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Self-Pulsation in Raman Fiber Amplifiers

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ABSTRACT
Dynamic behavior caused by Brillouin scattering in Raman fiber amplifiers is studied. Modes of self-pulsation steady state oscillations are found. Their dependence on amplification scheme is demonstrated.

Keywords: self-pulsation, Raman amplified, stimulated Brillouin scattering.

SUMMARY
When an intense continuous wave (CW) beam propagate through an optical fiber it creates a backward propagating wave due to spontaneous Brillouin scattering. This backward propagating Brillouin shifted wave appears approximately 10 GHz from the launched CW beam, when a typical silica optical fiber is used. The spontaneous backward propagating wave is amplified due to stimulated Brillouin scattering (SBS), where the frequency difference between the signal and the backward propagating wave is included in equation (1) through the terms + (R) or Raman (i = R) gain coefficient, z is the length, and t is the time. Furthermore αS, αB, and αR are the attenuation coefficients which for simplicity are identical. Similar ν and ν are the group velocities, which are assumed the same for all waves. ωS and ωB are the angular frequencies of the signal wave and the Raman wave respectively. The difference in energy between the Raman wave and the signal and Brillouin waves is included in equation (1) through the term +. The frequency difference between the signal and Brillouin waves is neglected. The pump for the Raman amplifier is assumed to have a linewidth broad enough to neglect Brillouin scattering on the Raman pump. Both Raman and Brillouin response is assumed instantaneous since we are dealing with CW and quasi-CW signal only.

Figure 1 shows what level of signal input power that is required to get a transmitted signal that is pulsing for the + (+) superscripts indicates forward (backward) propagating waves, gB is the Brillouin (i = B) or Raman (i = R) gain coefficient, z is the length, and t is the time. Furthermore αS, αB, and αR are the attenuation coefficients which for simplicity are identical. Similar ν and ν are the group velocities, which are assumed the same for all waves. ωS and ωB are the angular frequencies of the signal wave and the Raman wave respectively. The pump for the Raman amplifier is assumed to have a linewidth broad enough to neglect Brillouin scattering on the Raman pump. Both Raman and Brillouin response is assumed instantaneous since we are dealing with CW and quasi-CW signal only.

Figure 1 shows what level of signal input power that is required to get a transmitted signal that is pulsing for a round trip power reflectivity in the range from 0 to -140 dB. This is shown for two amplification schemes, a distributed and a discrete counter pumped Raman amplifier (Fig. 1a and Fig. 1b, respectively). The distributed Raman amplifier is a 100 km long fiber amplifier, with a total loss of 20 dB. The Brillouin and the Raman gain coefficient is 0.14 W-1m-1 and 0.7 W-1km-1, respectively [8]. In this case (Fig. 1a) three cases are compared, one...
where loss is neglected, one with loss, and one where the loss is counterbalanced by the Raman amplification. The Raman pump power is chosen exactly large enough to provide a Raman gain that equals the intrinsic attenuation. This is done by assuming an undepleted pump with no reflections, and equals 0.3 W. The discrete Raman amplifier, consists of a 200 m long fiber with an intrinsic attenuation of 0.8 dB/km and a Brillouin and a Raman gain coefficient equal to 0.8 W⁻¹m⁻¹ and 5 W⁻¹km⁻¹, respectively [7]. In Fig. 1b three cases are compared, one where loss is neglected, one with loss, and one where the signal is amplified by 20 dB by the discrete Raman amplifier. As in the case of the distributed amplifier, the Raman pump power is calculated assuming an undepleted pump with no reflections. For a 20 dB gain the Raman pump power equals 4.7 W.

Figure 1. Self-pulsation stability regions. The regions below the curves corresponds to CW output and the regions above corresponds to steady state oscillations. The round trip reflectivity is defined as \(10 \log_{10}(R_1R_2)\). If both fiber ends are cleaved at a 90° angle to the direction of the fiber, the reflection at each end equals \(\approx -15\ dB\), corresponding to a round trip reflectivity of -30 dB however, typical components and splices have significant lower reflections. The Brillouin is seeded with a single photon CW opposite the input signal.

The plots illustrate that for low signal power levels, high reflections are needed to reach self-pulsation. It is noted in Fig. 1a that the no loss region appears to be cut sharply for an input signal power close to 2 mW, similar in Fig. 1b around 180 mW. This is because the Brillouin wave gains so much power in one pass, which causes the system to oscillate. It is observed that the stability for the discrete Raman amplifier cuts off at around 7 mW, while the distributed Raman amplifier remain stable beyond 20 mW. This is believed to be contributed to the depletion of the Raman pump in the distributed amplifier so that the oscillation are inhibited by the fiber loss.

In conclusion, it is demonstrated that Brillouin scattering in optical fiber amplifiers may lead to steady state oscillations, when a launching a CW signal into the amplifier. We have shown that there is a significant difference between using a discrete or distributed Raman amplifier, where the distributed amplifier is significantly more robust against self-pulsation considering a fixed signal power level and a fixed total reflectivity.

REFERENCES