Controlling SBS in Measurements of Long Optical Fiber Paths

Application Note

Michael Kelly

Abstract

The transmission and measurement of optical power through kilometer lengths of optical fibers is degraded by the nonlinear effect of Stimulated Brillouin Scattering, SBS. The SBS effect causes excessive amounts of input power to be reflected within the fiber, limiting the achievable transmitted power.

By controlling the linewidth of the optical source, ideally without adding noise, the SBS problem can be avoided and high optical power can be launched into the fiber.

Agilent Technologies

Introduction

SBS stands for *Stimulated Brillouin Scattering* and is a problem for high laser power in long fibers. If there is high laser power with a narrow linewidth along the fiber, the SBS effect causes much light to be reflected. This limits the power that can be transmitted and makes the signal noisy. Therefore SBS is an issue for optical transmitters in optical networks and for instruments that test components or systems with long fibers. Such tests can include measuring the power budget of an amplified or unamplified transmission span, or testing Raman amplifier configurations. Fibers exhibiting SBS at power levels of interest to telecommunications are usually at least several kilometers in length, but this depends on the type of fiber.

The origin of SBS lies in the backscattering of signal light by acoustic waves in the optical material, which is weak in short fibers. The backscattered light is shifted to lower optical frequency (higher wavelength) by the Brillouin-shift frequency, which depends on the fiber material. For common single-mode silica fiber, the shift is about 11 GHz (0.09 nm at 1550 nm). The backscattered light in a fiber can then stimulate more of the forward traveling light to be backscattered. When there is enough signal power, the backscattered light can gain more power by this stimulated backscattering than it loses due to fiber attenuation. When the fiber is long enough, the backscattered power keeps increasing along the fiber in an avalanche-like process and can take most of the input optical power.

SBS is a nonlinear effect, because the amount of light backscattered, and the amount of light transmitted by the fiber, do not depend linearly on the power input to the fiber. At low input powers the backscattering is dominated by simple Brillouin and Rayleigh scattering which are linear and differ from each other by the Brillouin shift. But as the power is increased, the Brillouin scattered light is increasingly amplified by the stimulation process. At a power level called the *SBS threshold*, the amount of backscattered light increases very rapidly with increasing input power until it constitutes most of the input light. The transmitted power at the fiber output saturates at a level that barely increases with increased input power. For single-mode fiber, SMF, of lengths above 10 km, the SBS threshold can lie in the range of 6 - 10 dBm. Above this threshold, the insertion loss of the fiber is not independent of input power.

In addition to the power loss problem associated with SBS, there is also an increase in *Relative Intensity Noise*, RIN, on the transmitted signal. Rapid fluctuation in power is caused by the variability of the backscattered power due to the sensitivity of this nonlinear feedback-coupled effect on polarization and environmental influence, and on the beat noise resulting from all the spontaneously generated scattering along the fiber.

The importance of laser linewidth

Quantitative details about SBS can be found in Reference [1] and in the sources cited there. The proportion of light backscattered by the Brillouin effect and the amount of shift in optical frequency are properties of the fiber material and are also influenced by the frequency of the light, ν_0, and the waveguide properties of the fiber. As shown schematically in Figure 1, the Brillouin scattered light is characterized spectrally by the frequency shift from the "signal", ν_B and by the linewidth of this shift, δ_B.

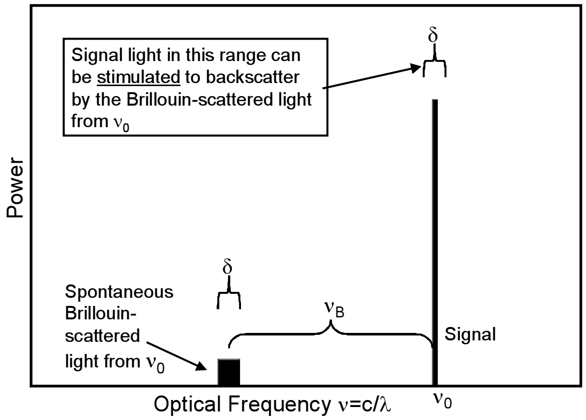

Figure 1. Schematic diagram of the Brillouin scattering spectrum. The Brillouin scattered light propagates backwards through the fiber.

As this spontaneously scattered light travels backwards through the fiber from its point of origin, it is joined by additional light scattered from other positions and also attenuated by the fiber. In the linear power regime, the total backscattered power remains a small proportion of the total power.

However the backscattered light also stimulates further Brillouin scattering from any forward-traveling light of frequency ν_f within the linewidth δ_B from ν_0, as illustrated in Figure 1. The forward and backward traveling light must also have parallel polarization components. This stimulated scattering is equivalent to the stimulated emission used in lasers and optical amplifiers. The amount of stimulated scattering is proportional to the power of the forward-traveling and of the backscattered light, so the result can be a continuous increase in backscattered power along the fiber in the reverse direction to the original signal light. This power increase along the fiber is like an avalanche, with larger amounts of light in turn causing larger amounts to backscatter.

The SBS effect only takes power from forward traveling light of frequency within a range of δ_B from the original frequency, which is typically 10-100 MHz in silica fiber. If the laser source has a linewidth that is narrower than this, as is typical for single-longitudinal-mode lasers like DFBs, then all the laser power contributes collectively to SBS. On the other hand, the spectrum of a multimode laser like a Fabry-Perot source typically consists of many lines with a spacing of more than 50 GHz. In this case, the backscattered light from one mode cannot take power from the other modes via SBS because they are outside of the frequency range. Each mode produces backscattering according to its individual power, which can remain below the SBS threshold even when the total from all modes is above the threshold. Thus the SBS threshold indicates a limit for spectral power density, corresponding to the amount of power within the linewidth δ_B. The SBS threshold depends on the effective linewidth, and the length and attenuation of the fiber, as well as the material itself. The effective area of the fiber is also important because it determines the overlap of forward and backscattered intensity. The attenuation and actual length of the fiber result in an *effective length for SBS*, which can be shorter than the actual length when the power over much of a long fiber is too low for SBS.

Linewidth broadening by modulation

Telecommunications signals benefit from the linewidth broadening due to the data modulation. However the SBS threshold may still be reached because much of the power remains at the “carrier” frequency [2]. Effective linewidth broadening can be achieved by a mild audio frequency modulation “tone” on the signal. The amplitude modulation of the laser current causes both the power and the optical frequency of the laser to be modulated. This “dithering” of the frequency around the unmodulated value results in a wider range of optical frequencies being present along the fiber length, even though the linewidth at any point is still narrow. This prevents all of the power in the fiber from contributing collectively towards the SBS threshold, similar to spreading the power over many simultaneous modes [3].

For testing power levels along a transmission span (or launching high powers into long fibers for other measurements such as evaluating Raman amplification), the test instrument needs a means of increasing the effective linewidth without degrading the measurement. Achieving linewidth broadening with tunable lasers based on external cavities is especially critical since they have narrow linewidths (typ. ~100 kHz).

One type of linewidth broadening that is useful in test instruments is based on amplitude modulation of the laser current at a rate that is high compared to the averaging time of the power sensors. In this way, the sensors detect a constant average power level, but each measument samples a broadened linewidth due to the frequency dithering over the averaging time. This principle is used in the *coherence control* feature of Agilent tunable and fixed laser sources to avoiding fluctuations in power measurements when reflections in the optical path cause multipath inteference, MPI. These instruments use a randomized current modulation to achieve optimal broadening. This feature is also effective against SBS, depending on the broadening achieved. It is especially useful in the Agilent 81662A and 81663A DFB laser sources, where the high output power makes the SBS threshold accessible. Adjusting the degree of modulation with the *coherence level* parameter allows the broadening to be optimized to the required level. A relatively low degree of modulation, (coherence level ~ 95%), has been observed to be sufficient for suppressing SBS from 25 km SMF.

One disadvantage of this modulation method is the associated modulation of the power. While this power fluctuation is averaged out during typical power measurements, it can degrade high speed time-dependent measurements. An example would be using a digital modulator with the CW laser to perform bit error ratio testing, BERT. In this case, the additional RIN due to the modulation can lead to a higher bit error ratio and a poorer eye diagram.

A new form of modulation for linewidth broadening, which avoids the generation of RIN, is provided in the Agilent Compact Tunable Laser series, including the 81940A, 81949A, 81980A and 81989A modules. The new feature, called *SBS control*, provides optical frequency modulation or dithering directly rather than via amplitude modulation, by modulating the length of the external laser cavity. This minimizes any fluctuation in the laser power. The modulation rate, adjustable up to 10 kHz, is sufficient to broaden the linewidth accumulated over lengths exceeding about 10 km. For example, the period at 5 kHz is 200 µs, corresponding to a path length of 40 km fiber. Since the SBS involves light traveling back-and-forth along the fiber, 20 km is sufficient for this 200 µs dithering period. While this relatively slow modulation is effective against SBS, it is too slow for suppressing typical MPI effects and does not replace the coherence control feature.

Example measurements

Using the setup illustrated by Figure 2, the effects of SBS and SBS control are shown in Figure 3. The 81940A laser output is connected to a long fiber through a coupler that taps 1% of the reflected power to one input of the 81635B dual power-meter module. The output of the long fiber is connected to the other module input. The reflection tap can also be connected to an optical spectrum analyzer in order to observe the Brillouin shift of the backscattered light.

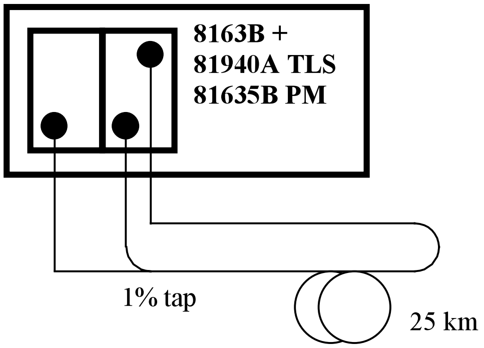

Figure 2. Simple setup for measuring the transmitted and reflected power from a long fiber, using an 81940A tunable laser module and an 81635B dual powermeter module.

The dependence of the two power levels on the launched power set at the laser are shown in Figure 3. The solid lines show that at input powers above the SBS threshold, the reflected power increases nonlinearly and the transmitted power saturates as the SBS reflects most of the power. The reflected power is the lower curve for low input powers, but exceeds the transmitted power beyond 10 dBm input power.

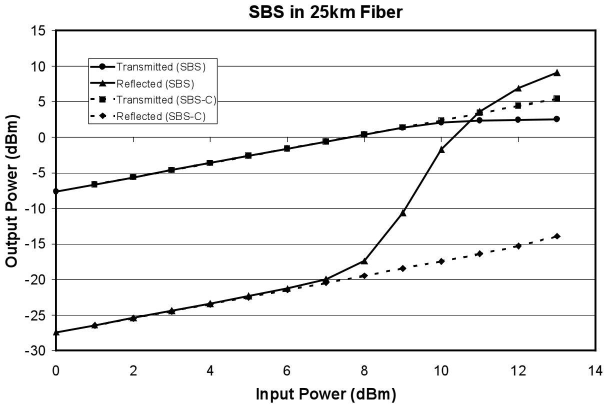

Figure 3. Transmitted and reflected optical power measurements from a 25 km fiber as a function of input power from the laser, without (solid line) and with (dashed line) the SBS-control modulation.

At the same time, fluctuations in the power measurements are observed and have been recorded here using the Min-Max function of the power sensors, Figure 4. As can be seen from the solid lines, the uncertainty of power measurements is greatly increased by the SBS-induced fluctuations. The strong peak in reflected power fluctuations corresponds to the input power for which the reflection is growing most steeply in Figure 3.

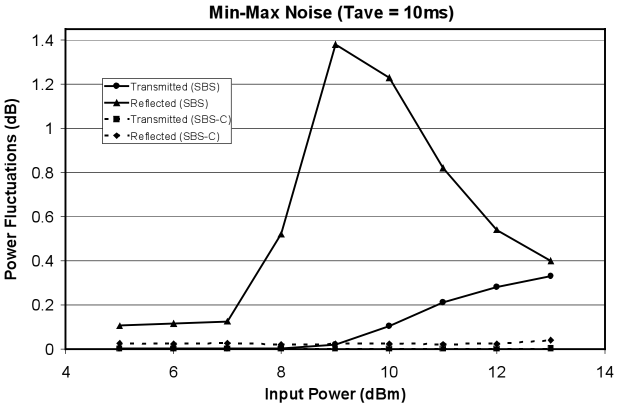

Figure 4. Measured fluctuations in the power transmitted and reflected by the 25 km fiber, with and without SBS control. The results were obtained using the Min-Max function of the power meter with an averaging time of 10 ms.

When the SBS control is operating, the transmitted and reflected power return to linear behavior, and the power stability is dramatically improved, as shown by the dotted lines in the two figures. In this case, the throughput of the fiber was increased by 2.9 dB. Similar improvement in power throughput can be achieved with the *coherence control* feature of some lasers, including the Agilent DFB modules. However this feature may result in degradation of the signal RIN. By contrast, as shown in Figure 5, the *SBS control* does not degrade the RIN, and instead eliminates the RIN caused by SBS. The measurements in Figure 5 were made with the Agilent 71400C Lightwave Spectrum Analyzer using 13 dBm input power from the 81940A tunable laser source, and yielded a RIN improvement after the fiber from –116.4 dB/Hz (due to SBS) to –144.1 dB/Hz using SBS control (for RIN at 11 MHz).

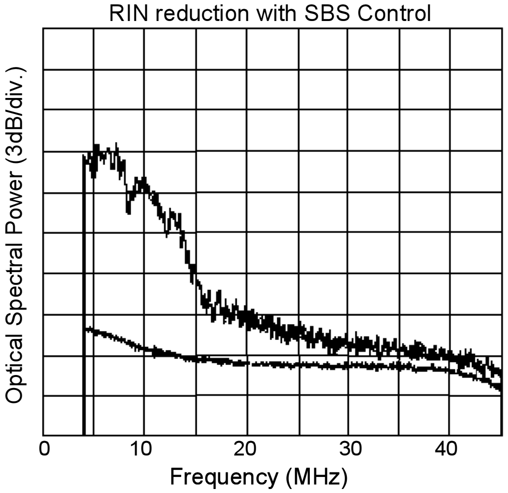

Figure 5. Spectrum analysis of the output signal from a 25-km fiber, using 13 dBm input power from the Agilent 81940A tunable laser, with (lower curve) and without (upper curve) activation of SBS control.

These results show the importance of considering SBS when making optical measurements involving long fibers paths, and emphasize the importance of SBS suppression in high power laser test instruments.

Agilent Technologies’ Test and Measurement Support, Services, and Assistance

Agilent Technologies aims to maximize the value you receive, while minimizing your risk and problems. We strive to ensure that you get the test and measurement capabilities you paid for and obtain the support you need. Our extensive support resources and services can help you choose the right Agilent products for your applications and apply them successfully. Every instrument and system we sell has a global warranty. Support is available for at least five years beyond the production life of the product. Two concepts underlie Agilent's overall support policy: "Our Promise" and "Your Advantage".

Our Promise

Our Promise means your Agilent test and measurement equipment will meet its advertised performance and functionality. When you are choosing new equipment, we will help you with product information, including realistic performance specifications and practical recommendations from experienced test engineers. When you use Agilent equipment, we can verify that it works properly, help with product operation, and provide basic measurement assistance for the use of specified capabilities, at no extra cost upon request. Many self-help tools are available.

Your Advantage

Your Advantage means that Agilent offers a wide range of additional expert test and measurement services, which you can purchase according to your unique technical and business needs. Solve problems efficiently and gain a competitive edge by contracting with us for calibration, extra-cost upgrades, out-of-warranty repairs, and on-site education and training, as well as design, system integration, project management, and other professional engineering services. Experienced Agilent engineers and technicians worldwide can help you maximize your productivity, optimize the return on investment of your Agilent instruments and systems, and obtain dependable measurement accuracy for the life of those products.

By internet, phone, or fax, get assistance with all your test & measurement needs

Online assistance:
www.agilent.com/comms/lightwave

Phone or Fax

United States:
(tel) 1 800 452 4844

Canada:
(tel) 1 877 894 4414
(fax) (905) 282-6495

Europe:
(tel) (31 20) 547 2323
(fax) (31 20) 547 2390

Japan:
(tel) (81) 426 56 7832
(fax) (81) 426 56 7840

Latin America:
(tel) (305) 269 7500
(fax) (305) 269 7599

Australia:
(tel) 1 800 629 485
(fax) (61 3) 9210 5947

New Zealand:
(tel) 0 800 738 378
(fax) 64 4 495 8950

Asia Pacific:
(tel) (852) 3197 7777
(fax) (852) 2506 9284

May 06, 2003

5988-9563EN

References

[1] X.P. Mao, et al., “**Stimulated Brillouin Threshold Dependence on Fiber Type and Uniformity**”, IEEE Photon. Technol. Lett. 4, pp. 66-69 (1992).

[2] Y. Aoki, K. Tajima and I. Mito, “**Input Power Limits of Single-Mode Optical Fibers due to Stimulated Brillouin Scattering in Optical Communication Systems**”, J. Lightwave Technol. 6, pp. 710-719 (1988).

[3] D.A. Fishman and J.A. Nagel, “**Degradations due to Stimulated Brillouin Scattering in Multigigabit Intensity-Modulated Fiber-Optic Systems**”, J. Lightwave Technol. 11, pp. 1721-1728 (1993).

Agilent Technologies