Laser Backreflection - The Bane of Good Performance

All lasers are susceptible to backreflections. Backreflections disturb the standing-wave oscillation in the laser cavity, increasing the effective noise floor of the laser. A strong backreflection causes certain lasers to become wildly unstable and completely unusable in some applications. Backreflection can also generate nonlinearities in the laser response which are often described as kinks. Most analog applications and some digital applications cannot tolerate these degradations.

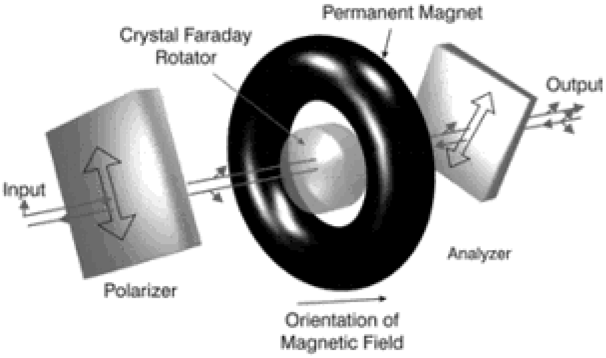
Explanation of Backreflections

The general knowledge has been that backreflections hurt the performance of a link because the reflected light gets into the laser cavity, disturbs the standing optical wave, and creates noise. Some lasers are very susceptible to backreflection due to the design of the laser chip itself. Most often the determining factor is how tightly the fiber is coupled to the laser chip. In a low power laser potentially only 5-10% of the laser power is coupled into the fiber. This means that only 5-10% of the backreflection would be coupled to the laser chip, making the laser relatively immune to backreflections. On the other hand, a high-power laser may have 50-70% of the laser chip output coupled to the fiber. This means that 50-70% of the backreflection is coupled to the laser cavity.

Optical Isolators

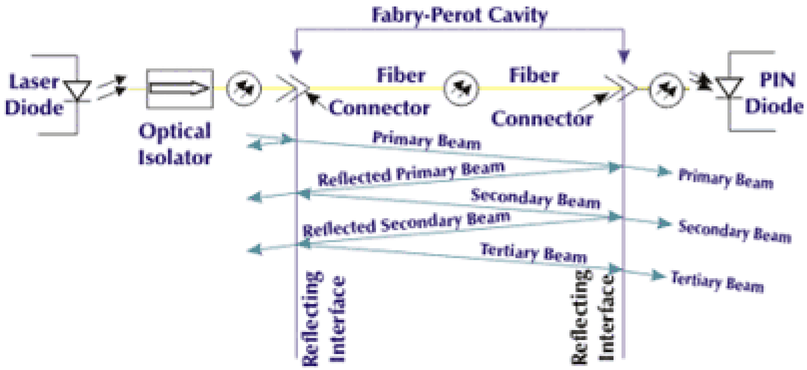
One strategy to reduce backreflections places an optical isolator at the laser output. In some cases, lasers incorporate dual isolators offering 50 dB or more reduction in backreflections reaching the laser. One would think that a double isolated laser would not be bothered by backreflections, but this is not the case. The noise that is generated by backreflections reaching the laser is only one possible source, in many cases a minor source of noise because of the widespread use of optical isolators. The Faraday rotator shown in Figure 1 and based on the Faraday effect, is one example of an optical isolator.

Figure 1 - Isolator Based on Faraday Rotator



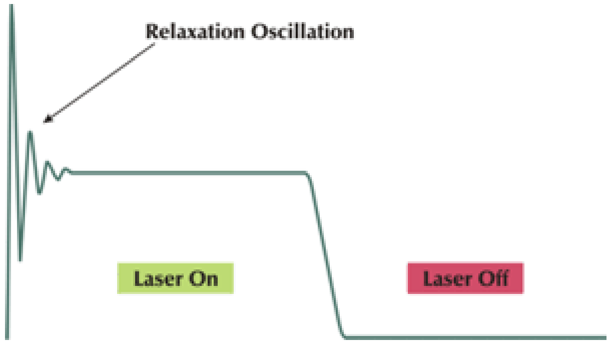
Before entering the Faraday rotator, which is usually an yttrium-iron-garnet (YIG) material, the light beam passes through a polarizer which is oriented parallel to the incoming state of polarization. The Faraday rotator then rotates the polarization by 45°. At the output, the beam passes an analyzer which is oriented at an angle of 45° relative to the first polarizer. Of all possible reflected beams, only those with a 45° orientation of the polarization are allowed to pass backwards. The polarization of the reflected beam is rotated by another 45° which results in a total rotation of 90°. This way, the reflected beam is blocked by the polarizer, reducing backreflections by 20 to 45 dB. In order not to disturb the proper function of the isolator, all of its surfaces should be antireflection-coated. A more significant source of noise in a modern fiber optic system can be Interfereometric Intensity Noise(IIN). This noise is generated by Fabry-Perot cavities created between multiple reflecting elements in the fiber plant, usually fiber optic connectors or splices. Fabry-Perot lasers break down into buried hetero and multi-quantum well(MQW) types. BH and related styles ruled for may years, but now MQW types dominate. MQW lasers offer significant advantages over all former types of Fabry-Perot lasers. They offer lower threshold current, higher slope efficiency, lower noise, better linearity, and much greater stability over temperature. As a bonus, the performance margins of MQW lasers are so great, laser manufacturers get better yields, so laser cost is reduced. One disadvantage of MQW lasers is their tendency to be more susceptible to backreflections. MQW lasers also perform poorly as detectors. The isolator design in Figure 2 works with polarized light. In newer designs, the input and output polarizers are replaced with birefringent crystals which eliminate the sensitivity to the polarization of the light.

Figure 2 - Generation of AM Noise by a Fabry-Perot Cavity



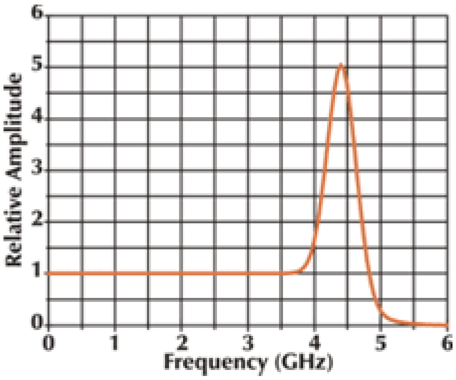
The amount of rejection offered by an optical isolator will improve problems caused by backreflections, but often will not eliminate them. The effects of these backreflections can disrupt a fiber optic transmission system. Figure 3 shows a laser waveform with no backreflection, and Figure 5 shows a laser waveform with a strong backreflection.

Figure 3 - Laser Optical Output With No Backreflection



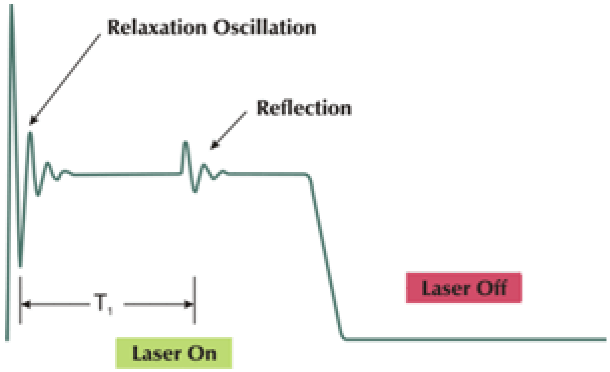
First the waveform in Figure 3 needs some explanation. As seen in the figure, the rising edge is followed by a damped oscillation. This overshoot and the subsequent oscillation is called the relaxation oscillation. Most lasers exhibit this phenomenon. It can be understood by looking at the frequency versus amplitude response of the laser as illustrated in Figure 4.

Figure 4 - Frequency versus Amplitude Response of a Laser



The laser exhibits a resonance (high gain point) near 4.4 GHz in this case. This will be the approximate frequency of the relaxation oscillation. The frequency of the resonance peak is a factor that limits the maximum data rate a given laser can transmit. When the maximum frequency component of the data stream gets close to the laser resonance frequency, performance degrades quickly. The frequency of the resonance and the magnitude of the overshoot depend on the drive levels applied to the laser. Overshoot is generally most severe when the laser is turned completely off and then back on. This condition is avoided in most practical data links by keeping the laser always above the threshold. The backreflection illustrated in Figure 5 shows the same characteristics as the initial relaxation oscillation. The time, T1, can be precisely measured to determine the distance to the reflecting point. Often, the frequency has to be greatly reduced to observe such reflections. One fallacy is that only close reflections matter. Closer reflections are often a bit stronger, but at 1310 nm or 1550 nm, fiber loss is so low that reflections from a distance of several kilometers can be significant.

Figure 5 - Laser Optical Output With Backreflection



Unfortunately, optical isolators do not substitute for properly polished, low-backreflection connectors. The technology for modern splices has advanced making fiber optic connectors the main source of IIN. In order to address the backreflection problem, the fiber optic industry first introduced PC (Physical Contact) polished connectors and later

Angled Physical Contact. The APC connectors especially go a long way towards eliminating any concern of backreflections from the fiber optic connectors. (IIN is even generated by the fiber itself, but that is a minor effect and beyond the scope of this discussion.) The basis for IIN, Rayleigh scattering, is the basis for a popular piece of fiber optic test equipment, the Optical Time Domain Reflectometer(OTDR).

Conclusion

Backreflections can be observed by monitoring the photodiode servo-loop for disturbances. To do this, place the end of the laser pigtail in glycerin, which will eliminate virtually all backreflections. Then note the output of the servo loop at that time. Afterwards, connect the laser pigtail to the system. Any significant perturbations noted are backreflections of sufficient amplitude to disturb the standing wave in the laser cavity. This directly observes laser backreflections. A less direct test for laser backreflections involves testing at frequencies where backreflections will occur at an exact multiple of the bit time. Basically, this procedure calculates the round trip transit time to the potential reflection interfaces in the system. It is generally easiest to measure the spacing between the high interference points when using this method. Often, the laser pigtail is made very short so that the first reflection occurs at a frequency higher than any frequency being transmitted by the system. However, longer fiber segments in the system will yield a low fundamental interference frequency and harmonics that will clutter the spectrum. Designing laser-based systems for low backreflections remains the only practical strategy.

Source: http://www.fiber-optics.info/articles/laser_backreflection_-_the_bane_of_good_performance