

LIVE-FIBER OTDR TESTING: TRAFFIC AND MEASUREMENT IMPAIRMENTS

022

TECHNICAL NOTE

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Motivations for Testing Live Fibers

Monitoring equipment for detecting and locating bends, material degradations or breaks in optical fiber networks is traditionally set up on dark fiber as this provides good balance between material cost, system provisioning effort and fault detection success rate. Most monitoring systems used for physical fault detection and positioning employ OTDRs; a dark-fiber monitoring approach typically uses a 1550 nm window test unit since this window produces lower fiber attenuation, maximizing the measurement range. Skipping over terminals, amplifiers and OADMs only requires optically connecting the appropriate ports and the next segment becomes visible for the OTDR, with almost no additional loss. It is also a well-known fact that monitoring only a few fibers within a cable geometry and structure (such as its outer part, one per tube or one per ribbon) is enough to provide information about the optical link quality.

So why is live-fiber testing and monitoring generating such rising interest?

- There may just not be enough dark fiber available to provide good fault detection sensitivity.
- In many situations, degradations can be very local (such as a connection removed voluntarily or not, a worn-out splice, aerial cable damage due to bullets, rodents, sabotages where only a few outer fibers were cut). So depending on the regional problems that are experienced or foreseen, the dark-fiber logic may not apply. In these cases, live-fiber monitoring or testing becomes the only solution that can provide complete surveillance.
- More importantly, optically testing live segments is a straightforward method to correlate transmission and physical path errors. In a long-haul system, more than 100 km can separate two network elements, a considerable distance to deal with if the only information is a B1 byte status change, signaling a specific section fault in the SONET/SDH section overhead coding. In metro, core or access networks, the trend is to remove expensive fast-detecting and processing electronics by optically switching paths, which directly remove points of surveillance between destinations. Unless these intelligent optical switches can embed an optical surveillance function, this movement drives the need for live-fiber and optical signal monitoring.

Deploying OTDR-based live-fiber testing and monitoring requires solid understanding of the stimulated Raman scattering (SRS) cross-effects between the OTDR's high-power pulses emitted in wavelength windows such as 1625 nm or 1650 nm and the traffic, generally emitting in the C and/or L band. To some degree, Raman scattering can affect both the OTDR dynamic range and the live signals. Minimizing stimulated and spontaneous Raman scattering is therefore a must in order to achieve seamless integration of OTDR-over-traffic signals. For our purposes, we will not specifically address the additional loss caused by wideband multiplexers used for injecting (and by-passing active elements) OTDR signals into live fibers; however, it is common understanding that these devices basically reduce the margin on transmit/receive lines by few dBs. This technical note provides some experimental results and a few design rules to adequately address the Raman scattering problem.

Spontaneous Raman Scattering (SRS)

Raman scattering can be spontaneous and eventually stimulated. The phenomenon starts occurring when signals in the medium get to an intensity level at which a small fraction of the incident wave starts generating new frequency-shifted waves propagating in both directions. This spontaneous emission occurs due to the fiber medium's vibrational modes, widely spread around the Raman gain peak, whose frequency is about 13 THz from (~100 nm) the pump's wave frequency. Spontaneous Raman scattering, which is usually a negligible feature for transmission system, becomes an important limitation for live-fiber monitoring. This is due to the fact that a non-negligible fraction of the traffic signal is scattered in the OTDR wavelength band and adds to the Rayleigh backscattering measured by the OTDR.

Stimulated Raman scattering is a well-known limitation for ultra-high-power transmission. As its threshold is in the 1 to 2 W range, it is usually negligible for low- to medium-traffic power level. In the context of live-fiber monitoring with long wavelength OTDR, the WDM traffic acts as a pump and the OTDR pulse acts as a signal that is being amplified. Since the OTDR power provides a seed for the amplification, Raman gain can be experienced at a power well below the usual threshold for stimulated Raman scattering. In the case of an OTDR pulse propagating at a wavelength where Raman gain exists, the OTDR pulse will acquire energy from the traffic and experience some gain. This energy transfer depletes the traffic bits amplitude.

The parameters that can control the amount of SRS are the following (somewhat in order of importance):

- The transmission, or pump, signal intensity and distribution along the fiber
- The OTDR pulses peak power level and propagating direction (co- or counter-propagating relative to pump)
- Difference in frequency between the pump and the seed (here, the OTDR pulse)
- The fiber type used for transmission, from which a Raman gain coefficient is derived

Experimental Setup

In order to measure this effect, we used a simple setup as shown in Figure 1. The setup reproduces a typical live-fiber RFTS system, except that the traffic is replaced by an amplified CW signal.

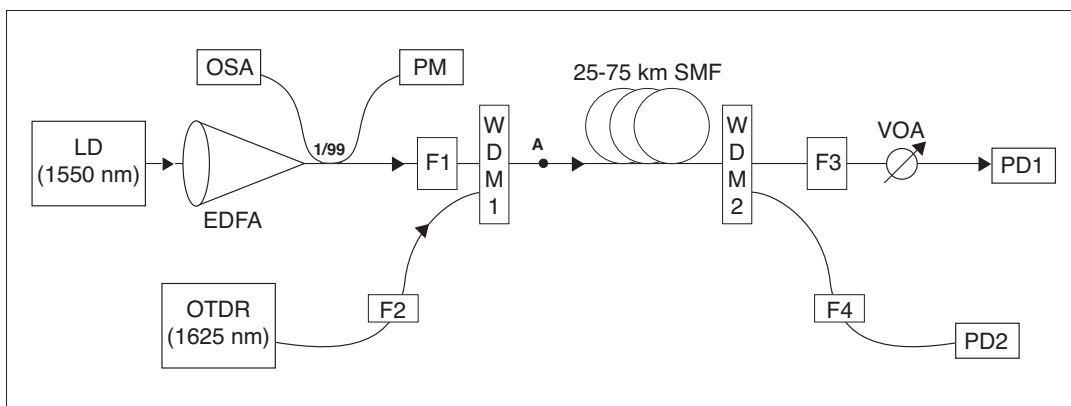


Figure 1. Experimental setup for live-fiber testing assessment

Item	Description/Model	Comment
LD	EXFO IQ-2400 DFB Laser with low SBS settings	Power: 2.5 dBm Wavelength: 1550.2 nm
EDFA	EAD-10-C (IPG-Photonics)	Used as a booster
F1, F3	BFC-16-13/15-N-9-1 (DICON)	1625 nm band; blocking filter
F2, F4	BFC-13/15-16-N-9-1 (DICON)	1310/1550 nm bands; blocking filter
WDM1, WDM 2	FCW-13/25-166-N-9-1 (DICON)	Three ports; 1625 to 1550 nm; WDM
PD1, PD2	Photodetectors	PIN with 50Ωload
OSA	EXFO IQS-5250B OSA	
PM	EXFO IQ-1103	Power monitor
VOA	EXFO FVA-60B-850-RS	Variable attenuator
OTDR	EXFO IQ-7534B-B-E1	1625 nm
SMF	SMF-28 (TM) Fiber	3 x 25 km fiber rolls
SCOPE	hp Oscilloscope: 54520A	500 MHz (not shown)

The configuration uses a single-wavelength source at 1550 nm. Due to the broadband nature of Raman interaction, a setup with only one wavelength representing the traffic is believed to be representative of the impact of a multiwavelength system (WDM). In first approximation, this is true when the total power and wavelength range of a WDM system is equal to the power and central wavelength of a single-channel system.

Traffic Depletion

When the traffic and the OTDR are co-propagating, all of the energy transferred to the OTDR originates from the bits that are 'synchronized' with the OTDR pulse (see Figure 2). This will cause a sudden depletion of the traffic amplitude. This sudden reduction of power may cause a significant BER increase. In the case of counter-propagation, the OTDR pulse takes energy from different 'parts' of the traffic signal so the effect on the traffic will be much less severe (in fact, it can be neglected). The gain on the OTDR pulse is expected to be roughly the same for co-propagating and counter-propagating directions

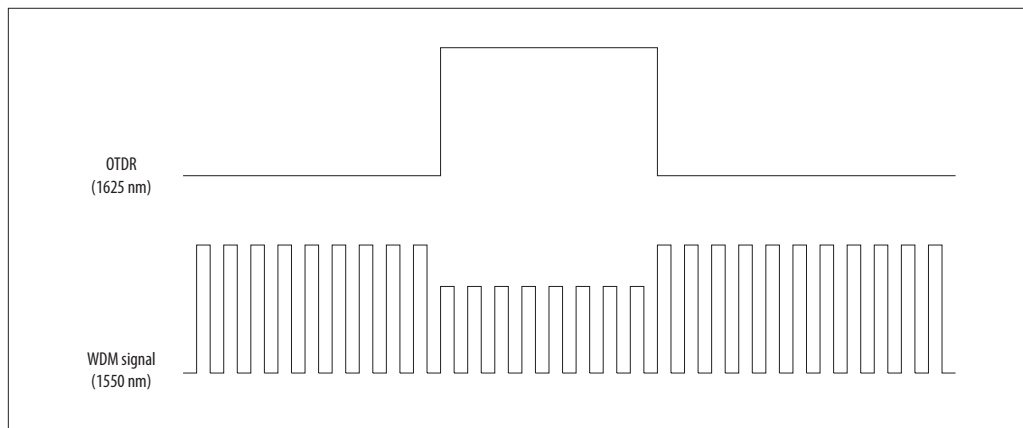


Figure 2. Amplitude of WDM signal as a function of time (co-propagation).

The experimental measurement and theoretical prediction of the WDM depletion as a function of pump power (WDM power) and OTDR power is shown here for a co-propagation case.

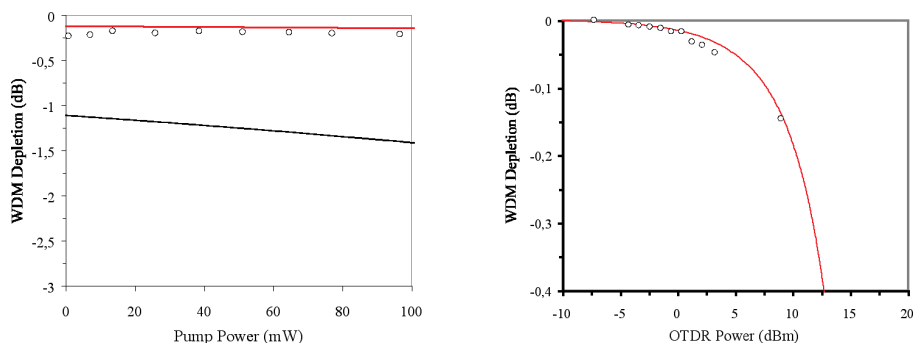


Figure 3. Graphic representation of WDM depletion vs. power

Figure 3 (left) illustrates an experimental measurement of WDM depletion (circles) and theoretical prediction (thin solid line) as a function of WDM pump power for an OTDR power of 8 mW (25 km SMF). The dotted line represents the theoretical WDM depletion in the case of a 50 mW OTDR and a 100 km SMF link. The figure on the right shows an experimental measurement of WDM depletion (circles) and theoretical prediction (solid line) as a function of OTDR power for a WDM signal power of 50 mW (5 km SMF).

These figures demonstrate that the percentage of depletion is not affected much by the traffic power. The depletion is significantly more affected by the OTDR power. In this experiment, we used the more powerful 1625 nm OTDR available (IQ-7504, 100 mW laser), less the component loss between the OTDR and the fiber spool. Looking at the dotted line in Figure 3 (left), we can see that the depletion will be important if a high-power OTDR signal is injected efficiently in a fiber. Accordingly, using high-power (large dynamic range) OTDRs in co-propagation situations would not be recommended.

OTDR Distortion

We know that the energy lost by the traffic is transferred to the OTDR pulse. This causes some OTDR pulse amplification as it propagates through the live fiber. The OTDR trace will be distorted accordingly. A lower apparent attenuation will be observed on the OTDR trace as seen in Figure 4.

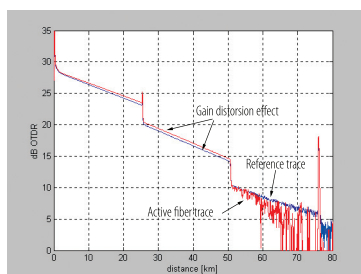


Figure 4. OTDR trace, with and without the presence of traffic.

An OTDR Raman gain of 1 dB will not cause any significant problems if the reference trace and further acquisitions are taken with a similar level of traffic. As we will see next, the significant increase in noise floor clearly shown in Figure 4 occurs well before distortion appears as a limiting factor.

The experimental measurement and the theoretical prediction of the OTDR gain (Raman gain) as a function of WDM power is shown here for a 25 km link of SMF fiber.

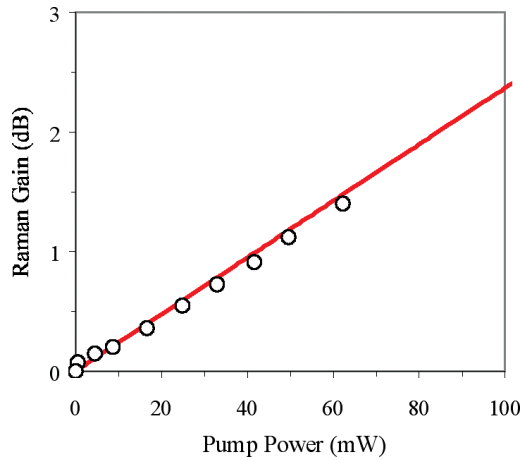


Figure 5. OTDR gain (Raman gain) as a function of WDM power for a 25 km SMF fiber, experimental data (dot) and theoretical data (solid line) for a 10 mW OTDR pulse power.

OTDR Penalty Due to Spontaneous Raman Scattering

The most troublesome impact that can be seen in Figure 4 is the rise in noise floor on the OTDR trace. This is due to the presence of significant spontaneous Raman noise scattering. Since this noise is created in the supervisory 16xx nm region, it is directed toward the OTDR port by the RFTS WDM coupler.

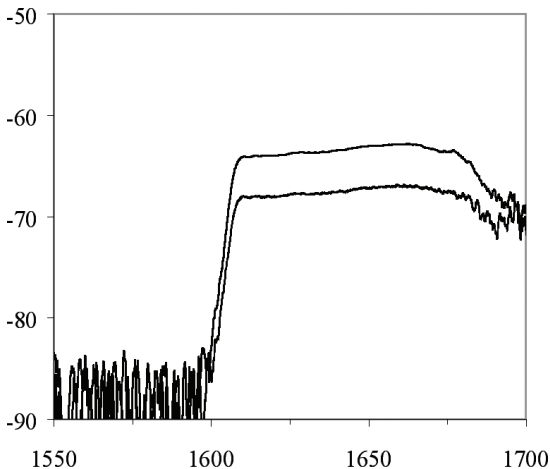


Figure 6. Raman scattered noise spectrum measured at the OTDR port with a 1 nm OSA resolution bandwidth for a 16 dBm WDM power.

WDM Signal power (dBm)	Backward spontaneous noise at OTDR (dBm)	OTDR dynamic range penalty (dB)
+8	-48.5	3
+2	-54.5	2
-3	-59.5	1
-6	-62.5	0.5
-10	-66.5	negligible

Table 2. OTDR penalty measured as a function of transmitter power (1546 nm) for a 50 km SMF link (co-propagation)

We see that there is roughly a 52 dB difference between the 1550 nm of injected power and the 16xx nm of backscattered power. Even if the backscattered signal is very low, it is known that the presence of a -60 dBm CW power injected toward the OTDR output port raises the OTDR noise floor. The maximum traffic power allowed in co-propagation is -3 dBm so that no significant penalty is applied to the nominal OTDR dynamic range. At -40 dBm, the OTDR will stop working because of receiver saturation. This is certainly the most important limitation to live-fiber monitoring at 1625 nm.

When the testing or monitoring is performed in the counter-propagation direction, it is the forward spontaneous Raman scattering that becomes critical. For a 25 km SMF link, the forward and backward spontaneous Raman scattering values are very similar (only a few dB difference). However, on a longer link, the forward scattering that is measured at the output of the fiber decreases compared to a shorter link. This is because most of the scattering is generated in the first part of the link (say, the first 30 km) and is then attenuated by the remaining fiber. So for a long link, monitoring in counter-propagation will be less affected by the added noise due to spontaneous Raman scattering. For a long link (100 km), forward scattering will be 12 dB lower than backward scattering.

Effects Summary

Coupling an OTDR to a live fiber for testing purposes requires adding WDMs and filters to protect transmit/receive equipment from the backscattered or transmitted OTDR signals. Component insertion loss, isolation and cross-talk specifications are the first issues to consider in the implementation of live-fiber OTDR testing. Once the link loss budget is established with these new components, system engineers, helped by EXFO technical staff, should evaluate the impact of SRS on both the OTDR performance and, eventually, on traffic depletion.

The principal limitation to live-fiber monitoring at 1625 nm (and any wavelength within a large range about 100 nm beyond the transmitting signals), will come from the spontaneous Raman scattering noise that reaches the OTDR port. Since the OTDR is a very sensitive device, it takes a rather small CW signal at its input to raise the noise floor. This typically limits the maximum amount of traffic that can be injected in a live system. Counter-propagation live-fiber OTDR testing, due to the non-synchronized nature of OTDR pulses and traffic signals, provides definite advantages, especially in case of rather long links, since it does not only reduce the spontaneous noise reaching the OTDR, but also blurs the stimulated Raman scattering. In case of bidirectional transmission, OTDR power and transmission power levels may require adjustments so that the effect remains negligible.

The Future of Live-fiber Testing and Monitoring

Live-fiber testing and monitoring is defined as a non-intrusive test on a given fiber, whether it is one section or multiple sections carrying live data, voice or video signals, for assessing the quality of an optical fiber link. The use of an OTDR for detecting and locating degradations is more valuable on live fibers than on dark ones because one can measure, pinpoint and eventually correlate problems raised by other systems dedicated to measuring signal quality such as BER, Q-factor or other more sophisticated parameters. Dark-fiber monitoring has a clear advantage compared to a live-fiber approach because it is simple and cost-effective to implement, and by nature, it is a non-intrusive method.

EXFO researchers and engineers continue to work at diminishing the impact on traffic and on the quality of the measurements so that the deployment of live-fiber testing and monitoring can be readily available and applicable to most situations.



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