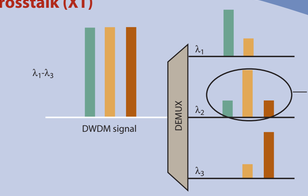
Understanding DWDM and ROADM Networks

Crosstalk (XT)

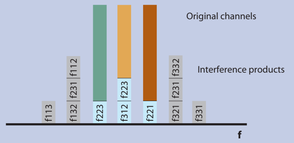


Crosstalk occurs in devices that filter and separate wavelengths. A proportion of optical power intended for a specific channel is found in an adjacent or different channel.

Effects: generation of additional noise affecting optical signal to noise ratios (OSNR), leading to bit errors.

Solutions: use appropriate optical channel spacing, for example 0.4 nm → 10 Gb/s.

Four Wave Mixing (FWM)

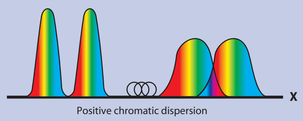


This interference phenomenon produces unwanted signals from three frequencies ($f_{xyz} = f_x+f_y-f_z$) known as ghost channels. As three channels automatically induce a fourth, the term four wave mixing is used. FWM is problematic in systems using dispersion shifted fibers (DSF). Wavelengths traveling at the same speed at a constant phase over long periods increase the effect of FWM.

Effects: power transfer to new signal frequencies (harmonics), channel crosstalk and bit errors.

Solutions: use of fibers with CD, irregular channel spacing.

Chromatic Dispersion (CD)

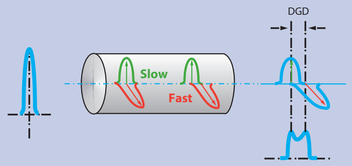


CD – the phenomenon of the different wavelengths of an optical pulse traveling at different velocities along a fiber and arriving at different times in the receiver.

Effects: decrease of peak power, pulse broadening and bit errors.

Solutions: use of fibers or modules with reverse CD values (DCF/DCM).

Polarization Mode Dispersion (PMD)

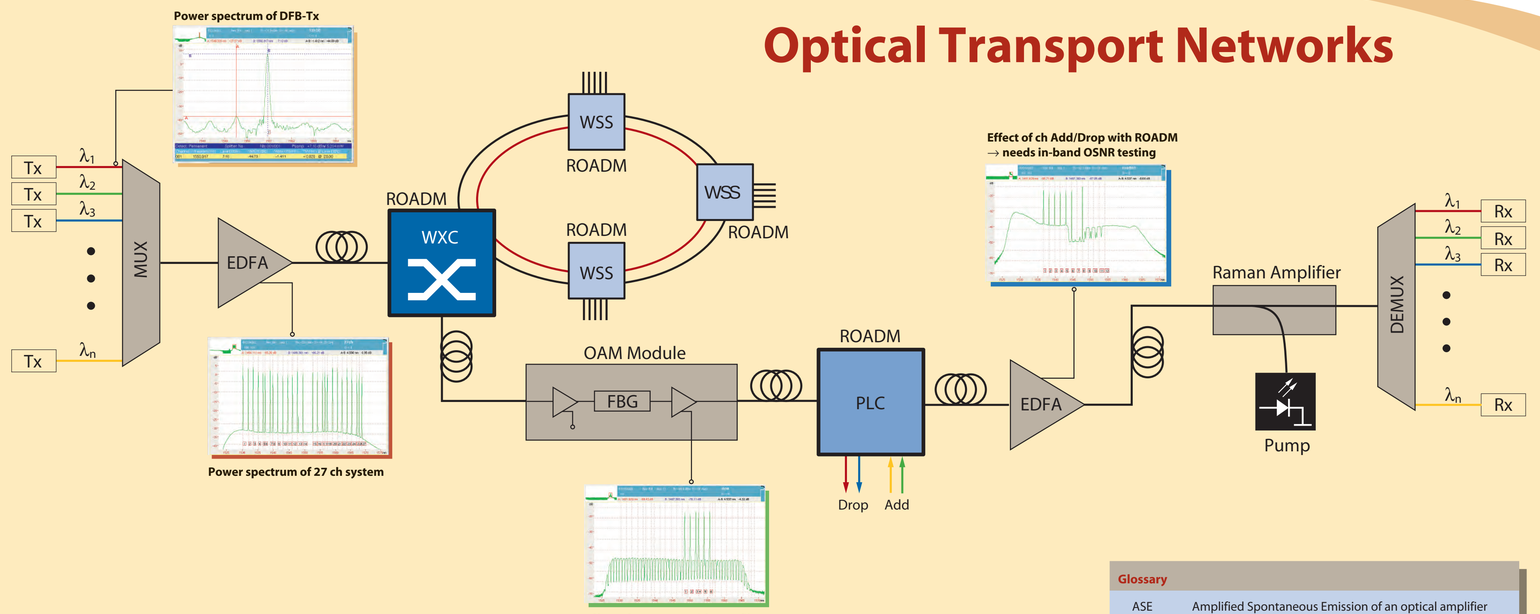


PMD – the effect of the different polarization modes (fast axis and slow axis) of a signal statistically traveling at different velocities due to fiber imperfections. Time difference is called Differential Group Delay (DGD).

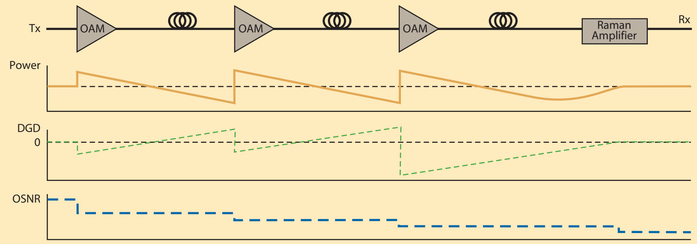
Effects: decrease of peak power distortion of pulse shape and bit errors.

Solutions: careful fiber laying (no stress), use of new fiber with low PMD values, exact fiber geometry.

Optical Transport Networks



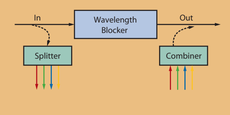
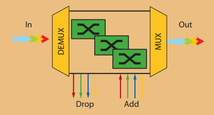
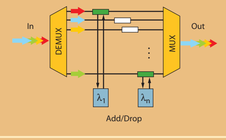
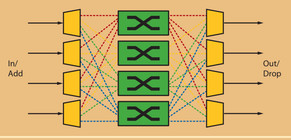
Span Loss and Dispersion Management of a Link



Chromatic dispersion management is used to reduce FWM crosstalk in high speed long distance networks. Optical amplifiers with integrated dispersion compensators (OAM) are distributed along the link to recover the optical power and to overcome the positive dispersion of the fiber. Each amplifier will reduce the optical signal to noise ratio (OSNR) due to the ASE noise (amplified spontaneous emission noise).

$$OSNR = \frac{\text{Optical signal power}}{\text{Optical noise power}}$$

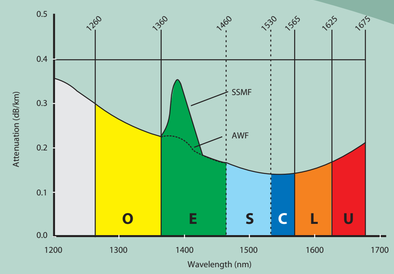
ROADM Types

	Wavelength Blocker (WB)	Small Switch Array (PLC)	Wavelength Selective Switch (WSS)	Wavelength Cross Connect (WXC)
Block Diagram				
Ports	2 DWDM ports (1 In, 1 Out)	2 DWDM ports + N single λ ports (1 In + 1 Out + N Add + N Drop)	N+1 DWDM ports (1 In + 1 Out + N-1 Add/Drop)	2N DWDM ports (N-1 In + N-1 Out + 1 Add + 1 Drop)
Network Function	Dynamic channel equalizer + wavelength blocking	Not colorless Dynamic Thru & Add channel balancing	Colorless → switches λs from In to Out/Drop and Add to Out	Colorless → switches λs from In or Add to Out or Drop
Application	Long-haul, ultra long-haul Point to point → 2 degree ROADM	Metro/Edge Lowest cost → 2 degree ROADM	Metro/Edge Ring structure → ≥2 degree ROADM	Ring interconnection Mesh cross connect → ≥3 degree ROADM

Glossary

ASE	Amplified Spontaneous Emission of an optical amplifier
CD	Chromatic Dispersion
CWDM	Coarse Wavelength Division Multiplexing
DCF	Dispersion Compensation Fiber
DCM	Dispersion Compensation Module
Demux	Optical Demultiplexer
DFB	Distributed Feedback laser
DGD	Differential Group Delay
DWDM	Dense Wavelength Division Multiplexing
EDFA	Erbium Doped Fiber Amplifier
FBG	Fiber Bragg Grating
FWM	Four Wave Mixing
MUX	Optical Multiplexer
OAM	Optical Amplifier Module (incl. dispersion compensation)
OSNR	Optical Signal to Noise Ratio
PLC	Planar Lightwave Circuit
PMD	Polarization Mode Dispersion
ROADM	Reconfigurable Optical Add Drop Multiplexer
WB	Wavelength Blocker
WSS	Wavelength Selective Switch
WXC	Wavelength Cross Connect
XT	Crosstalk

Optical Bands



SSMF Standard single mode fiber AWF All wave fiber

O Original band C Conventional band
E Extended band L Long band
S Short band U Ultra long band

CWDM ITU-T G.694.2: $\lambda_n = 1271 \text{ nm} + n$, max. 18 channels

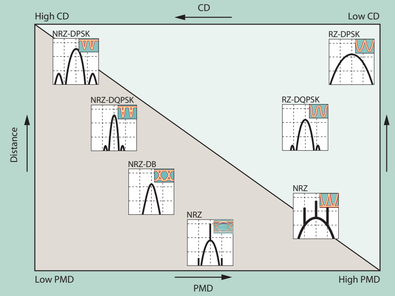
DWDM ITU-T G.694.1: $f_n = f_r \pm n$, $f_r = 193.10 \text{ THz} = 1552.12 \text{ nm}$

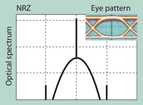
C-band 196.0 - 191.5 THz (1529.54 - 1565.48 nm)
L-band 191.5 - 184.5 THz (1565.48 - 1624.88 nm)

Maximum Number of Channels					
Channel spacing [GHz]	200	100	50	25	12.5
C-band	22	45	90	180	360
L-band	35	70	140	280	560

Maximum Number of Channels (at 1550 nm)	$\delta\upsilon = \{c/\lambda^2\}\,\Delta\lambda$				
GHz	200	100	50	25	12.5
nm	1.6	0.8	0.4	0.2	0.1

40G Modulation Techniques





New modulation techniques are used in high speed 40G networks to shift dispersion limitations.

NRZ formats are used to overcome large CD.

RZ formats are used to handle high PMD.

A modulation of the phase is used to increase transmission distance affecting complexity and cost of the system.

The modulation techniques have direct impact on the optical spectrum and the eye pattern.

NRZ Non Return to Zero
RZ Return to Zero
DB Duo Binary
DPSK Differential Phase Shift Keying
DQPSK Differential Quadrature Phase Shift Keying