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# Optical Signals Modulation and Compensation of Chromatic Dispersion

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South-East Europe Fibre Infrastructure  
for Research and Education

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- Modulation (and demodulation) formats
- Signal formats
- Chromatic dispersion (CD)
- CD management
- Conclusions



# Modulation Formats (Schemes)



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- How to convert an electrical signal into an optical stream?
- On-Off Keying (OOK)
- A simple digital modulation scheme, easy to implement
- Intensity modulation with direct detection (IM/DD)
- Incoherent (the intensity only, no phase coherence)
- Direct or external ( $\text{LiNbO}_3$ ) modulations
- Two basic choices for the signal formats – return-to-zero (RZ) and nonreturn-to-zero (NRZ)
- Carrier suppressed (CS), Single side band (SSB), Vestigial sideband (VSB), Chirped (C) both for RZ and NRZ (CS-RZ, C-RZ,...)



# Advanced Modulation Formats



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- Coherent - well known from radio and microwave systems and literature
- Improvement of receiver sensitivity (up to 20 dB) when compared to IM/DD systems [1]
- More efficient use of bandwidth by increasing the spectral efficiency (higher tolerance to nonlinear effects, chromatic dispersion CD, polarization mode dispersion PMD)
- More complicated and more expensive



# Advanced Modulation Formats



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- Amplitude-shift keying (ASK)
- Phase-shift keying (PSK)
- Frequency-shift keying (FSK)
- Differential phase-shift keying (DPSK)
- Differential quadrature phase-shift keying (DQPSK) – Wi-Fi
- Optical Duo Binary ODB (also known as phase shaped binary modulation)



# Advanced Modulation Formats



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- Signal formats can be RZ, NRZ, CS-, etc. again
- DQPSK, ODB are *multilevel* modulations
- Multilevel – more amplitude levels (to achieve spectral efficiency better than 1 bit/s/Hz), 40 Gb/s is 10 Gbaud for a 16 level modulation
- DQPSK (information is encoded in the 4 differential optical phase between successive bits)
- ODB (in simplest scheme - two consecutive bits are summed -> a three level code is created, AM-PSK)
- RZ-DPSK, NRZ-DPSK, CS-RZ OOK, RZ-ODB have been studied extensively (better tolerance to different impairments)



# Demodulations



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- Optical signals are modulated and transmitted
- Attenuation, dispersion, noise, nonlinear effects
- The data must be recovered @ BER  $10^{-9}$ ,  $10^{-12}$ ,  $10^{-15}$  ...
- Coherent (transmitted signal plus local oscillator) and incoherent (OOK) receivers
- Photo detector, pre-amplifier, filter (equalizer)



# Chromatic Dispersion



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- The speed of light is wavelength dependent
- Time broadening of pulses because different spectral components of the pulse travel at different speeds
- Critical at higher bit rates e.g.  $\geq 10$  Gb/s
- Can be (easily) compensated - a deterministic phenomena
- Different measurement methods (TIA/EIA)
- $D$  – chromatic dispersion coefficient, ps/(nm\*km)
- $D = 17$  ps/(nm\*km) for G.652 fibre (standard single mode fibre)







- Dispersion compensating fibres (DCF)
  - A special kind of fibre, compensates all wavelengths (the only solution for „grey“ transmitters)
  - Adds link loss, especially for long-haul applications
  - Stronger non-linear effects (due to a smaller core diameter)
- Fibre Bragg gratings (FBG)
  - Narrow-band elements – a stabilized DWDM laser is a must
  - „Wide-band“ FBGs available today (for 50 ITU DWDM channels)
  - Signal filtering, spectrum shaping, tuneable compensators
  - Cost effective





- Optical Phase Conjugation (OPC)
  - A nonlinear optical technique (midspan spectral inversion)
  - The complex conjugate of a pulse-propagation equation
  - Four-wave mixing in a nonlinear medium (phase conjugators)
- Electronic pre-compensation
  - A relatively new technique
  - An electrical signal is pre-distorted before converting into an optical domain
  - Dispersion can be easily tuned for up to thousands kilometers of G.652 fibre



# CD Measurements



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- Modulated Phase-Shift Method (FOTP 169)
- Differential Phase-Shift Method (FOTP 175)
  - Both phase-shift methods are accurate, measurement through optical amplifiers, expensive
- Spectral Group Delay Measurement in the Time Domain (FOTP 168)
  - Still accurate enough, no measurement through optical amplifiers
- Relative group delay is measured and the dispersion coefficient  $D$  is calculated



# CD limitations



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- Typical values (receivers can have different tolerance to CD!)

Bit rate (Gbit/s)	Maximum length of G.652 link (km)
2,5	1000
10	80
40	4



# Conclusions



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- OOK, NRZ: the most important and wide-spread today
- DPSK, RZ are promising technologies (still simple enough)
- Soliton systems (dispersion managed solitons)
- Compensating fibres are in the same position as NRZ-OOK
- But Bragg gratings and electronic pre-compensation are emerging technologies (as new modulation formats)





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**Thank you for your attention!**

