Raman-Induced Power Penalty in PONs using 0-order approximation

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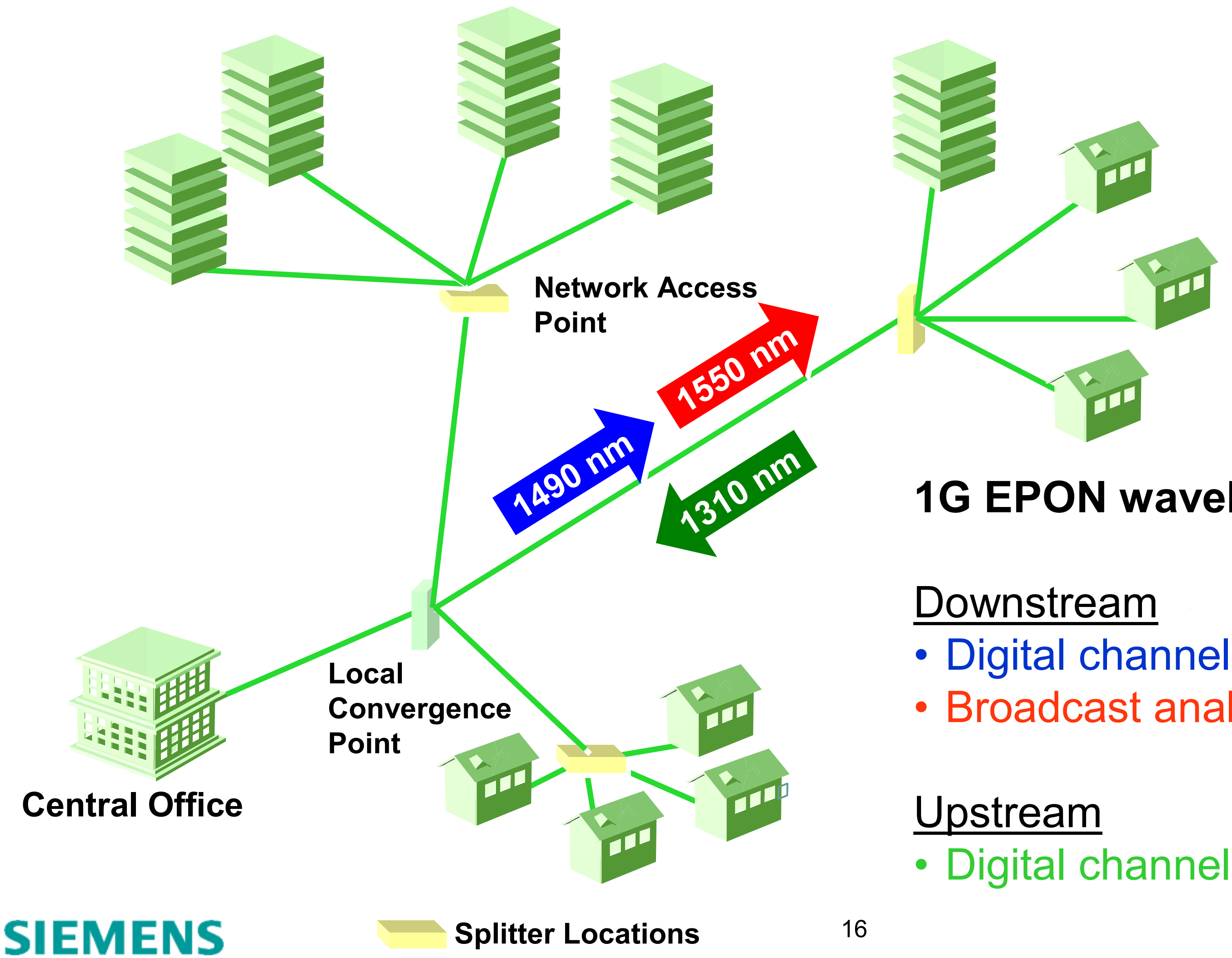
Passive Optical Network (PON) Architecture (IEEE 802.3-2005 1G EPON only)



1G EPON wavelength allocation

Downstream
- Digital channel at 1490 nm
- Broadcast analog video at 1550 nm

Upstream
- Digital channel at 1310 nm

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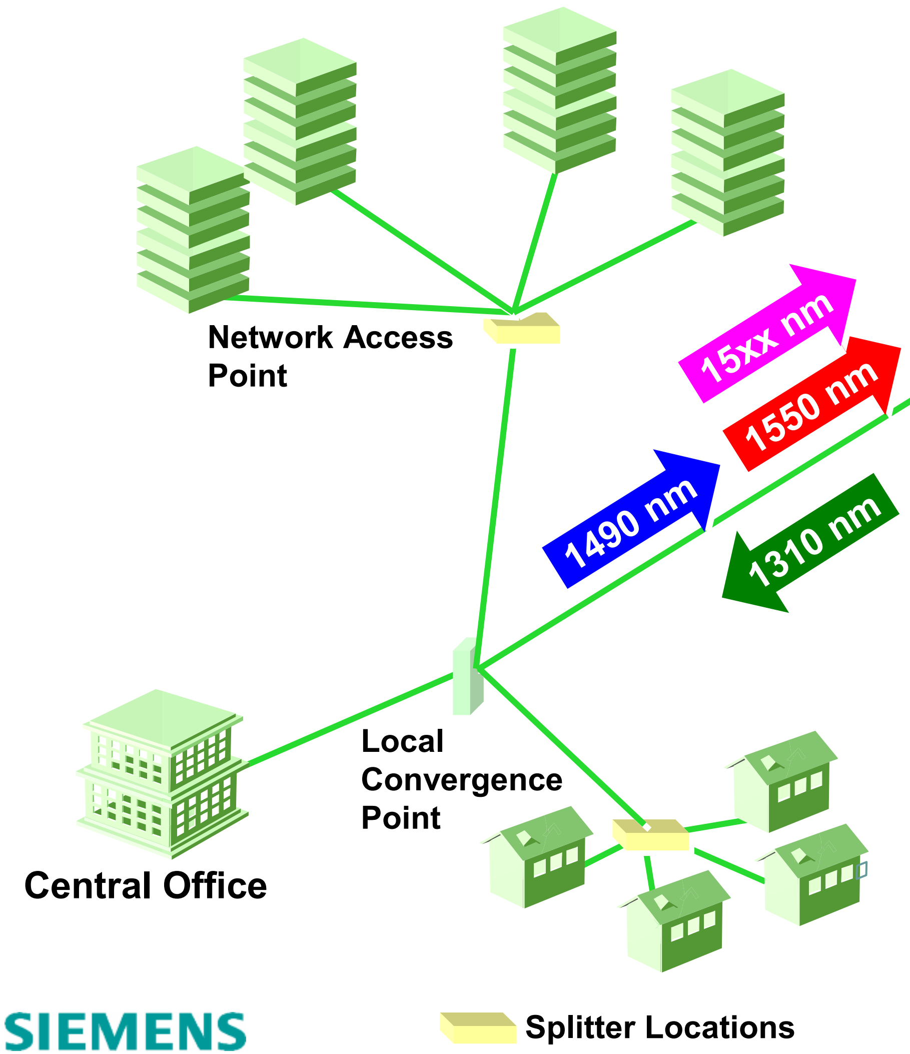
Passive Optical Network (PON) Architecture (1G and 10G EPON on the same ODN)



1G/10G EPON wavelength allocation

Downstream

- Digital channel at 1490 nm (1G signal)
- Digital channel at 15xx nm (10G signal)
- Broadcast analog video at 1550 nm
- Upstream
- Digital channel at 1310 nm (most likely TDM shared)

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Raman-induced power penalty

- In a 1G EPON (IEEE 802.3-2005) the downstream digital traffic is carried in 1490 nm window, while the CATV analog signal is broadcast in 1550 nm window
- These signals lie within the Stokes shift of silica and therefore experience Raman interaction
- The latter causes depletion of the digital signal which acts as a pump for the analog signal

Pump depletion: theoretical model

- Coupled equations describe pump-signal interaction due to Raman effect

signal, 1550 nm

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

undepleted signal approximation

'pump', 1490 nm

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

Extra loss due to Raman effect

- Solution

$$P_p(z) = P_{p0} \exp\left[-\frac{\lambda_s}{\lambda_p} C_R \frac{P_s(0)}{\alpha_s} \left(1 - e^{-\alpha_s z}\right) - \alpha_p z \right]$$

Average power penalty

$$\Delta_{\mathrm{dB}} = \kappa C_R(\Delta\lambda) P_s L_{eff}$$

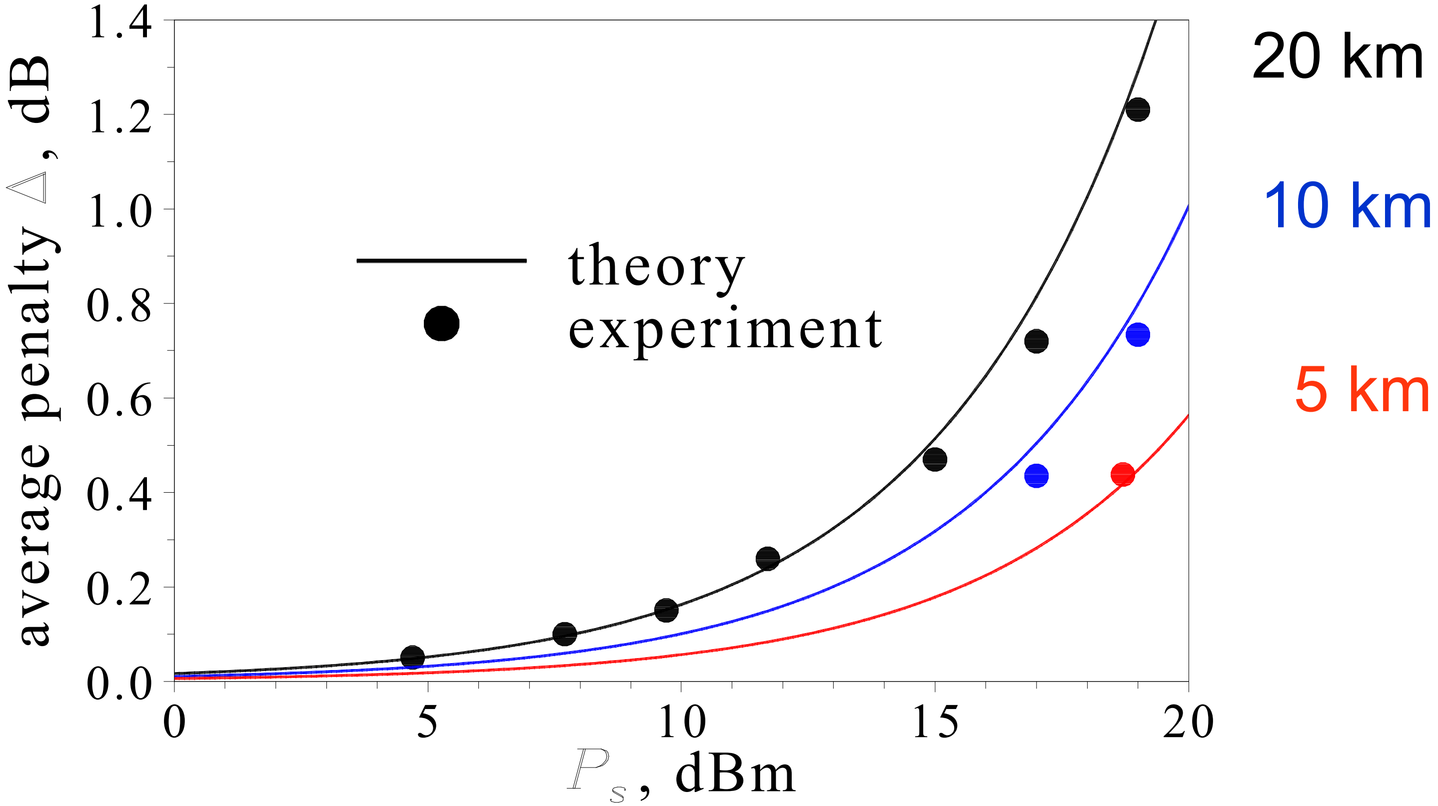
$$\kappa = (10 \log_{10} e)\lambda_s / \lambda_p$$

$$L_{eff} = (1 - e^{-\alpha_s L}) / \alpha_s$$

C_R polarization-averaged Raman gain coefficient (depends on the wavelength difference $\Delta\lambda$)

P_s signal power at 1550 nm

Average penalty for SSMF @ 1470 nm



- undepleted signal model gives good accuracy
- penalty does not depend on the pump power

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Comments

- The presented, 0-level approximation of the power penalty of the digital signal in 10G EPON accounts for polarization-dependent Raman gain
- Details can be found in **A. Kobyakov, M. Sauer, and A. Boskovic, ECOC'04, paper We4.P.086**
- Power penalty can be compensated for by increasing the launch power of the digital signal without extra penalties
- Exact impact of the polarization-dependent Raman gain on digital channel depletion depends on the downstream channel allocation for 10G EPON system

New Excel spreadsheet features [1]

- A new block of cells [AL1:AP13] including the following calculation steps:
  - launch power: parameter given in dBm [AP2] and recalculated into mW [AP3]
  - video overlay wavelength: parameter given in nm [AP4]
  - Frequency_delta: calculated as the frequency difference between the digital and analog transmission channel central wavelengths, expressed in THz [AP5]

$$Frequency\_delta = abs\left(\frac{c}{\lambda_s} - \frac{c}{\lambda_p}\right) \cdot 10^5$$

  - Kappa [AP6]: calculated using the following equation:

$$\kappa = (10 \log_{10} e)\lambda_s / \lambda_p$$

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New Excel spreadsheet features [2]

- attenuation [AP8] calculated in dBm using formula from cell [P5], treating 1550 nm as the target signal wavelength
- attentuation [AP9] recalculating the value from [AP8] into linear regime using the following formula

$$\alpha_s = \alpha_{dB} \cdot \ln(10)/10$$

- effective fiber length Leff [AP10], calculated using equation:

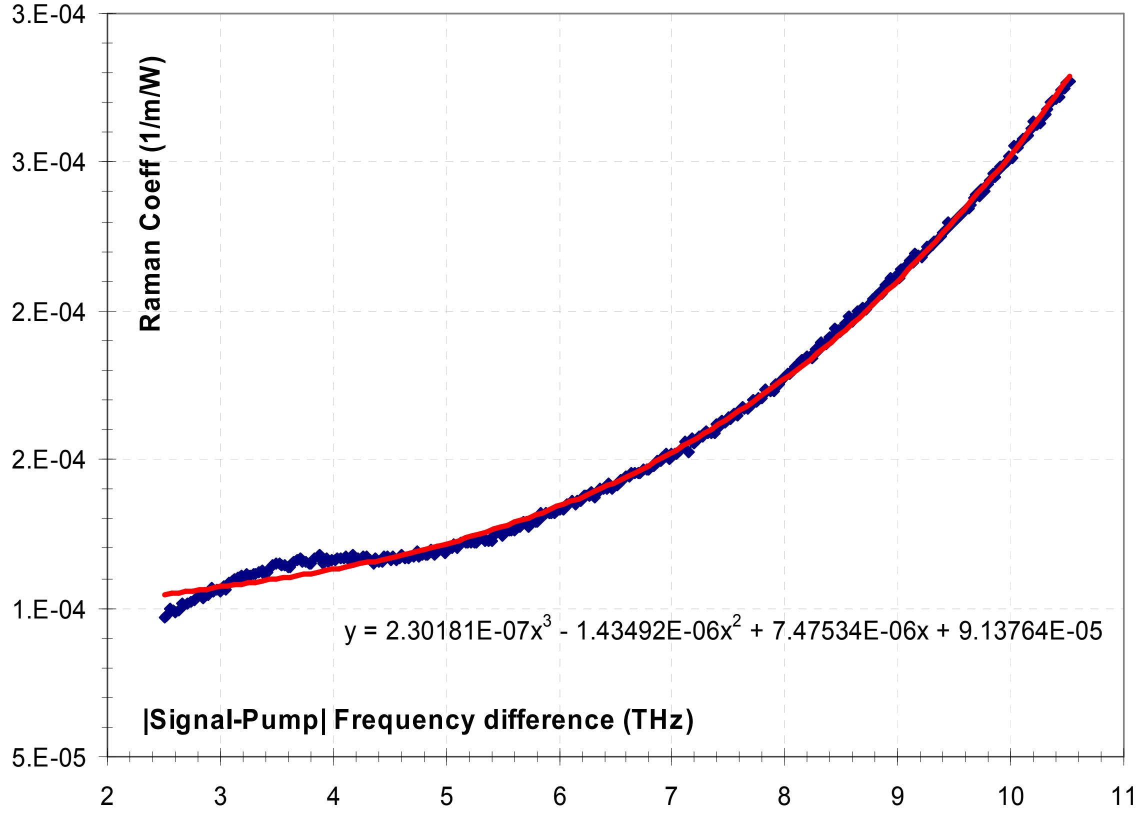
$$L_{eff} = \left(1 - e^{-\alpha_s \cdot L}\right)/\alpha_s$$

- Cr parameter [AP7], estimated based on the approximated polarization-averaged Raman gain coefficient (valid for pump signal in 1470 – 1530 nm window)

$$\mathrm{C_R} = 2.30181 \cdot 10^{-7} \cdot (\Delta\lambda)^3 - 1.43492 \cdot 10^{-6} \cdot (\Delta\lambda)^2 +$$

$$+ 7.47534 \cdot 10^{-6} \cdot (\Delta\lambda) + 9.13764 \cdot 10^{-5}$$

New Excel spreadsheet features [3]

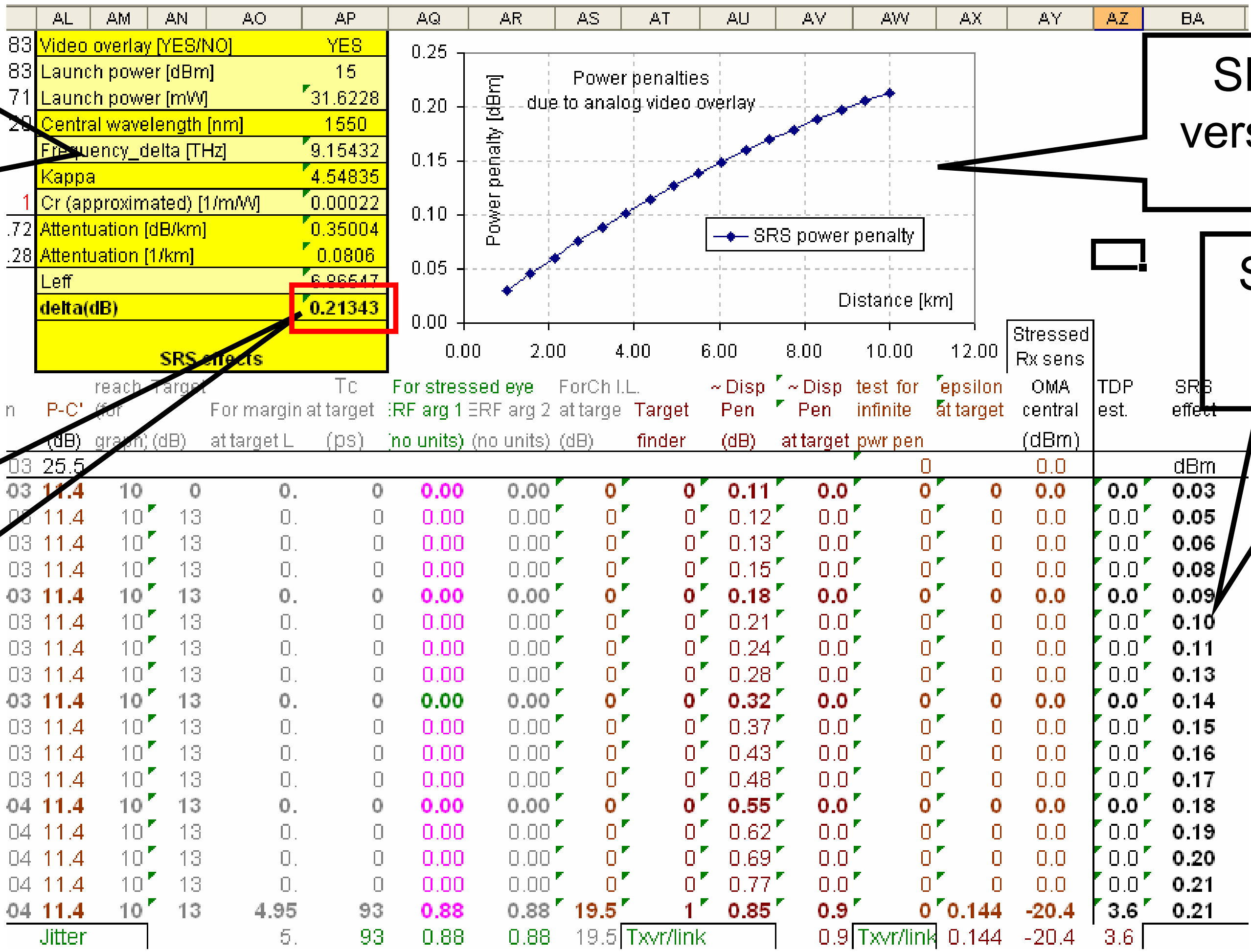


- 0-order approximation valid for 1470-1530 nm window
- replaces complex Cr parameter model with a 3rd polynominal
- depends only on the absolute value of the pump-signal frequency difference, thus is easy to estimate

New Excel spreadsheet features [4]

New cells estimating the SRS power penalty

Final value of SRS induced power penalty



SRS penalty versus distance (chart)

SRS penalty versus distance