Suppression of Stimulated Brillouin Scattering
Introduction
This technical note discusses the phenomenon and suppression of stimulated Brillouin scattering (SBS) in optical links. Specific commentary is focused on these issues as they relate to Lumentum tunable lasers. Lumentum tunable laser assemblies (TLA) feature optional SBS suppression implemented through a controlled frequency dither.

Stimulated Brillouin Scattering
This non-linear phenomenon can be considered in terms of three waves in optical fiber. Consider an incident wave propagating along an optical fiber. If this incident wave reaches a threshold power, it will excite an acoustic wave within the fiber. Although this threshold power may vary, the phenomenon of acoustic wave excitation is unavoidable. This acoustic wave alters the optical properties of the fiber, including the refractive index. This fluctuation in refractive index scatters the incident wave, creating a reflected wave that propagates in the opposite direction. This scattering is known as Brillouin scattering. Since the scattering effect is caused by the incident light wave, the process is known as stimulated Brillouin scattering (SBS). The incident wave is often referred to as the pump wave, while the reflected wave is also known as the Stokes wave.

This effect can occur in single channel or multiple channel systems at threshold powers of just a few milliwatts in singlemode fiber. The scattering effect transfers power from the incident wave to the reflected wave. The lost energy is absorbed by molecular vibrations in the fiber. Due to this loss of energy, the reflected wave has a lower frequency than the incident wave. The frequency shift is approximately 11 GHz (0.09 nm) in optical fiber. For typical WDM and DWDM systems, this small frequency shift does not create crosstalk with other channels. The harmful effects of SBS can be classified into three categories:

- attenuation
- power saturation
- backward-propagation
Attenuation of the incident signal occurs when power is lost to the acoustic and reflected waves. Furthermore, SBS limits the maximum amount of power that can be transmitted over a fiber. After a certain point, an increase in incident power no longer leads to an increase in received power. The backward propagating wave can create noise in transmitters and saturate amplifiers. Isolators are required to limit these effects to a single span.

An approximate expression for the threshold power is show in Equation 1.

\[ P_{th} = \frac{2 f_b A_e}{g_B L_e} \left( 1 + \frac{\Delta \nu_S}{\Delta \nu_B} \right) \]

where:
- \( b \) = number between 1 and 2, depending on wave polarization state
- \( A_e \) = effective area, typically 50 \( \mu \text{m}^2 \) for singlemode fiber
- \( g_B \) = SBS gain coefficient, approximately \( 4 \times 10^{-11} \text{ m/W} \)
- \( L_e \) = effective transmission length; accounts for power loss in link
- \( \Delta \nu_S \) = linewidth of laser source
- \( \Delta \nu_B \) = SBS interaction bandwidth, approximately 20 MHz at 1.55 \( \mu \text{m} \)

Equation 1

For long links, \( L_e \sim 20 \text{ km} \). This effective length accounts for the distribution of optical power over the length of the physical link, including the effects of attenuation. It is clear from Equation 1 that the threshold power depends strongly on source linewidth. Assuming that \( b = 1 \) (worst-case scenario), the SBS threshold power is 2.6 mW for a source with 20 MHz linewidth, and 14.4 mW for a source with 200 MHz linewidth.

There are three principal ways to mitigate the effects of SBS:

• Use phase modulation instead of amplitude modulation. This reduces the power of the optical carrier. The effective linewidth is proportional to the bit rate. This option is not always practical due to concerns over standards and interoperability.

• Ensure that the power per channel is much less than the SBS threshold. This may be possible in metropolitan networks. However, to accomplish the same goal in long haul networks requires a reduction in amplifier spacing, or a distributed amplification scheme, with the associated cost and complexity.

• Increase the linewidth of the source. Direct laser modulation increases the linewidth, but can cause a significant dispersion penalty. Using an external modulator with a narrow linewidth source only increases the SBS threshold slightly, since most of the power is still contained in the optical carrier. Another widely utilized approach is to dither the laser frequency over a few hundred MHz or more. This increases the SBS threshold power, but without the dispersion penalty associated with direct modulation.

Suppression of Stimulated Brillouin Scattering

The structure of the Lumentum sampled-grating distributed Bragg reflector (SG-DBR) laser lends itself particularly well to a controlled frequency dither. A chip schematic is shown in Figure 2.

Figure 2      Schematic of Lumentum SG-DBR chip

The schematic in Figure 2 includes a monolithically-integrated semiconductor optical amplifier (SOA). In the SG-DBR architecture, the front and rear mirrors consist of sampled gratings with multiple reflectivity peaks. By injecting current into these mirrors to change the effective index of refraction, the peaks may be precisely aligned or misaligned to produce high reflectivity and high sidemode suppression ratio at the desired wavelength. This tuning mechanism is used to select a particular cavity mode. By injecting current into the phase section, the position of the cavity modes may be precisely controlled. It is apparent that a low magnitude dither applied to the phase section would increase the effective linewidth without compromising other laser qualities such as power or wavelength. The residual amplitude modulation is minimal.

During the manufacturing process, the laser chip is placed on a carrier, loaded into a hermetic package, and finally becomes the major component in the completed tunable laser assembly (TLA). The TLA includes a microprocessor and other control electronics to support laser commands. A lookup table containing current settings for each ITU channel is also stored on board. After an ITU channel is chosen, the command “Set SBS” (see Figure 3) is used to control the frequency sweep of that particular channel. This command may be accessed using the evaluation software or directly through the TLA interface.

Figure 3      “Set SBS” Command [0x29] on Lumentum Demonstration software
The default setting is “SBS Off.” In this case, the lasing frequency is not dithered. The scattering linewidth is not changed. Please consult the Lumentum technical note: Relative Intensity, Phase Noise and Linewidth for more information about Lumentum laser linewidth with SBS suppression disabled. When enabled, the peak-to-peak frequency sweep of the lasing wavelength can be set between 0.1 and 1.2 GHz, in 0.1 GHz steps. To adjust SBS settings using the demonstration software, click 0x29 – Set SBS. The SBS parameter dialogue box will appear. Choose the desired amplitude for the lasing frequency sweep, either SBS Off for no sweep or a value from 0.1–1.2 GHz.

The SBS function is implemented internally using a digital-analog converter (DAC). The dither waveform is a sawtooth with a frequency of 12 kHz. The sawtooth waveform is chosen to ensure equal optical power density over the sweep range. The phase dither is synchronized with the sampling rate of the internal wavelength locker. By comparing the actual frequency sweep with the intended frequency sweep, the proper dithering amplitude can be precisely selected. The output analog signal from the DAC is then superimposed on the signal sent to the phase section. No user-provided signal is required. By placing a dither on the signal sent to the phase section, the cavity mode selected by the front and rear mirror combination is swept back and forth over the selected frequency range.

The Lumentum TLA includes an integrated wavelength locker with reference and etalon photodiodes. The reference photodiode is used to measure output power. The etalon photodiode is used as a frequency reference. Figure 4 shows output from the reference and etalon photodiodes with SBS suppression enabled. The triangle waveform is clearly visible on the output from the etalon photodiode. This shows that the output frequency is being modulated as expected. The other trace shown is that of the reference photodiode. The peak-to-peak variation on this signal is less than 0.02%. This confirms that the SBS suppression scheme does not lead to residual amplitude modulation.

In laboratory experiments, the SBS suppression function was found to serve two purposes.

- Increase SBS threshold power
- Reduce low-frequency RIN after propagation through fiber

The increase in SBS threshold power is expected due to the increase in scattering linewidth. Figure 5 shows the onset of SBS for three different launch conditions. These test were conducted using an EDFA and a 75 km fiber span. A 2 x 2 coupler was used to extract the transmitted and reflected power. The reference laser is an external-cavity test and measurement laser. Backscattered power begins to increase sharply at a launch power of +7 dBm. This is typical behavior for a narrow linewidth laser with no suppression scheme implemented. The second curve shows the reflected power versus launch power for a Lumentum 3105 TLA without SBS suppression active. Even in the absence of active suppression, it is clear that the SBS threshold is higher than in the case of the external-cavity laser. This is due to the exceptionally narrow linewidth of the reference laser. The third curve shows the same power characteristic for a Lumentum 3105 TLA with SBS suppression active and a frequency sweep of 2 GHz. No SBS behavior is detected, even at launch powers as high as +13 dBm.

It is apparent that the SBS threshold power can be substantially increased through use of the suppression feature, reducing the reflected power signal and eliminating power saturation. This improvement has a significantly positive impact on amplifier spacing and receiver sensitivity requirements in optical networks. The SBS suppression feature is particularly useful in applications where high launch powers and stretched link budgets are required. Examples include unamplified submarine links and links across restricted access regions.
The second effect is more subtle. Figure 6 shows the RIN spectrum of a Lumentum TLA at three different launch powers after propagation through 50 km of fiber. The operating wavelength is 1551.319 nm.

![RIN Spectrum after 50 km of fiber for launch powers of +7.4, 9.0, and 11.0 dBm](image6.png)

Figure 6 RIN Spectrum after 50 km of fiber for launch powers of +7.4, 9.0, and 11.0 dBm

The RIN spectrum shows a clear peak at 11 GHz caused by SBS for the highest launch power. As expected, this tone is eliminated when the launch power is reduced below threshold. It is also eliminated by turning on SBS suppression. Figure 7 shows the received noise power spectrum for a launch power of +11.0 dBm with no dither, with 0.4 GHz dither, and with 1.2 GHz dither.

![Noise Power Spectrum for Launch Power of +11.0 dBm under three dither conditions](image7.png)

Figure 7 Noise Power Spectrum for Launch Power of +11.0 dBm under three dither conditions

The low-frequency noise spectrum is also markedly improved after the introduction of SBS suppression. The exact contribution to low frequency noise made by SBS is uncertain, but it is clear that the noise level is reduced by the phase dither.

![RIN Spectrum after 50 km Fiber under three dither conditions on logarithmic scale](image8.png)

Figure 8 RIN Spectrum after 50 km Fiber under three dither conditions on logarithmic scale

The low-frequency RIN does not depend on gain current, suggesting that it is independent of the white phase noise level. It is believed that SBS contributes to low-frequency phase noise, or that the suppression dither limits another noise contribution.
Summary
Stimulated Brillouin scattering (SBS) causes power saturation in optical fiber and can occur at powers of just a few milliwatts. The harmful system effects limit amplifier spacing and add to network costs. Lumentum tunable lasers include an optional feature that increases the SBS threshold by applying a controlled dither to the phase section. This feature eliminates the SBS reflected power signal and also reduces low-frequency noise.

References