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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 (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. ≥ 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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- [4] OFC 2005 proceedings





Thank you for your attention!

