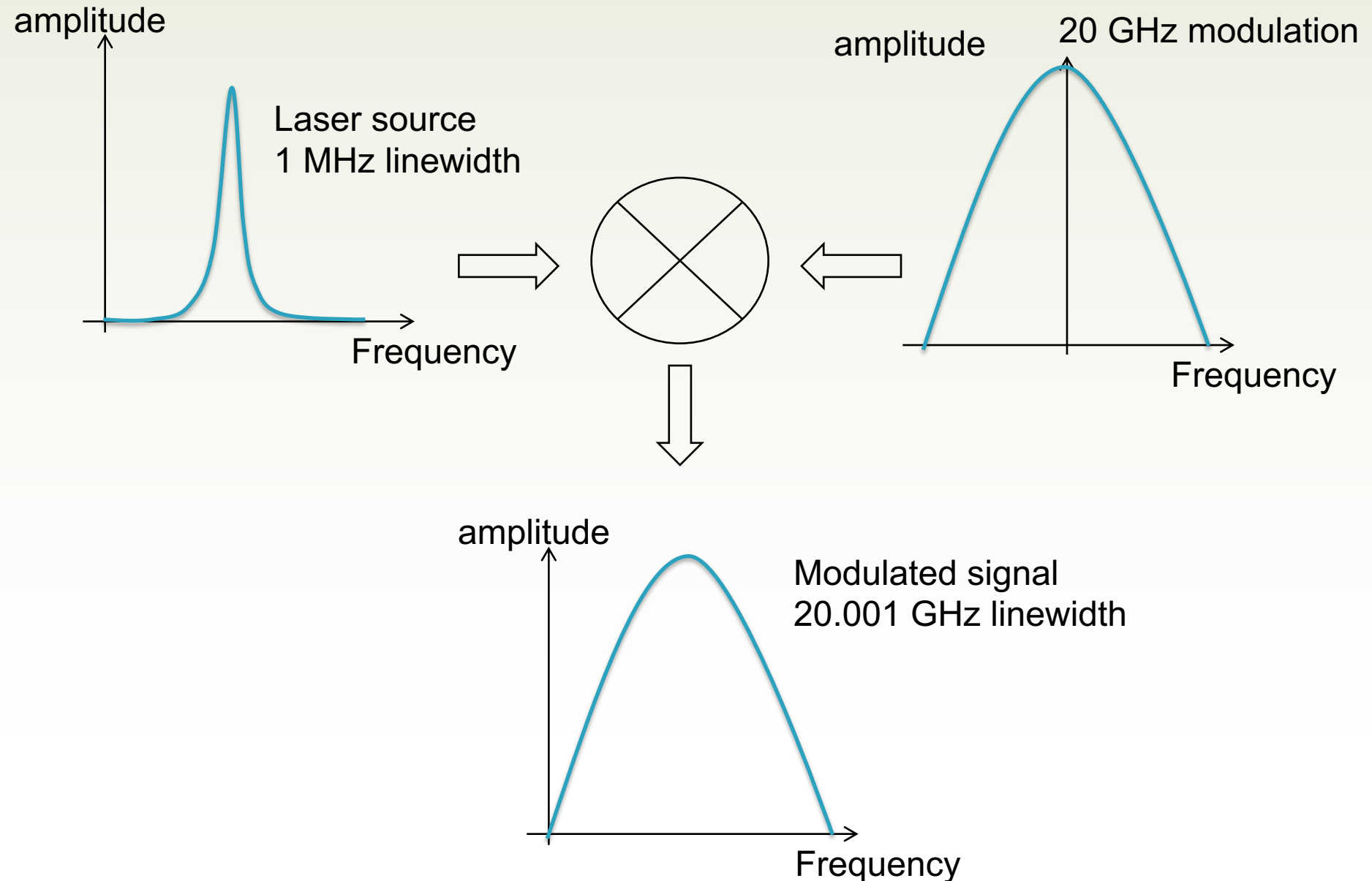
Chirp-Dispersion Interaction

- 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 $\sim 2B$ – 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 limitation 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

End of Video 3