Brillouin Scattering in Raman-Pumped Fibers: An Experimental Investigation

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ABSTRACT

In this paper, we present a report about the impact of the distributed second order Raman amplification on Brillouin Scattering in a long haul 100km fiber system experimentally. The second order lasers at 1486nm created by the primary pump at 1395nm amplify the signal centered at 1550nm and extend the Brillouin scattering distance. Experimental results show that, both the Brillouin scattering efficiency at high powers and the Brillouin threshold are reduced

Keywords: Brillouin scattering, Raman amplification, Brillouin scattering efficiency, threshold.

1. INTRODUCTION

Raman amplification has been widely used in the long haul and large capacity WDM transmission systems [1-2] and long distance distributed sensing systems [3-4] because of the low noise performance, distributed signal amplification and its flexibility in setting the amplification bands. Brillouin scattering has been widely used in the long distance distributed temperature and strain measurement, although it is one of the various optical nonlinear affects that limit the optical signal power to be injected into the fiber in the optical telecommunication system. In recent years, many researches about Brillouin scattering on the performance of Raman amplification had been reported [5-8] in the long haul fiber communication systems with distributed Raman amplifications, because the effect of stimulated Brillouin scattering (SBS) will significantly limit the maximum achievable optical output power in the fiber communication network and, thus, affect the overall signal-to-noise ratio realizable. There were also a few reports about the influence of the Raman amplification on the Brillouin scattering in the optical communication. In distributed Brillouin scattering sensor systems, preamplifier (EDFA) and Raman amplifier were used to enhance the back scattering signals, and further extend the measurement distance. But few researches about the effect of the Raman amplification on the Brillouin scattering especially for the long range distributed Brillouin sensing system have been reported.

In our investigations, Raman amplification was achieved by launching a continuous wave (CW) 1395nm fiber Raman pump source at the front end of the fiber. This achieved the expected gain, the 1395nm Raman laser was used for primary pump and created a Stokes peak around 1486nm in forward and backward propagation direction, which acted as the second order laser to pump the sub sequential fiber and remotely pump two sections of Erbium-doped fiber (EDF) inserted in the fiber span to further amplify the signal and extend the measurement range. The fiber span includes 50km single mode fiber (SMF) plus 5.4m EDF, then 25km SMF, 5.4m EDF and the last 25km SMF. We set the 1395nm Raman power at 31.1dBm, and the experimental results show that the probe signal and its Brillouin signal are amplified by Raman amplification at lower probe power (4.01dBm) , but when the probe signal increases to a certain level (up to 10dBm), Brillouin signal with Raman amplification is even smaller than that without amplification. So in the long distance distributed strain and temperature sensing system base on Brillouin scattering, optimization of probe signal is very important for the extension of the measurement range.

2. EXPERIMENTAL SETUP

Schematic diagram of the experimental setup is shown as in Figure 1. A continuous-wave (CW) tunable laser source (TLS) with 150 kHz line width was used to perform the experiments. The CW probe signal was amplified by a boost

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erbium-doped fiber amplifier (EDFA) before launching into the fiber. The amplified spontaneous noise generated from the EDFA was filtered using a tunable filter (TF), which has 0.3nm bandwidth. A variable optical attenuator (VOA) was used to change the probe power. A 3-ports optical circulator launched the CW probe signal into the fiber through the wide band wavelength division multiplexer (WDM) coupler, which also coupled the 1395nm Raman pump light into the fiber. The Brillouin signal was taken at the port 3 of the circulator. The isolator (ISO) was used to prevent the reflection of the signal in order to protect the light source and EDFA.

The CW Raman fiber laser emits un-polarized light at 1395 nm with 0.5nm bandwidth. The maximum available launched CW pump power was 2W. Both CW probe signal and the CW Raman pump co-propagate in the whole fiber length. This 1395nm pump acted as the primary pump and provided first order Raman gain around 1486 nm. When the primary pump power is above the threshold necessary to overcome the attenuation of the first Stokes, this secondary pump at 1486nm can be used to Raman amplify the signal centered on 1550 nm and to simultaneously remotely pump several meter length of Erbium doped fiber (EDF) with an erbium concentration of 100 ppm. The WDM was spliced to a 50km long SMF, and two sections of 5.4m EDF were inserted in the transmission SMF at a distance of 50km and 75km from the front end of the fiber, respectively.

The Brillouin and Rayleigh signal were measured from output 1 using optical spectrum analyzer (OSA) with 0.01nm resolution. We also did the probe signal power measurement from output 2 at different position such as 50km, 75km and 100km from the front end of the fiber using OSA.

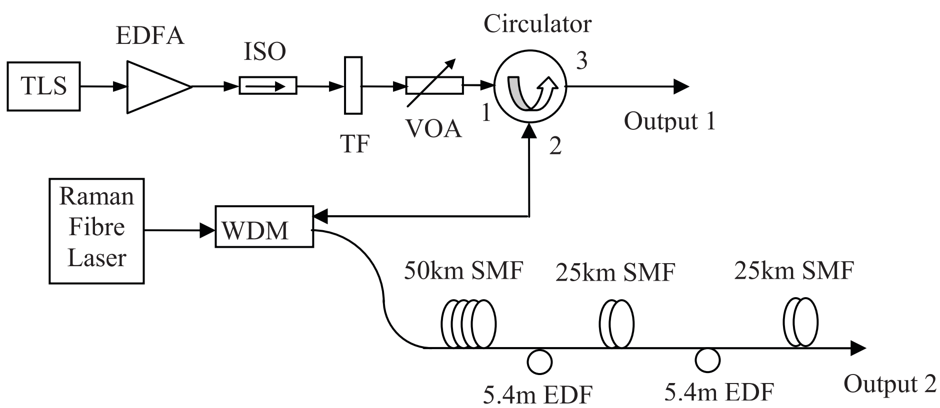


Figure 1 Schematic of the experimental setup

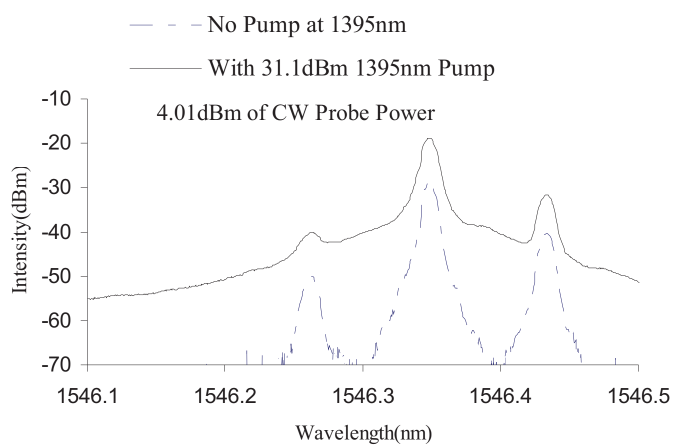
3. RESULTS AND DISCUSSION

The Brillouin and Rayleigh backscattered signals generated from the entire 100km fibers are shown in Figure 2(a, b, c). The Raman pump power was fixed at 31.1dBm, and the power at the second order pump of 1486.53nm measured at the 50km position from the front end of SMF is -8.05dBm (OSA, with 0.01nm resolution), the wavelength of the CW probe signal was set to 1546.2nm, its power was changed by VOA from 4dBm to 18.0dBm.

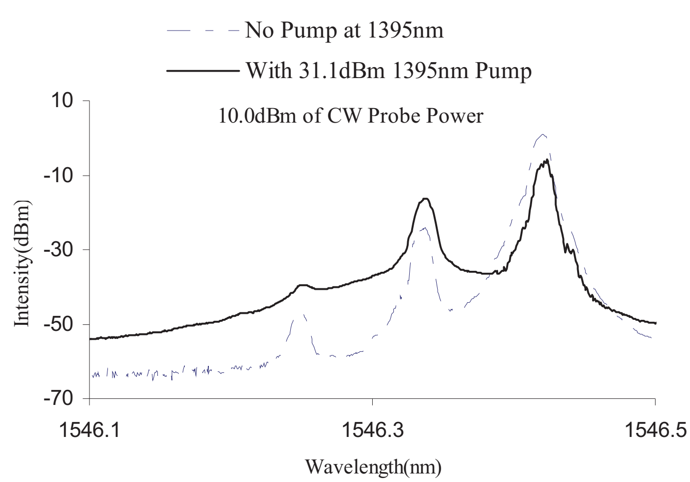
When the probe power is at 4.01dBm as shown in figure 2(a), the Brillouin and Rayleigh scattering signal without Raman amplification is much smaller than that with Raman amplification, because 4.01dBm is below the threshold of Brillouin scattering of the SMF; when applying Raman amplification, the probe signal (4.01dBm) is amplified, then the Brillouin signal power and Rayleigh signal so increases.

When the probe power increases further to 10dBm as show in figure 2(b), the Brillouin signal without Raman amplification is 6.5dB larger than that with Raman amplification, although the Rayleigh signal without Raman amplification is 7.6dB smaller than that with Raman amplification. This means that more probe signal is converted to Brillouin signal in the case of no amplification because 10dBm is already above the Brillouin threshold of the fiber, in this case, if the signal is further amplified by Raman amplification, Rayleigh signal increases and Brillouin signal is reduced, Raman amplification has a negative influence on the Brillouin scattering at high probe signal power.

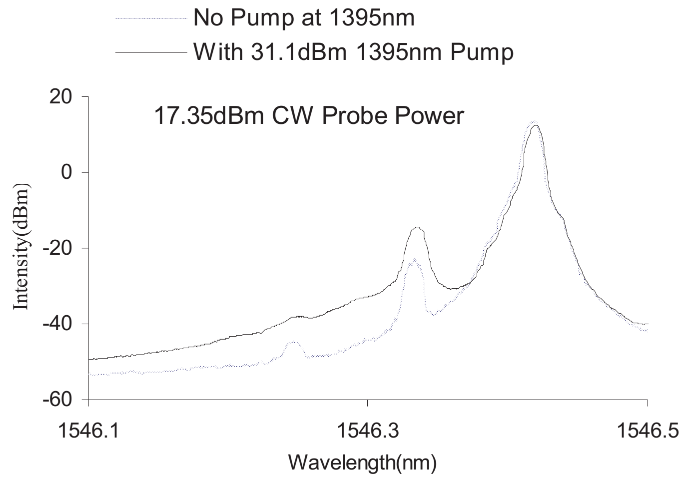
We further increased the probe signal power to 17.35dBm as shown in figure 2(c), the difference between the Brillouin signal power with and without Raman amplification becomes as smaller as 1.09dB. The Brillouin signal without amplification is slight larger (1.09dB) than that with amplification, and the Rayleigh signal without amplification is much smaller (9.16dB) than that with amplification. This can be explained to be that the Brillouin threshold is becoming larger comparing with the case of no Raman amplification. In the case of Raman amplification, only when the probe signal power (17.35dBm) is increased above its higher threshold, more probe signal power can be converted to Brillouin signal.



(a)



(b)



(c)

Figure 2 Brillouin signal power versus the input probe power with and without Raman pump (a) for the case of 4.01dBm probe power; (b) for the case of 10.0dBm probe power; (c) for the case of 17.35dBm probe power

Figure 3 is the relationship of Brillouin signal power versus the probe signal power with and without Raman amplification. For the case without Raman amplification, Brillouin signal rapidly increases with the probe signal within a certain probe power range. After the certain level (here is about 10dBm), it reaches to the saturation region. With Raman amplification, the increasing rate of the Brillouin signal becomes larger after 4.01dBm of probe power, but the slope of Brillouin signal with probe signal power in the case of Raman amplification is smaller than that without Raman pump when the probe power is below 10dBm. And at high probe power such as above 10dBm, the Brillouin signal with Raman pump was smaller than that in the case of no Raman pump. So Raman amplification has a negative influence on the Brillouin scattering at high probe power. In the long range Brillouin Scattering sensing system, the probe signal power and the signal distribution along the fiber will definitely affect the brillouin signal intensity and further influence the sensing performance. In the long haul distributed Brillouin sensing system, the setting of the probe signal power is much important to the system performance.

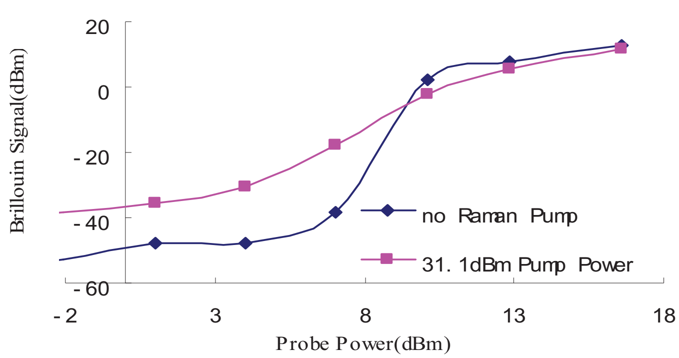


Figure 3 Brillouin signal power versus input probe signal power with and without 1395 Raman amplification

Figure 4 shows the probe signal power distribution along the fiber at different input probe power with 31.1dBm 1395nm Raman pump laser. We took the measurement from the output 2 at different positions (50km, 75km and 100km) of the long haul fiber using OSA with 0.01nm resolution as in figure 1. For the 50km case, there is no EDF in the system; for the 75km case, one section of 5.4m EDF was inserted at 50km position from the front end of the fiber. The input probe power was set to 4.0dBm, 10.0dBm and 12.82dBm respectively. For the three cases of input signal, the signal was reduced at 50km position because the total loss of the fiber is larger than the Raman gain. At 75km position, signal was amplified by Raman and Erbium dope fiber amplification to a certain level for the 4dBm and 10dBm case. For the larger input signal power 12.82dBm, the signal power at 75km was slightly smaller than that at 50km, this means the fiber loss is slightly larger than the gain provided by amplification due to the EDFA and Raman gain saturation. At 100km position, the signal power decreases again for the three cases, and is nearly equal to the signal power at 50km position. From the distribution of the probe signal power, we can see that the probe signal was distributed amplified and the signal power at 100km is almost same as the power at 50km position for the three input probe power although the power at the front parts of the fiber is different. In the long distance distributed Brillouin sensing system, the probe signal should be pulse signal and its distribution will directly affect the measured Brillouin signal intensity along the fiber. So the optimization of the probe signal, Raman pump and position of the EDF are important for the long distance distributed sensing system.

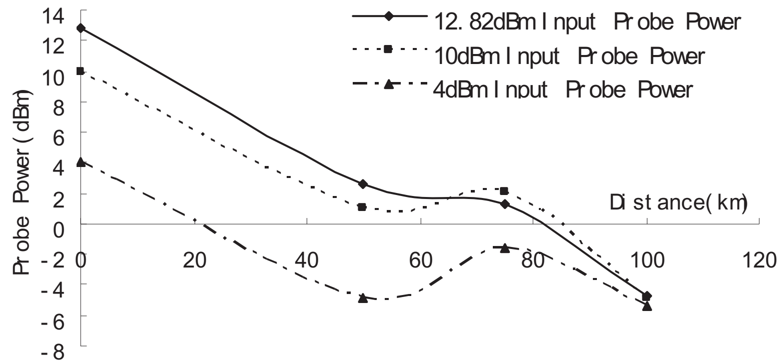


Figure 4 Probe signal power distribution along the transmission fiber with 31.1dBm 1395nm Raman pump laser

4. CONCLUSIONS

We experimentally investigated the impact of the distributed second order Raman amplification on the Brillouin scattering in a long haul 100km fiber. 1395nm Raman pump acts as the primary pump and produced Stoke light around 1486nm which is the second order pump, the 1486nm light further pump the sub fiber and EDF inserted in the fiber and extend the Brillouin scattering distance. Experimental results show that both the Brillouin scattering efficiency at high powers and the Brillouin threshold are reduced. In this investigation, continuous probe signal around 1550nm was used, in order to further analyze the impact of Raman amplification on the long distance distributed Brillouin sensing system, we will utilize pulse probe signal in the system and measure the real Brillouin signal distribution along the fiber with higher distance resolution in the near future.

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