Non-linear effects in PON fibre channel

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Task -2- Participants

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Introduction

- higher splitting ratios (1x64 and 1x128)
  - problem: higher splitter losses
  - higher launched power to achieve the same performance
- **target:** assess the system degradation caused by nonlinearities
  - assess the maximum allowed launched power with minimized non-linear effects

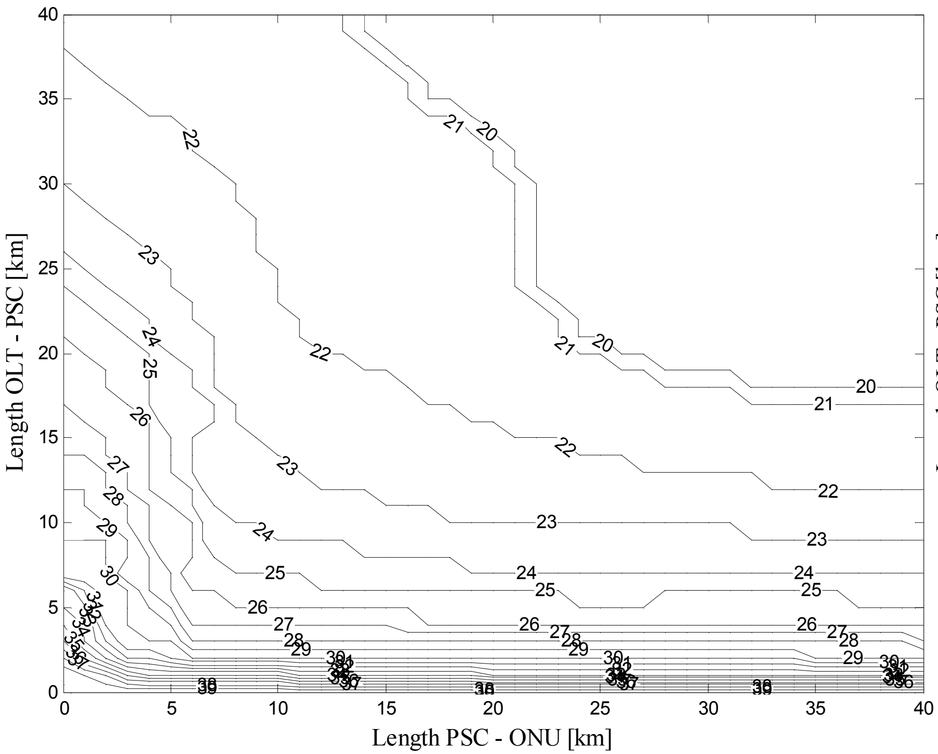
	Simulation analysis	**Analytical estimation**
Linear effects	Attenuation	
	Fiber dispersion	
Nonlinear effects	Self-Phase Modulation (SPM)	Stimulated Brillouin Scattering (SBS)
		Stimulated Raman Scattering (SRC)

Simulation assumptions

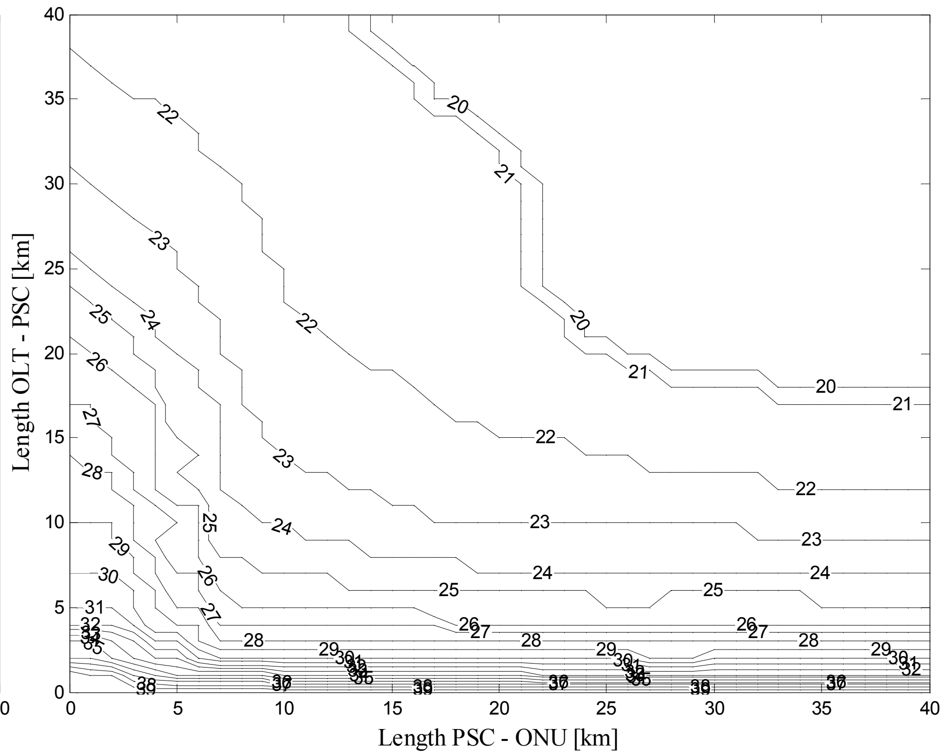
- λ = 1550 nm (downstream channel)
- external modulation in the OLT TX
- NRZ modulation format
- α = 0.22 dB/km
- $L_{OLT\text{-}PSC}$ = 0 – 40 km
  - (0 – 20 km for PX10/20 systems + extended reach for comparison)
- $L_{PSC\text{-}ONU}$ = 0 – 40 km
  - (0 – 20 km for PX10/20 systems + extended reach for comparison)
- single PSC module with 64 / 128 ports (depending on scenario)
- fibre channel transmission effects
  - attenuation
  - dispersion
  - Self-Phase Modulation (SPM)

Simulation results (128 ONUs)

Maximum launched power [dBm] to guarantee
a normalized eye open penalty not exceeding 1 dB



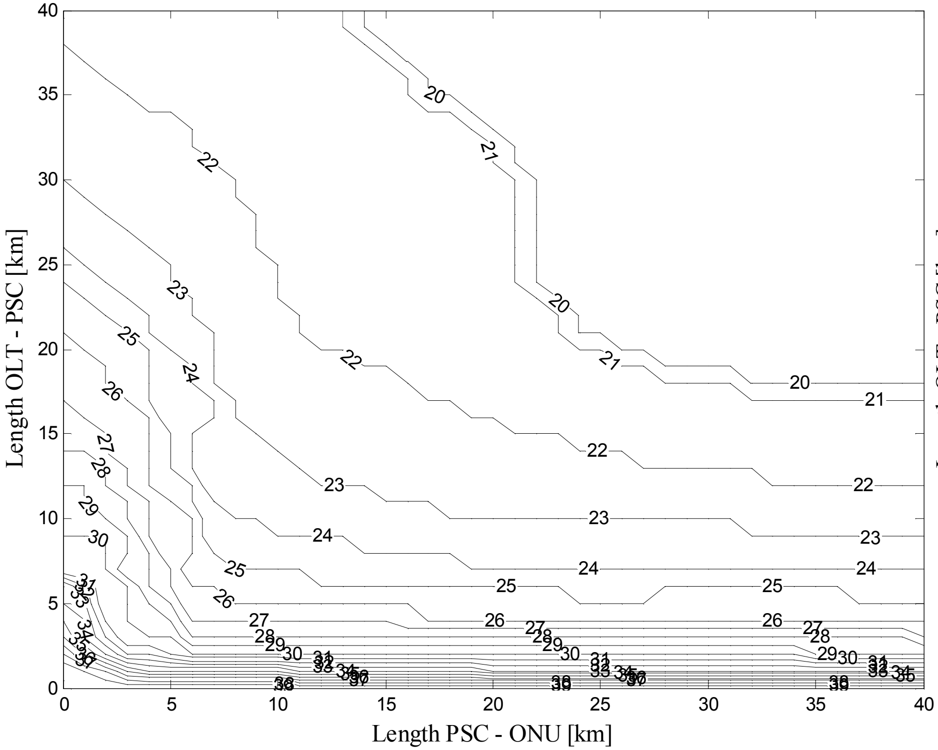
Nonlinear fibre between PSC and ONUs



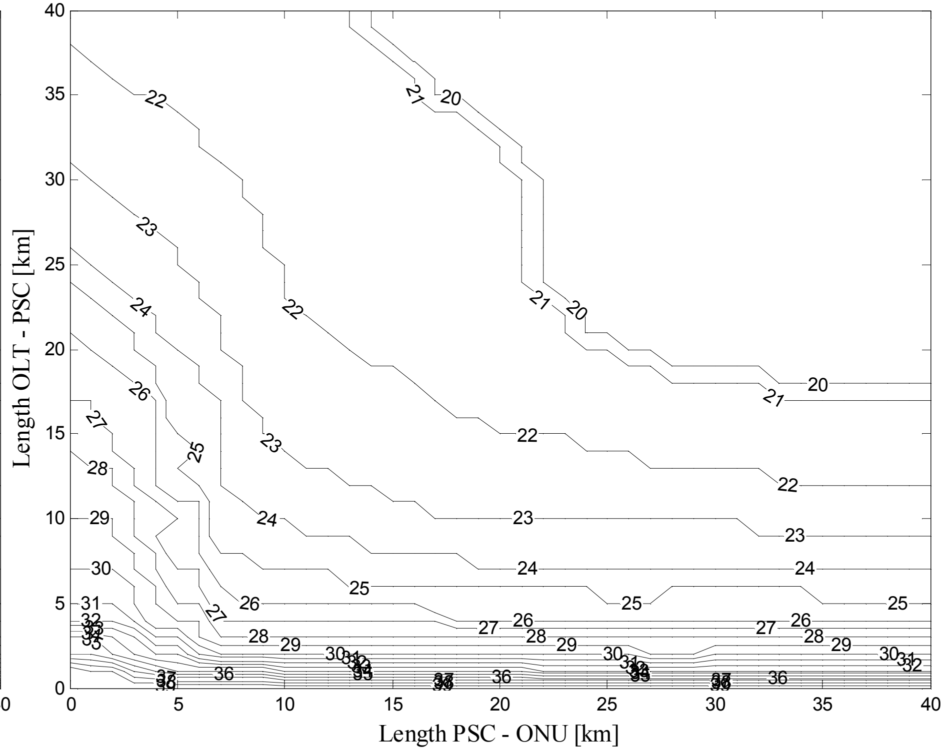
Linear fibre between PSC and ONUs

Simulation results (64 ONUs)

Maximum launched power [dBm] to guarantee
a normalized eye open penalty not exceeding 1 dB



Nonlinear fibre between PSC and ONUs

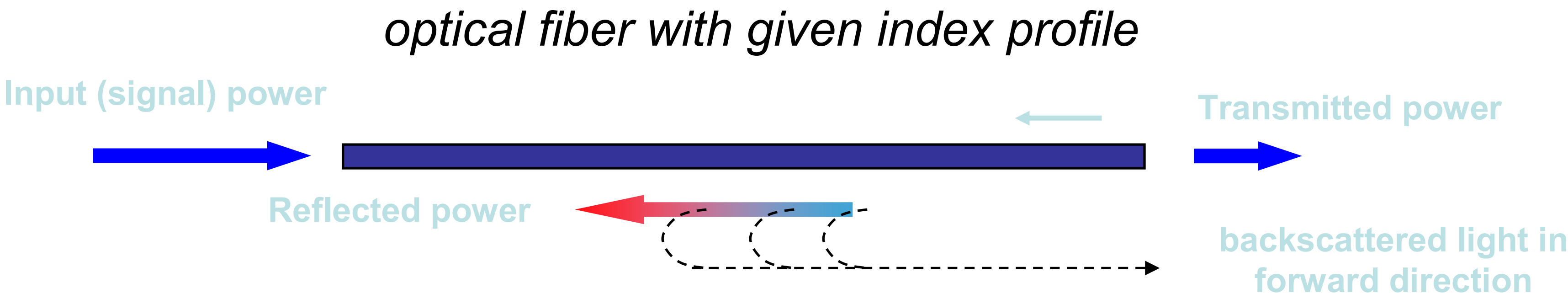


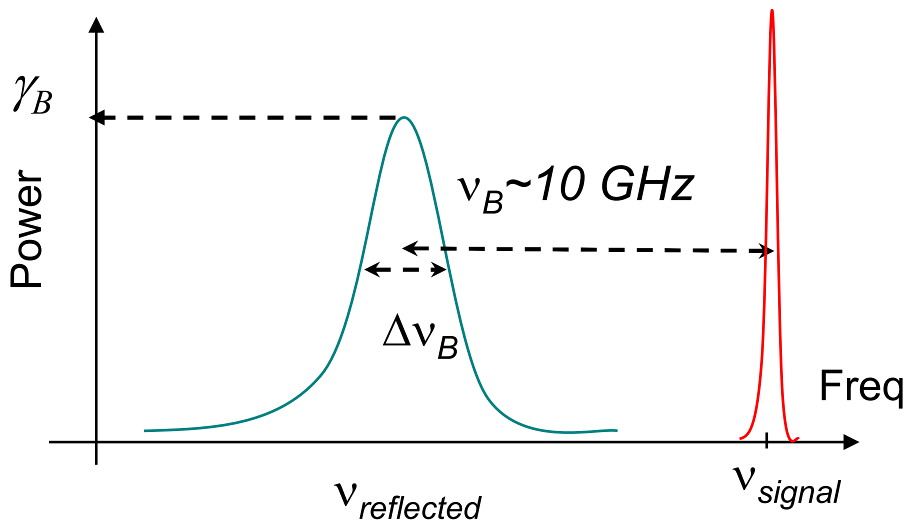
Linear fibre between PSC and ONUs

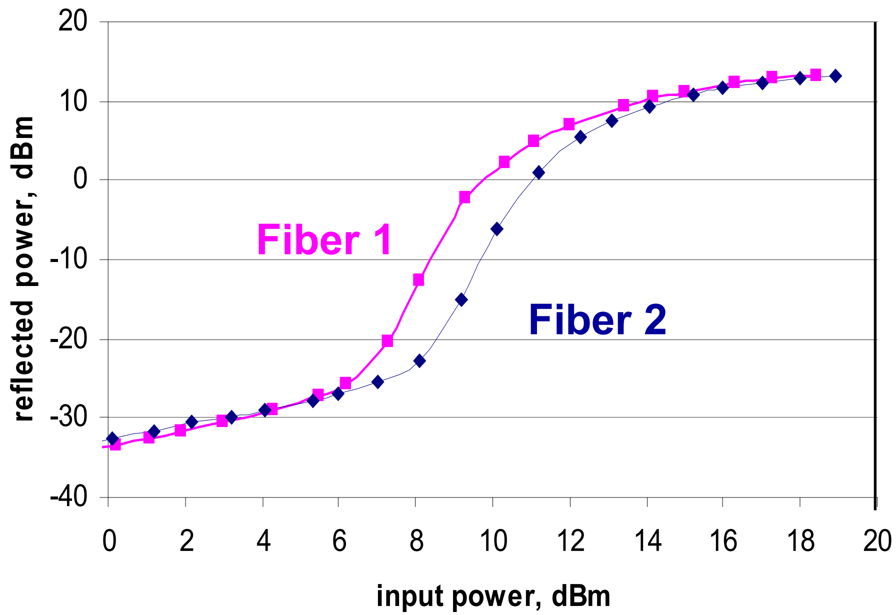
Simulation results - conclusions

- SPM does not limit the 10G transmission @ 1550nm
  - no significant degradation in the systems performance
  - very high launched powers are admissible without penalties
- linear transmission in the drop sections (PSC <-> ONUs)
  - signal power level is already quite low
  - nonlinear effects may be neglected
  - drop section contribute to penalty through additional dispersion

Experimental Observation of SBS (Reminder)







SBS analytical estimations – assumptions

$$P_{SBS}^{CW} \approx 21 \frac{A^{ao} k_{SBS}}{g_B L_{eff}} \left(\frac{\Delta\nu_{SBS} + \Delta\nu_P}{\Delta\nu_{SBS}} \right)$$

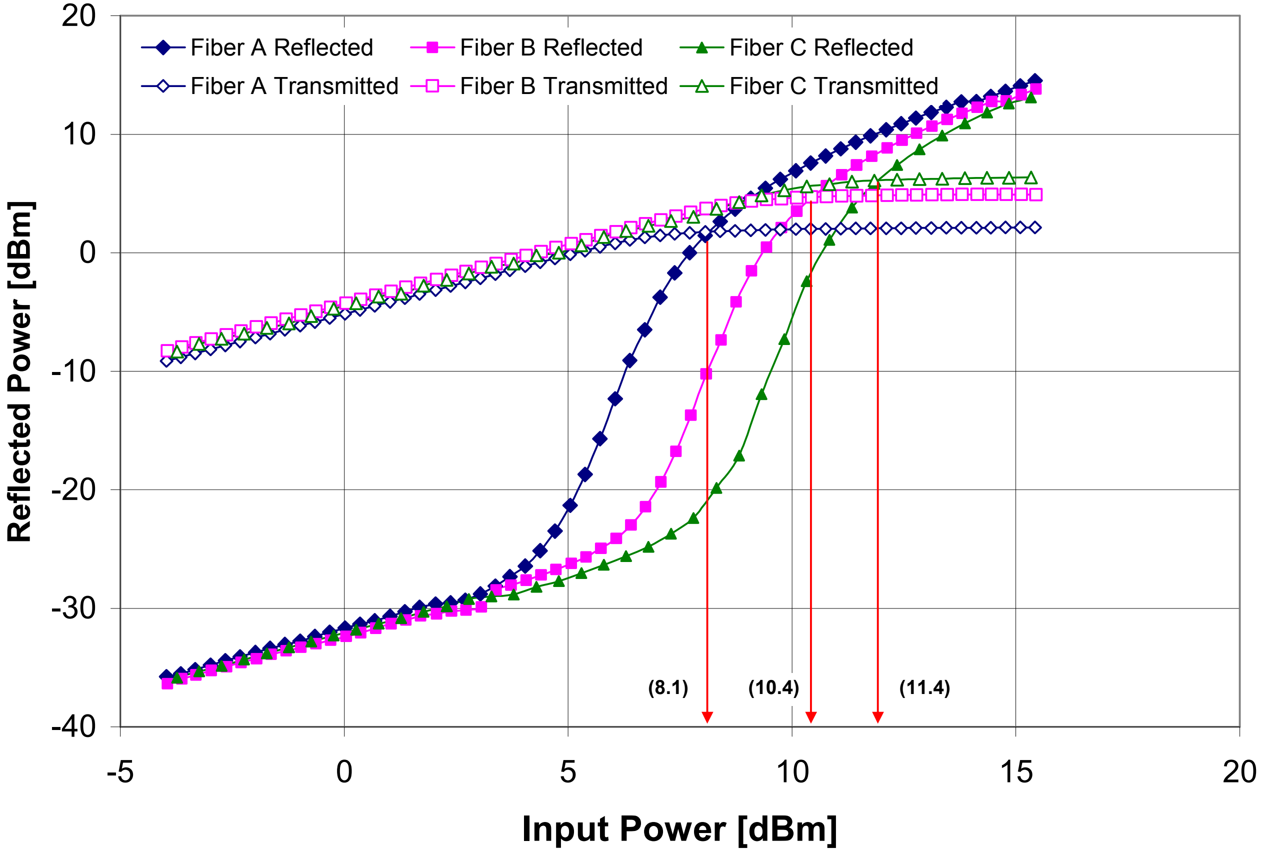
$$L_{eff} = \frac{1 - exp(-\alpha L)}{\alpha}$$

$$A^{ao} = 2\pi \left[\frac{\int_0^\infty f^2(r) r dr}{\int_0^\infty \xi(r) f^2(r) r dr} \right]^2 \int_0^\infty \xi^2(r) r dr$$

- Stimulated Brillouin Scattering (SBS) calculations from first principles are difficult due to complex nature of interaction of light wave with acoustic waves expressed by A^{ao} but scaling with length and source linewidth is straightforward
- Assumptions:
  - α = 0.22 dB/km with complete polarization scrambling (k_{SBS} = 3/2)
  - Brillouin bandwidth ($\Delta\nu_{SBS}$) = 50 MHz and light source CW linewidth ($\Delta\nu_P$) = 50 MHz

	Worst case SBS (PSC near ONUs)	**Best case SBS** (PSC near OLT)
Feeder length	20 km	0.5 km
Effective length	12.6 km	0.49 km

SBS threshold definition (ITU-T 650.2)



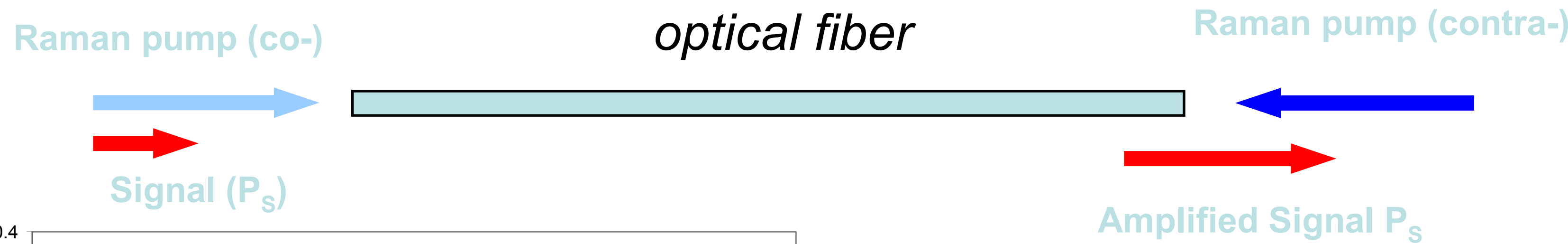
- Fiber A – G.652 compliant fiber with Aeff=85 μm^2
- Fiber B – G.655 compliant fiber with Aeff=72 μm^2
- Fiber C – G.652 compliant fiber with Aeff=88 μm^2 (with enhanced SBS threshold)

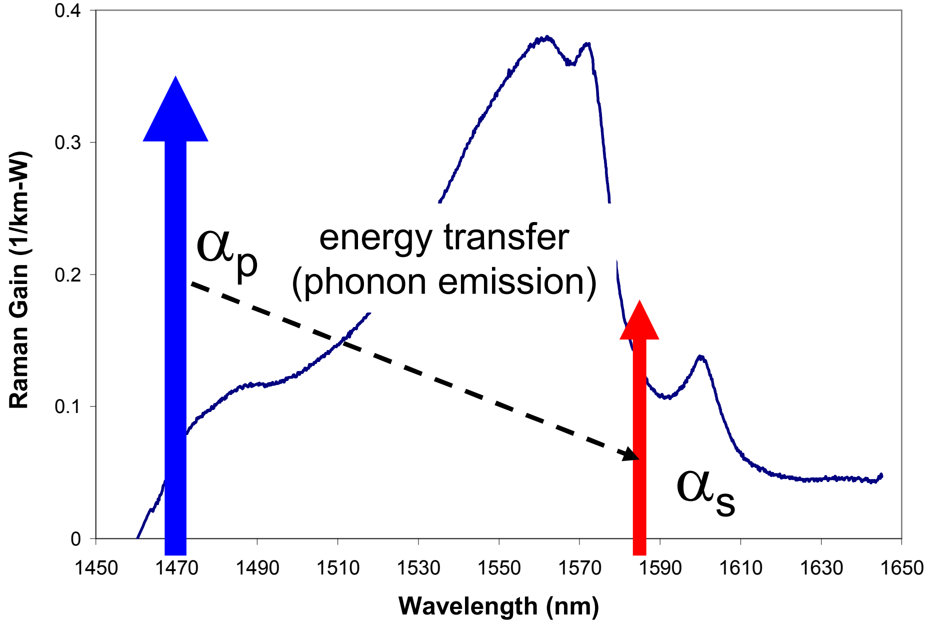
SBS threshold for G.652 fibers – results

	SBS (CW)		SBS (10 Gbit/s NRZ)		SRS
	Worst case	Best case	Worst case	Best case	
Threshold power	8.1 dBm	22.2 dBm	11.1 dBm	25.2 dBm	slides 11-13

- worst case scenario – long feeder section, PSC near ONUs
- best case scenario – short feeder section, PSC near OLT
- SBS is the fundamental limitation
- SBS threshold enhanced G.652 fibers improve SBS threshold by >3 dB
- minimizing SBS related impairments with active equipment
  - increase the source linewidth
    - directly modulated source → high dispersion penalties @ 1550nm !!
  - frequency dithering to the laser source
    - directly modulating the laser with a sinusoid at a frequency significantly lower than the low-frequency cutoff of the receiver
    - the dither frequency is outside the receiver bandwidth, so it will not degrade the signal in the presence of dispersion up to a certain limit

Stimulated Raman Scattering (SRS) – Reminder





$$\frac{dP_s}{dz} = C_R P_s P_p - \alpha_s P_s$$

$$\frac{dP_p}{dz} = -\frac{\lambda_s}{\lambda_p} C_R P_s P_p - \alpha_p P_p$$

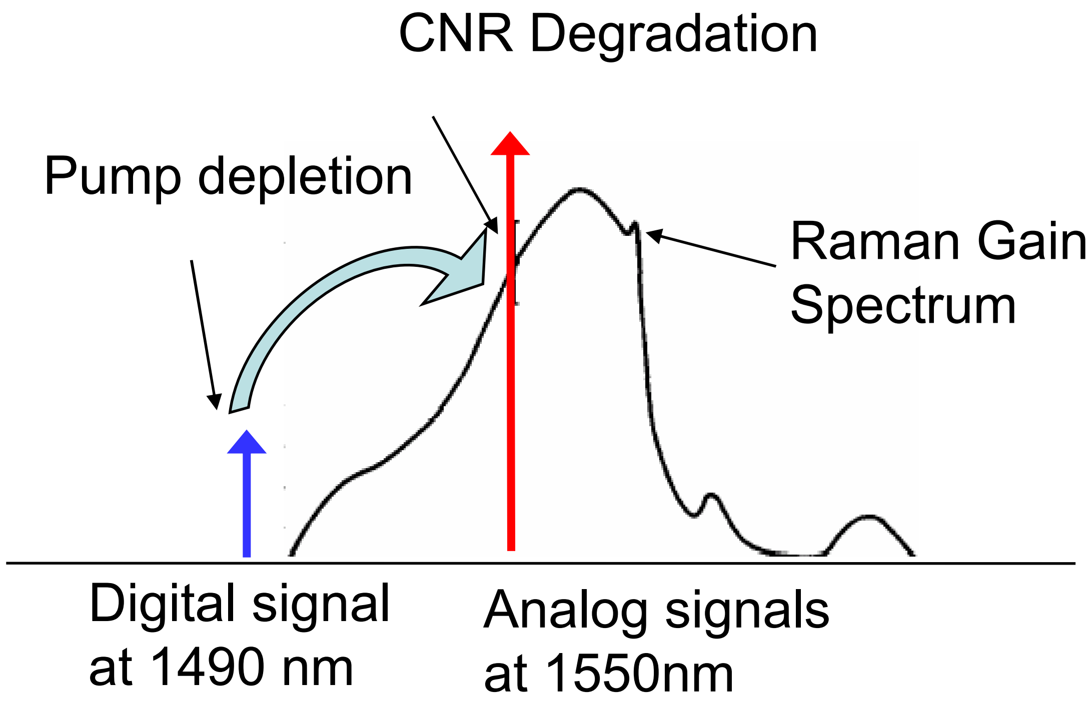
$$G_R = \exp\left[\frac{g_R}{A_{eff,Raman}} \frac{P_p(0)}{\alpha_p}\left(1 - e^{-\alpha_p z}\right)\right]$$

- SRS typically starts at higher power than SBS
- For a single wavelength energy transfer from signal to Stocks component is unlikely because SBS will occur first and limit the signal power.

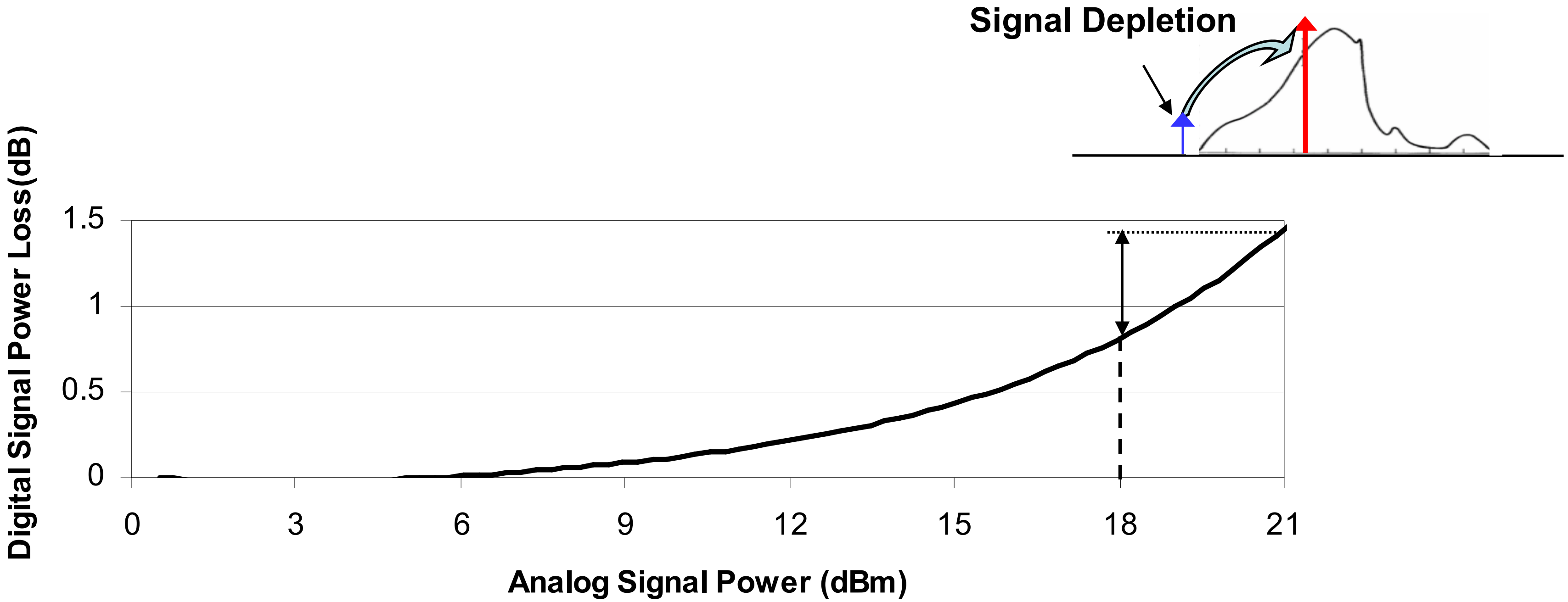
Raman Interaction of two signal waves

RF overlay is deployed

- Low power digital signal acts as Raman pump for high power analog signal
- Raman interaction causes two penalties
  - Power depletion of digital signal
  - CNR degradation of analog signal



Digital Signal Depletion



- Digital signal suffers from loss of power as the analog signal power is increased
- Effect occurs at current launched analog power levels (~18 dBm) and gets worse at higher power levels
- Overcome by launching higher power digital signal