北京郵電大學
BEIJING UNIVERSITY OF POSTS AND TELECOMMUNICATIONS

UCDAVIS
COMPUTER SCIENCE

Challenges of Raman Amplification in Ultra-Wideband System

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EDFA

EDFA uses the Erbium-doped fiber as optical amplification medium to directly enhance the signals. It enables instantaneous amplification for signals with C-band and L-band.

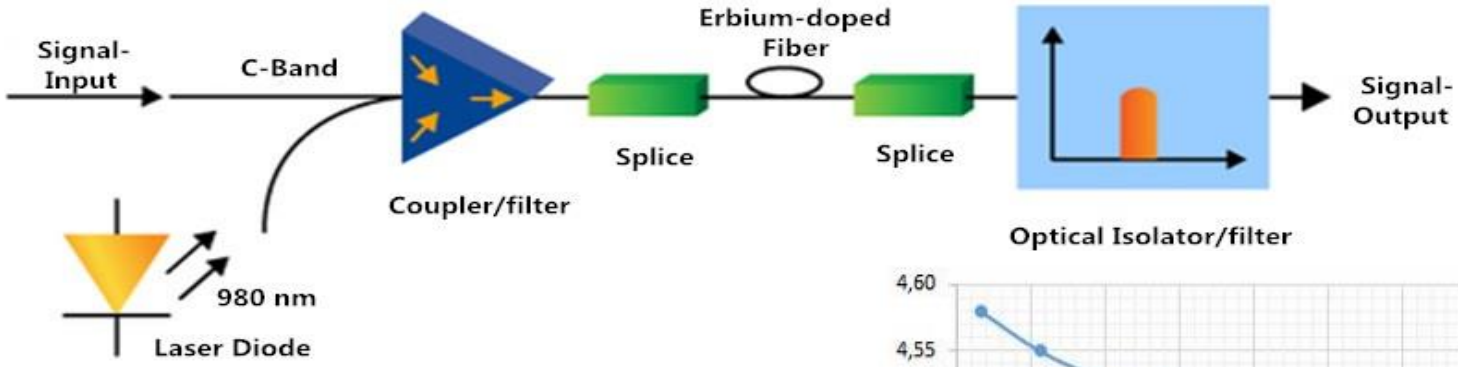

Fig. 1. EDFA configuration.

The main drawbacks of EDFA is that the noise is still relative high and the principal source of noise in EDFA is Amplified Spontaneous Emission (ASE).

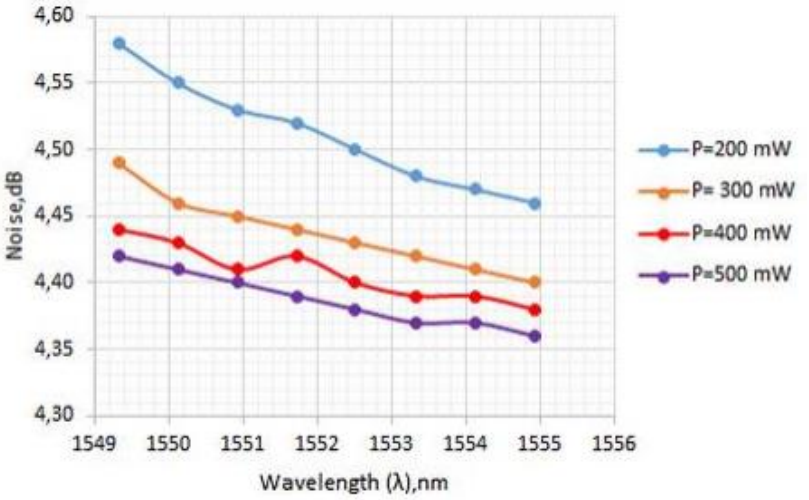

Fig. 2. EDFA noise figure depending on the pump power for 30m fiber.

Raman Gain

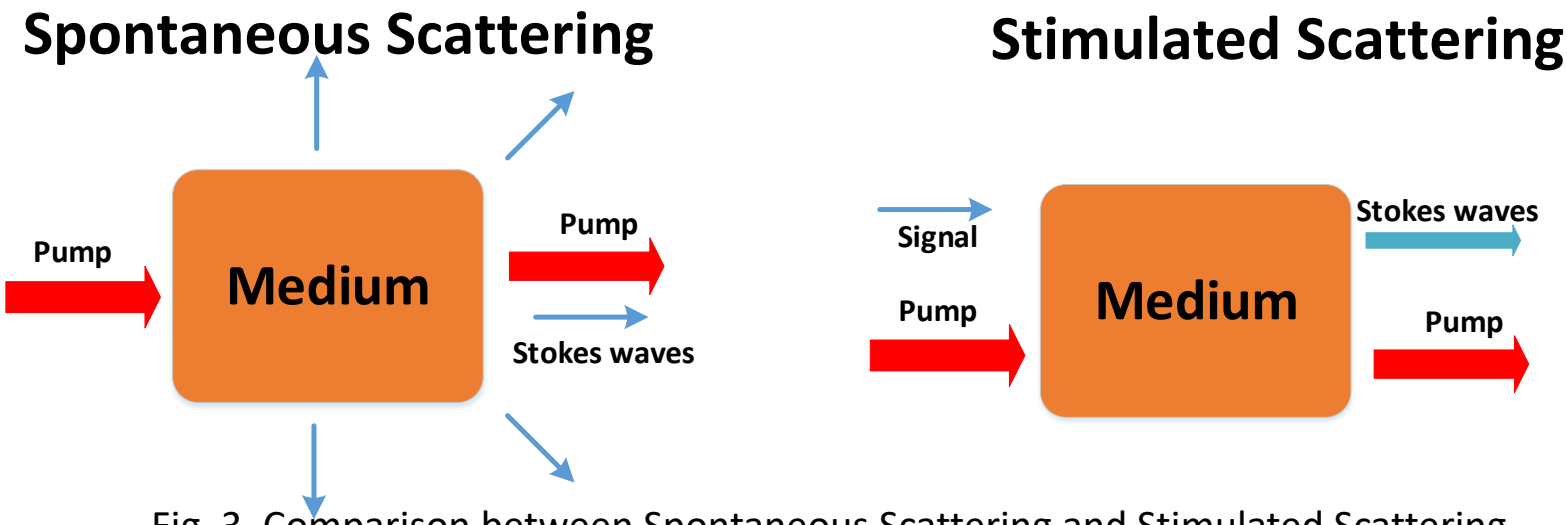

Fig. 3. Comparison between Spontaneous Scattering and Stimulated Scattering.

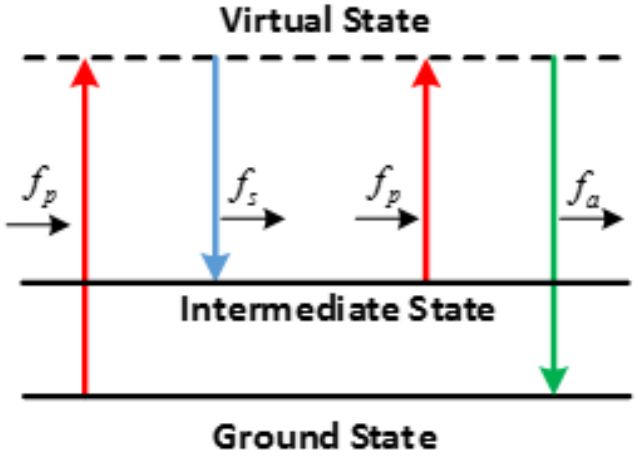

Fig. 4. Schematic of amplification by Spontaneous Raman Scattering.

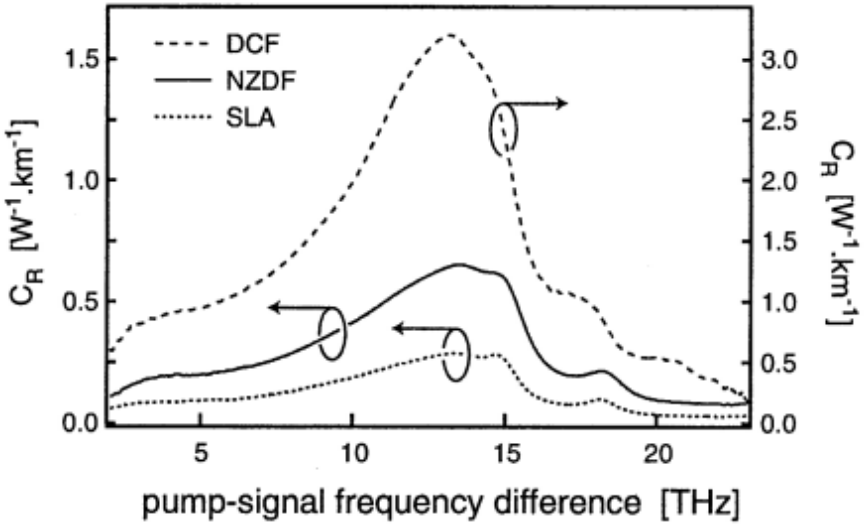

Fig. 5. Raman gain efficiency spectra.

Raman Amplifier vs. EDFA

- EDFA is discrete amplifier in which the gain is lumped at a point of the transmission line.
- Raman amplifier can be distributed amplifier, which retain the optical signal level over a long distance along the transmission line.

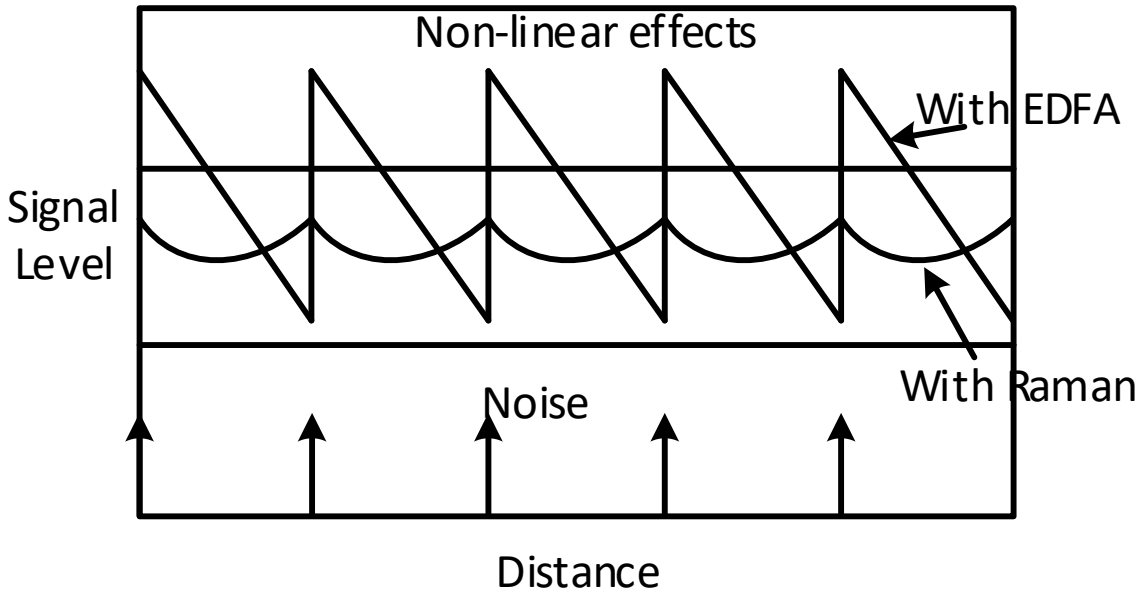

Fig. 6. Signal levels on a long haul link with EDFA and SRA.

Raman Amplifier vs. EDFA

Table 1. Differences between EDFA and Raman amplifiers

Property	EDFA	Raman Amplifier
Wavelength (nm)	1525-1565, 1570-1610	All Wavelength
Gain (dB)	>40	>25
Noise Figure (dB)	4	-2
Pump Power (dBm)	25	>30

Advantages:

- Generate very less noise
- Amplify beyond C band
- Use a common transmission fiber and does not require an additional gain medium

Drawbacks:

- Require higher pump
- Polarization dependent

Raman Amplifier

- Raman gain does not depend on the relative direction of propagation of a pump and signal.
- Raman scattering is a fast process (sub-picosecond).
- The total number of photons in the pump and Stokes beams remains constant during SRS.

$$\frac{I_s}{\omega_s} + \frac{I_p}{\omega_p} = constant$$

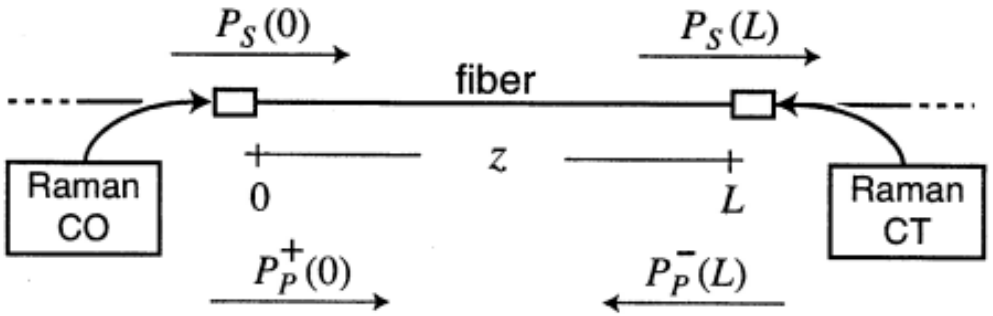

Fig. 7. Schematic of a simple Raman fiber amplifier, that is co-pumped and counter-pumped.

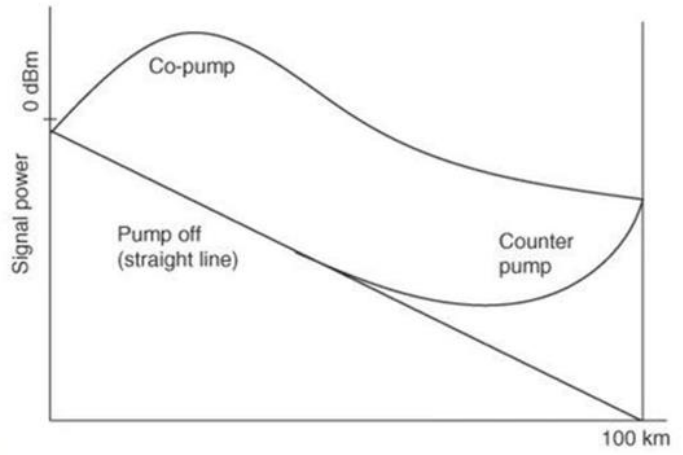

Fig. 8. Raman signal gain curve for co-pump and counter-pump configuration.

https://www.cisco.com/c/en/us/support/docs/optical-networking/ons-15454-m6-multiservice-transport-platform-mstp/212834-practical-aspects-of-raman-amplifier.html

Raman Amplifier

Two kinds of Raman amplifiers are available on the market.

- Discrete Raman amplifier
  - Gain in a box (high nonlinear fiber)
  - Its gain fiber is relatively short, generally within 10 km.
- Distributed Raman amplifier
  - Gain with transmission fiber
  - Its gain fiber is much longer, generally dozens of kilometers.

On-off Raman gain is used to define the increase in signal power at the amplifier output when the pumps are turned on.

$$G_{on-off} = \frac{P_s(L) \text{ with pumps on}}{P_s(L) \text{ with pumps off}} = \exp\left(C_R L_{eff}\left[P_p^+(0) + P_p^-(L)\right]\right)$$

Here, L_{eff} is an effective length, within which most of the Raman gain occurs: $\left(1 - \exp\left(-\alpha_p L\right)\right)/\alpha_p$

Challenges of Raman Amplifier

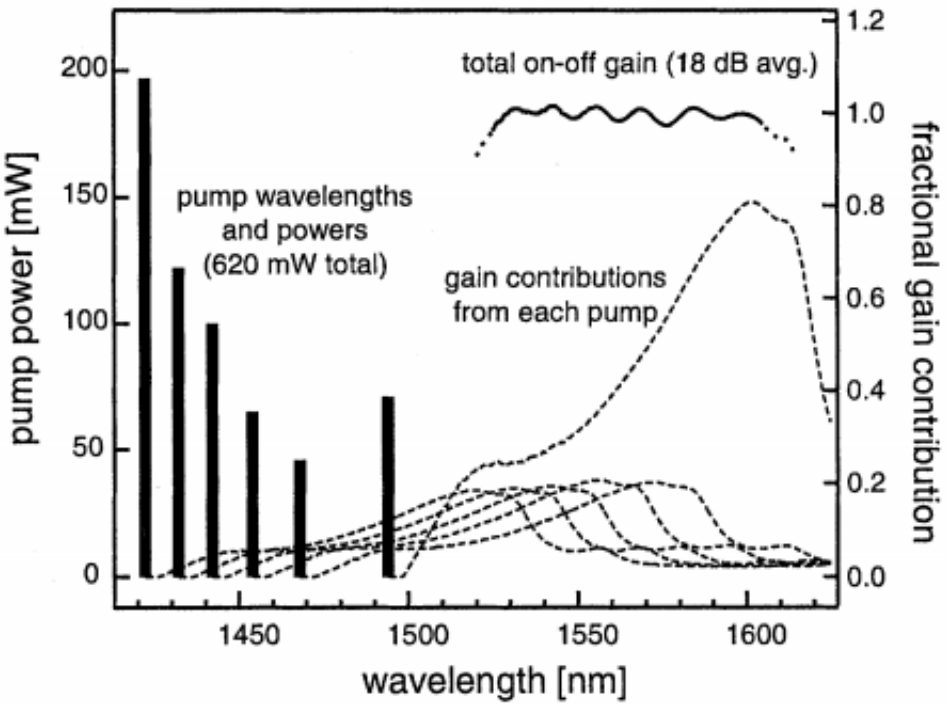

Fig. 9. Numerical example of broad-band Raman gain obtained using a broad pump spectrum to pump a NZDF.

Bars show the counter pump wavelengths and input powers. Solid line shows the total small-signal on-off gain. Dashed lines show the fractional gain contribution from each pump wavelength.

J. Bromage et al., "Raman Amplification for Fiber Communications Systems," *J. Lightw. Technol.* vol. 22, no. 1, pp. 79 - 93, Jan. 2004.

Challenges of Raman Amplifier

The same Raman gain is also detrimental to WDM systems. Since a short-wavelength channel can act as a pump for longer-wavelength channels and thus transfer part of the pulse energy to neighboring channels.

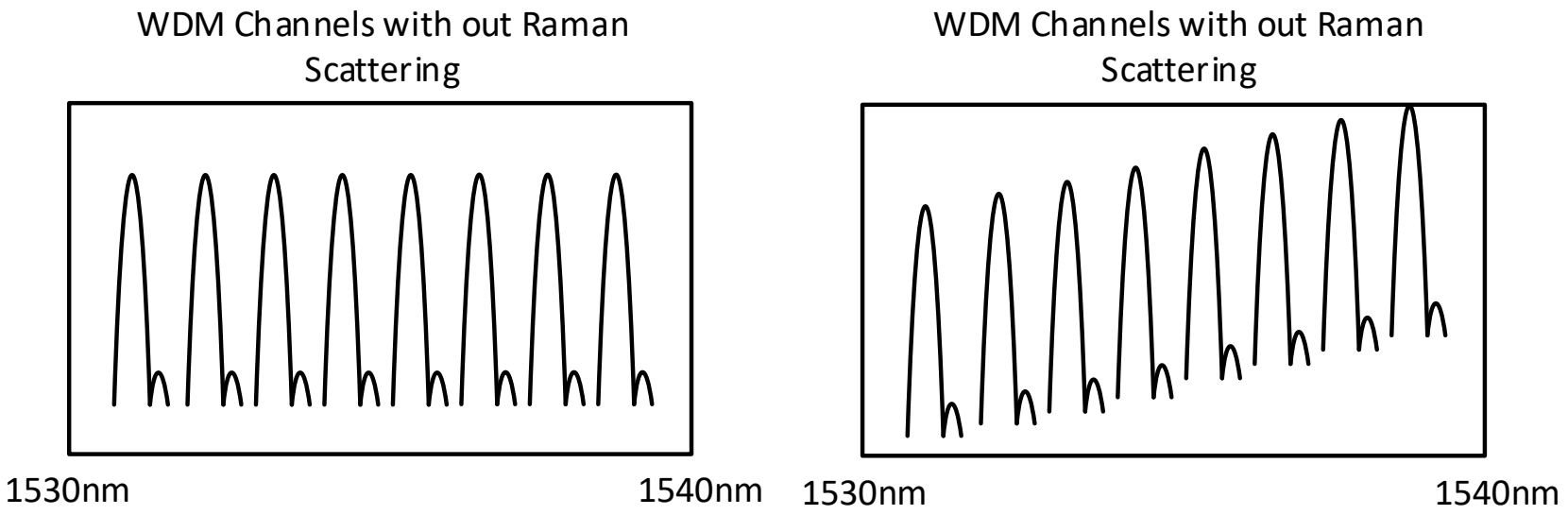

Fig. 10. Cross-talk in Stimulated Raman Amplifier.

Challenges of Raman Amplifier

Considering multi-band optical system, the placement of pumps becomes more complicated since the spectrum range increases, more inter-band Raman scattering induced.

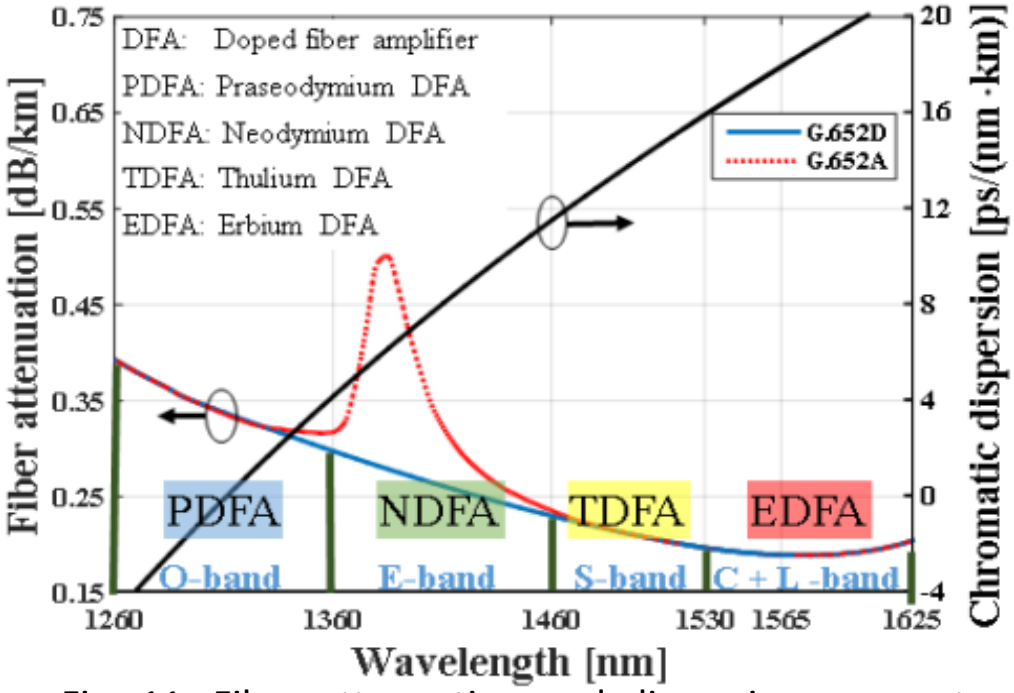

Fig. 11. Fiber attenuation and dispersion parameters over the multiband SMF spectrum.

A. Napoli et al., "Towards Multiband Optical Systems," in *Photonic Networks and Devices*, NeTu3E.1, July 2018.

Challenges of Raman Amplifier

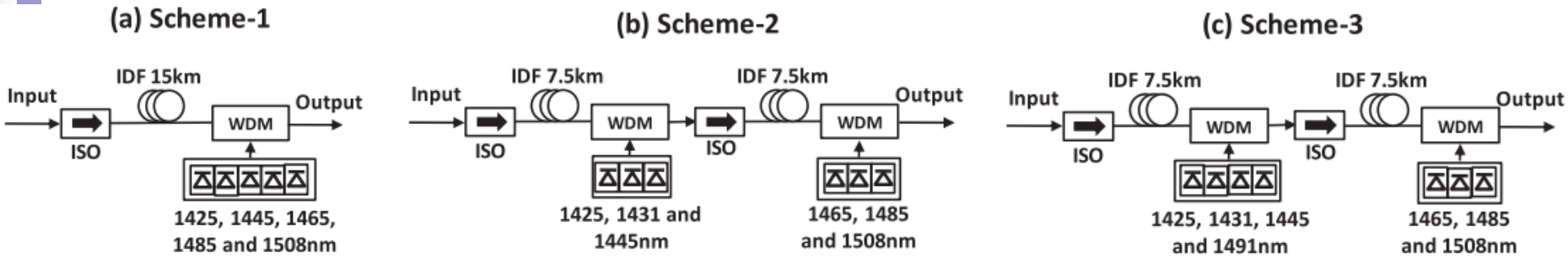

Fig. 12. Experimental setup of backward pumped discrete Raman amplifiers (DRA): (a) scheme-1: conventional single stage; (b) scheme-2: dual stage DRA with short (long) wavelength pumps in the first (second) stage; and (c) scheme-3: dual stage DRA with an additional 1491 nm pump in the first stage.

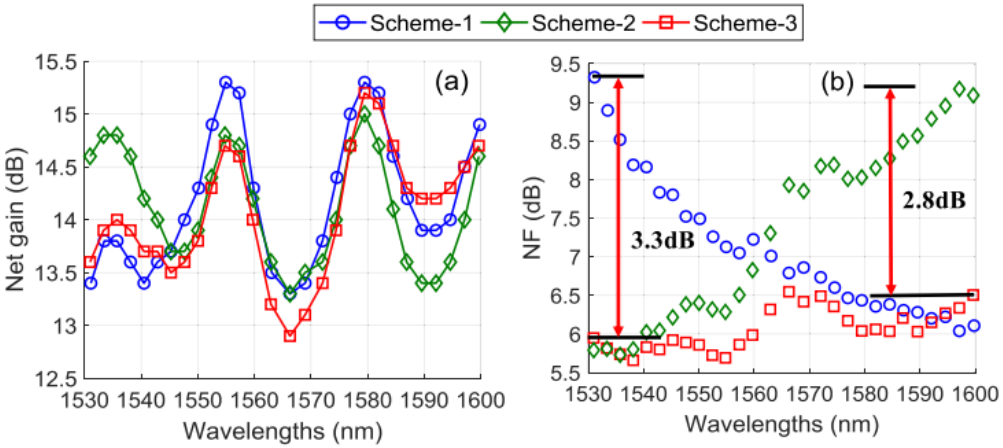

Fig. 13. Comparison of (a) net gain and (b) noise figure (NF) for single stage (scheme-1) and dual stage (scheme-2 and scheme-3) DRAs over 70 nm amplification bandwidth.

M. A. Iqbal et al., "Noise Performance Improvement of Broadband Discrete Raman Amplifiers Using Dual Stage Distributed Pumping Architecture," *J. Lightw. Technol.* vol. 37, no. 14, pp. 3665 - 3671, July 15 2019.

Challenges of Raman Amplifier

Counter pump distributed Raman amplifiers are often combined with EDFA to extend span distances. This hybrid configuration can smooth the gain spectrum and provide 6dB improvement in the OSNR.

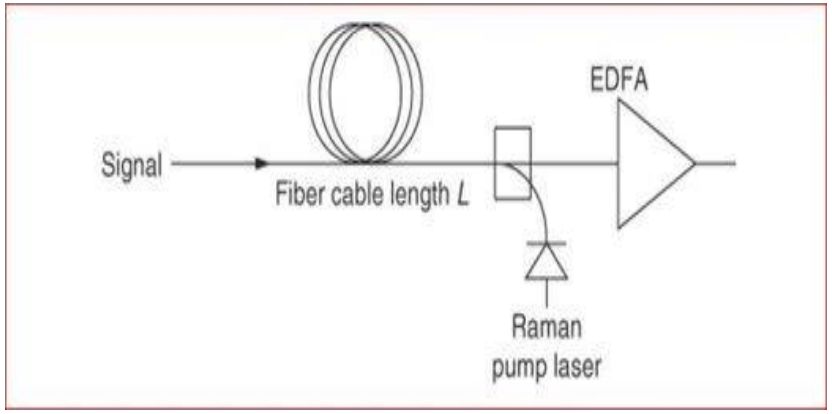

Fig. 14. Hybrid EDFA/Raman amplifier configuration.

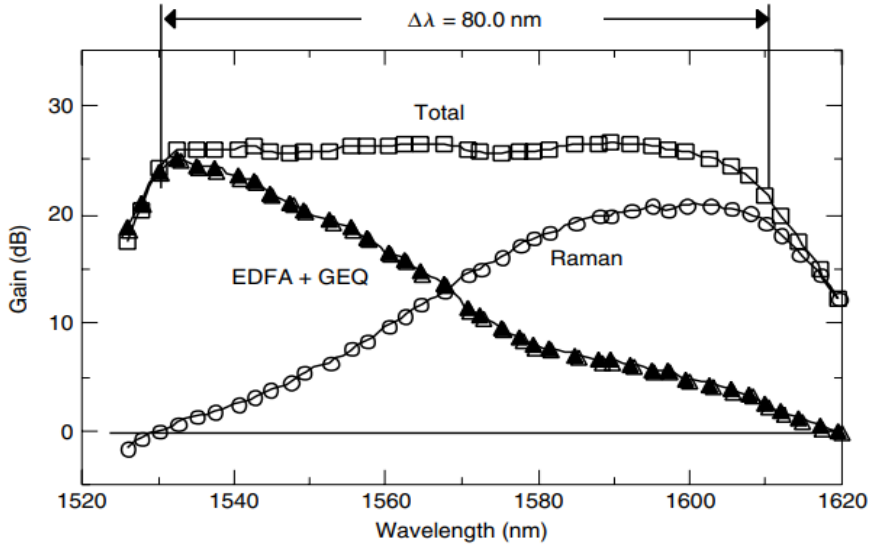

Fig. 15. Gain spectra of a wideband hybrid amplifier.

https://www.cisco.com/c/en/us/support/docs/optical-networking/ons-15454-m6-multiservice-transport-platform-mstp/212834-practical-aspects-of-raman-amplifier.html

Conclusions

- Origin of Raman scattering and the properties of Raman gain.
- Comparison between Raman amplifier and EDFA.
- Some properties of Raman amplifier.
- Challenges of Raman amplifier in broad-band and multi-band system, which can be backbone networks, submarine networks, and data center networks.

Thank you!

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