Enhanced anti-Stokes Raman gain in nonlinear waveguides

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Abstract

We show that, under certain conditions, modulation instability in nonlinear waveguides gives rise to the usual double-sideband spectral structure, but with a Raman gain profile. This process is enabled by the energy transfer from a strong laser pump to both Stokes and anti-Stokes sidebands in a pseudo-parametric fashion. We believe this striking behavior to be of particular value in the area of Raman-based sensors which rely on sensitive measurements of the anti-Stokes component.

Pulse propagation in optical fibers

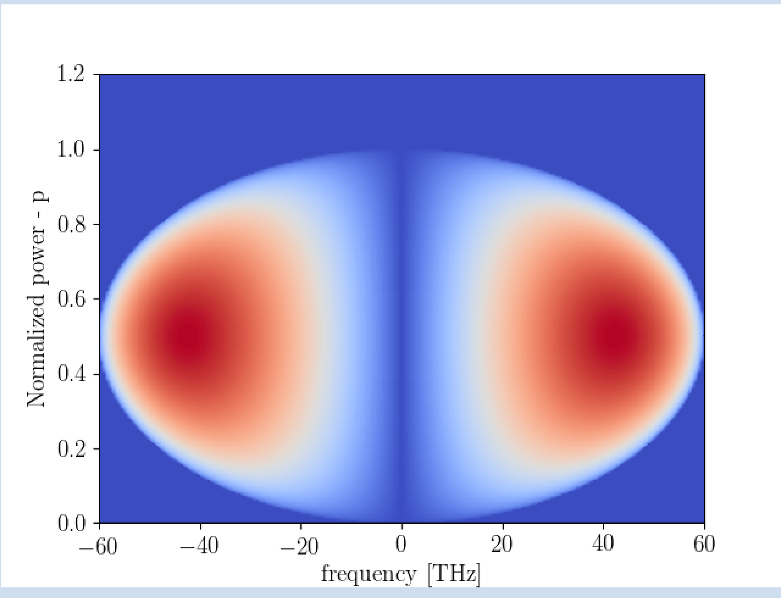
$$\frac{\partial A(z,T)}{\partial z} - i\sum_{m\geq 2}\frac{i^m}{m!}\beta_m\frac{\partial^m}{\partial T^m}A(z,T) = i\left(\gamma_0 + i\gamma_1\frac{\partial}{\partial T}\right)\left[A(z,T)\int_{-\infty}^{\infty}R(T')\,|A(z,T-T')|^2\,dT'\right]$$

The total number of photons is a conserved quantity. At a frequency $\omega_0+\Omega$, the photon count is given by

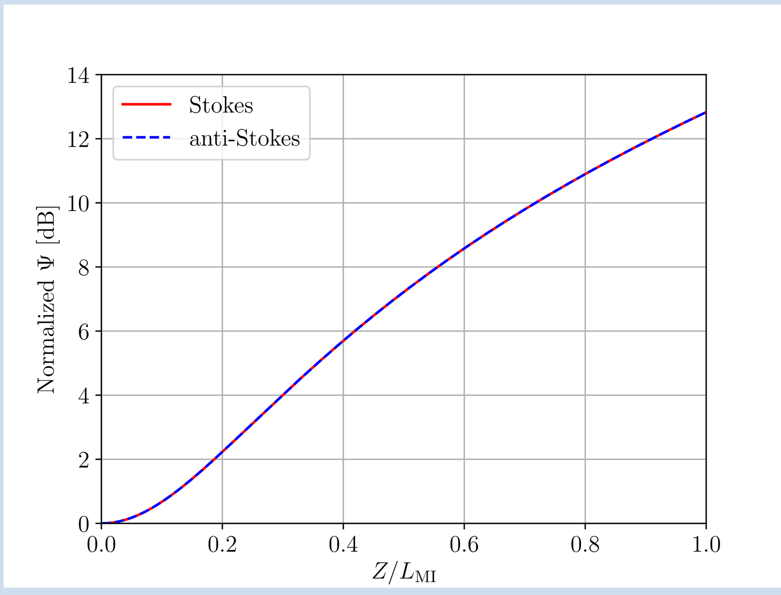
$$\Psi(\Omega) = \frac{|A(z,\Omega)|^2}{\hbar\,(\omega_0+\Omega)}$$

Modulation instability gain

MI is a parametric process where two photons from a CW pump are transferred to both low- and high-frequency bands, one photon each.



MI gain profile

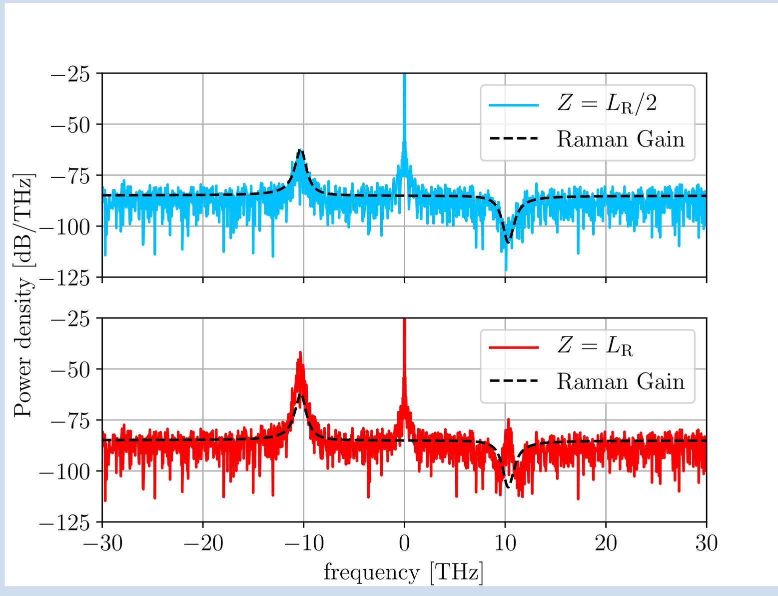


CW pump + 2 seeds for $p = 0.8$

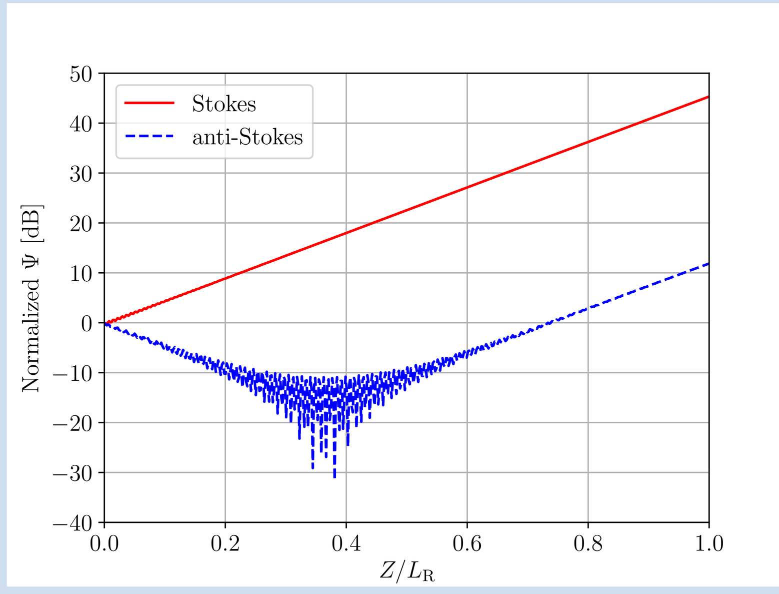
- There is a **power cutoff** above which the MI gain vanishes.
- **Gain occurs simultaneously** in both bands.

Raman amplification

Stimulated Raman scattering is a non-parametric process that enables the amplification of the Stokes band (at frequencies lower than the pump).



CW pump + noise

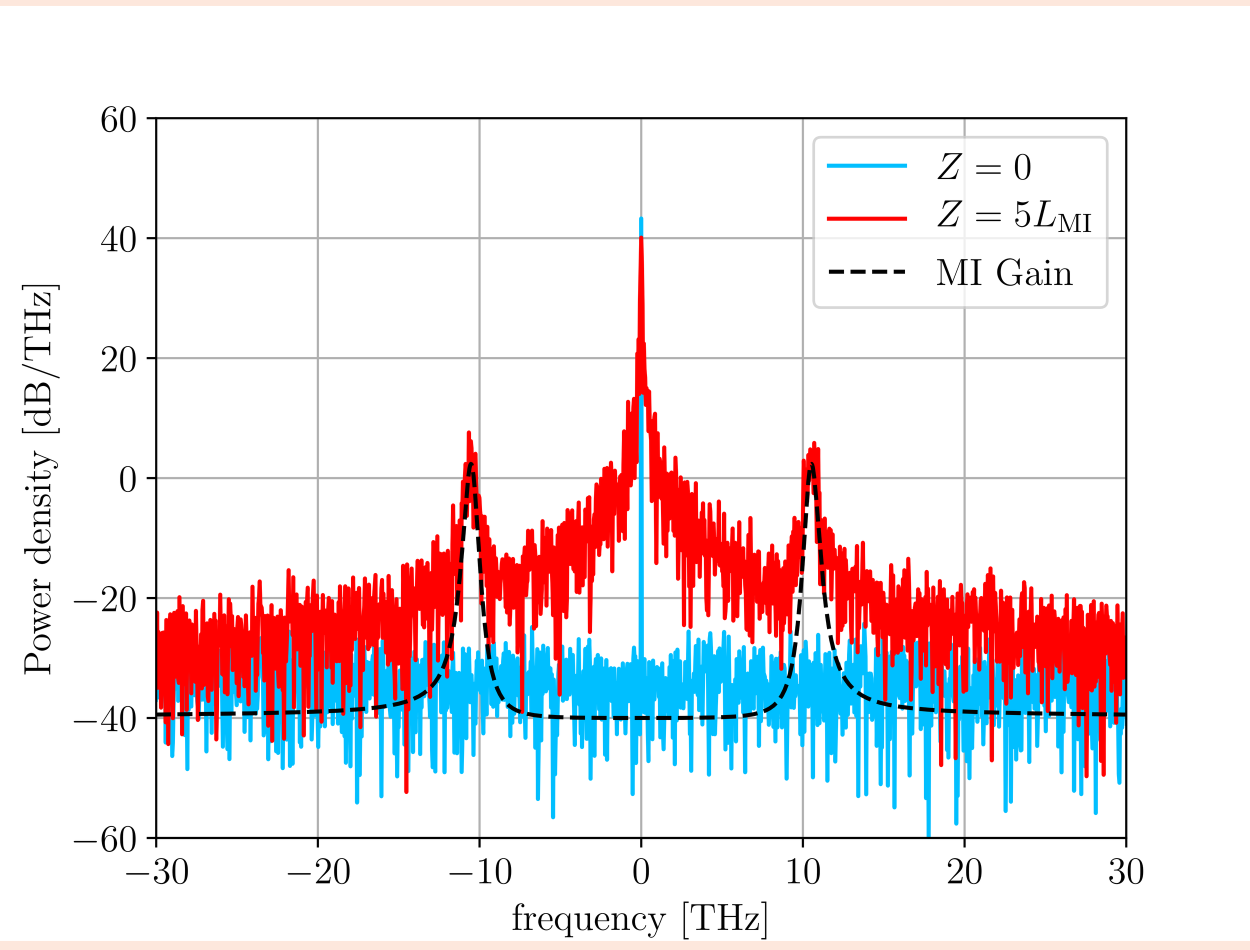


CW pump + 2 seeds

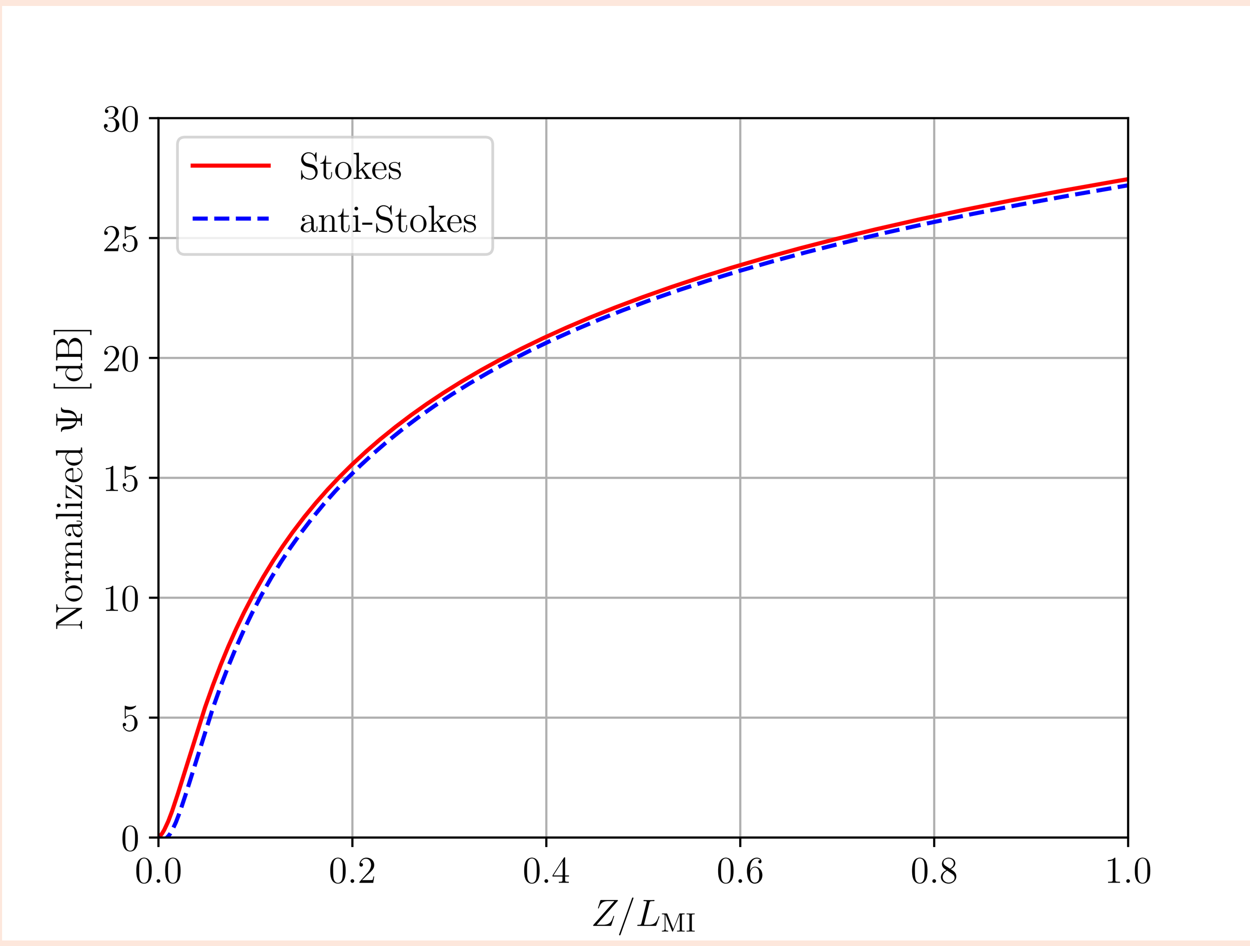
- **Initially, the Stokes (anti-Stokes) band gains (loses) photons** due to Raman.
- Gain in the anti-Stokes band is due to four-wave mixing.

Pseudo-parametric gain

There is still gain beyond the MI power cutoff when Raman scattering is taken into account



CW pump + noise for $p = 3.0$



CW pump + 2 seeds for $p = 1.1$

- **The gain profile mimics the shape of the Raman response** in the Stokes band.
- **Gain occurs almost simultaneously** in both bands.

Acknowledgements

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