Application Note

Correlation OTDR based fiber optical fault locator
exemplary signal behaviour

Introduction

This application note describes the signal performance of the correlation OTDR based fiber optical fault locator module (FL) and gives some initial help for troubleshooting for users starting with the device.

The current hardware and firmware release corresponds to the instruction manual version 2.6 of January 2006. The most recent instruction manual should be referred to get initial information about the working principle of the device and its controls including command lists for the interface. Customers who start programming a control and analysis software for the module should carefully review information supplied in the manual.

The standard FL product is intended to operate with single mode fiber and currently the majority of applications work with such fiber (SMF). The following test data have been achieved with SMF unless noted contrary.

Measurements at fiber lengths up to 10 km

According to the currently specified resolution of the FL modules of 5 meters measurements typically span a fiber length of at least 1 km. Doing so the number of sample points is large enough and in the same range of order of the available sample points of the FL module (256).

The fact that Rayleigh backscattering integrates over distance is an argument for not choosing a lower than 5 m resolution: the hardware allowing a resolution of down to 1.3 m would not detect enough Rayleigh scattering to identify loss events along the fiber. It should be mentioned also that at a resolution better than 5 m due to high-frequency crosstalk in the FL electronics a ringing signal might be observed within the first few sample points. See the manual to check whether or not the device is specified for a resolution better than 5 m.

Nonetheless in this first section of the application note we will discuss some results measured with less than 5 m resolution. To prevent disturbances by the ringing signal a usual trick is to use some pre-fiber, thus shifting the start of the test fiber out of the affected area.

In fig. 1 the pre-fiber length is slightly above 100 m and the tested fiber length < 100 m. The coupling between both fibers is done by FC/APC connectors. The second peak visible is from another FC/APC connection in 4 m distance. The tested length is terminated by an FC/PC connection shown by the third and largest peak. Behind the FC/PC connector approx. 1km of extra fiber is installed to shift any large reflection from an open fiber end or connector out of the window of view.

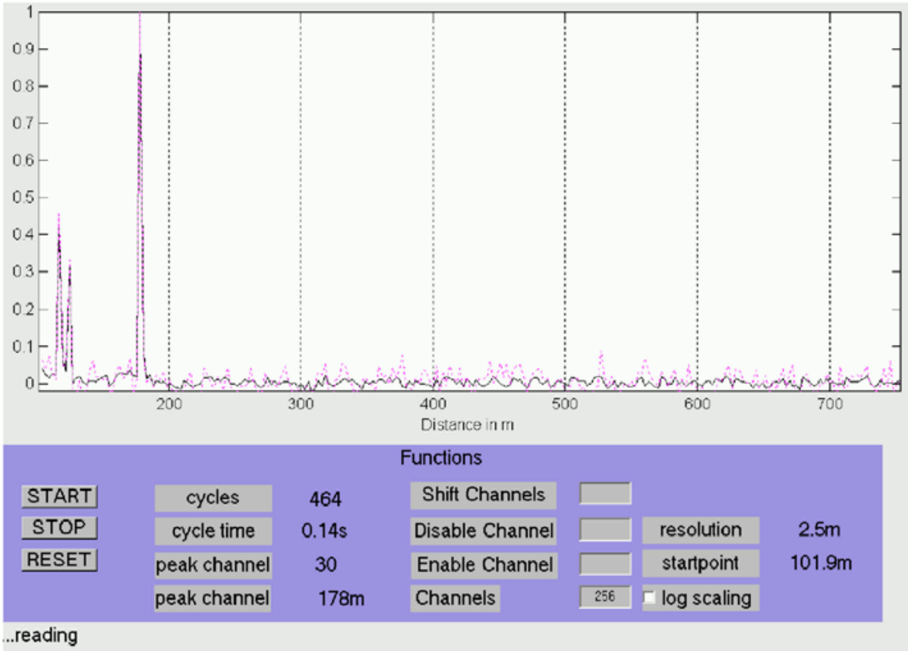

Fig. 1: Two FC/APC connections and a FC/PC connection within approx. 80 m test fiber

Please note that the display doesn´t start at the beginning of the test fiber – the window of view is shifted by 101.9 m to the left into the pre-fiber region. The signal strength is quite large. The result of the measurement (red line) occurred within 0.14 s. Averaging doesn´t improve the signal much (dark line) – the residual noise represents artefacts of the measurement procedure.

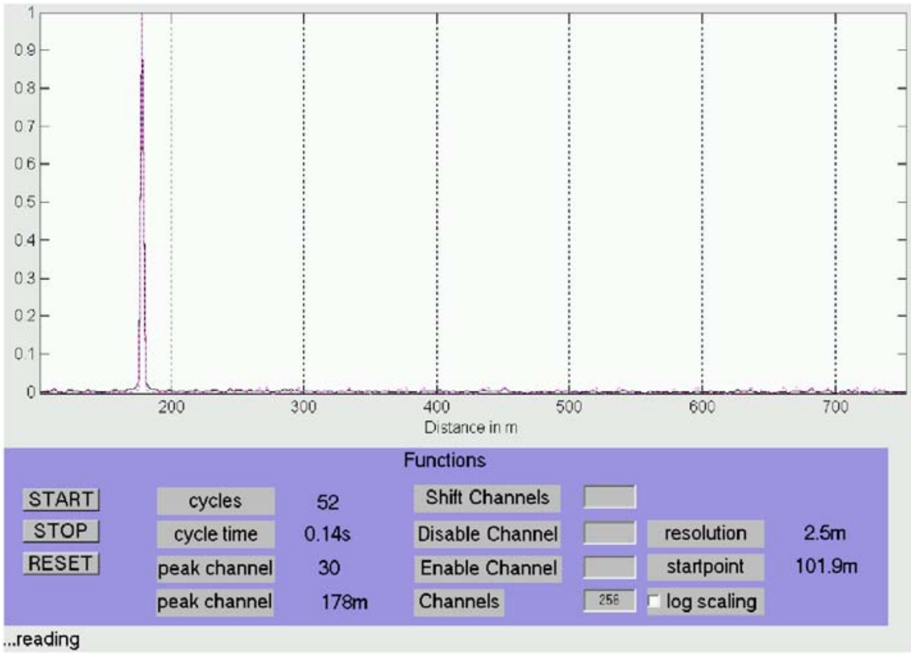

Fig. 2: Two FC/APC connections and an open FC/PC connection within approx. 80 m test fiber

In fig. 2 the third connector (FC/PC) is opened and as a result its large reflection dwarfs the signals of the two FC/APC connections visible in fig. 1. When bending the fiber ahead of this open FC/PC connector, thus inducing a loss to this reflection signal, the relative sizes of the FC/APC and FC/PC connector reflections re-establish – see figure 3. The exact location of the bending attenuation cannot be determined due to the lack of Rayleigh signal at this high resolution setting. Please note that the attenuation is strong enough to decrease the high 4 % reflection signal to a value lower than the relatively small reflection strengths of the FC/APC connections.

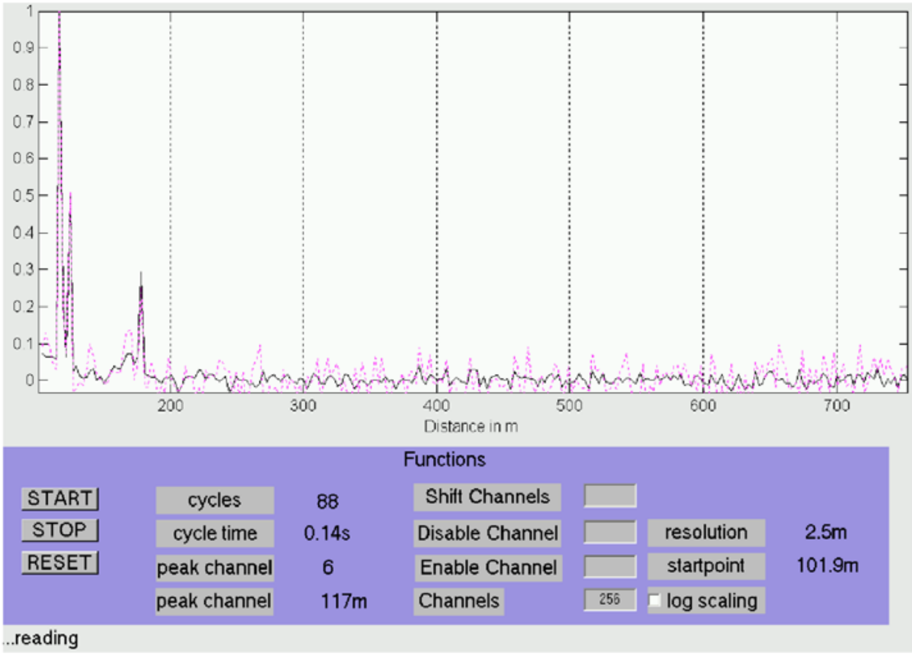

Fig. 3: Two FC/APC connections and an open FC/PC connection within approx. 80 m test fiber, plus an attenuation applied ahead of the open connection

Another test setup consists of 2.85 km graded index multimode fiber (62.5 µm core diam.), see figures 4 and 5. In fig. 4 the FL module is measuring an approx. 330 m wide region (1020 m – 1350 m) where attenuation was induced by bending. This attenuation then adds to the fiber attenuation of 2.3 dB/km at 850 nm (the operation wavelength of the FL module). When averaging over 58 measurements (duration is 20 s) the location of the induced weak attenuation event can be determined.

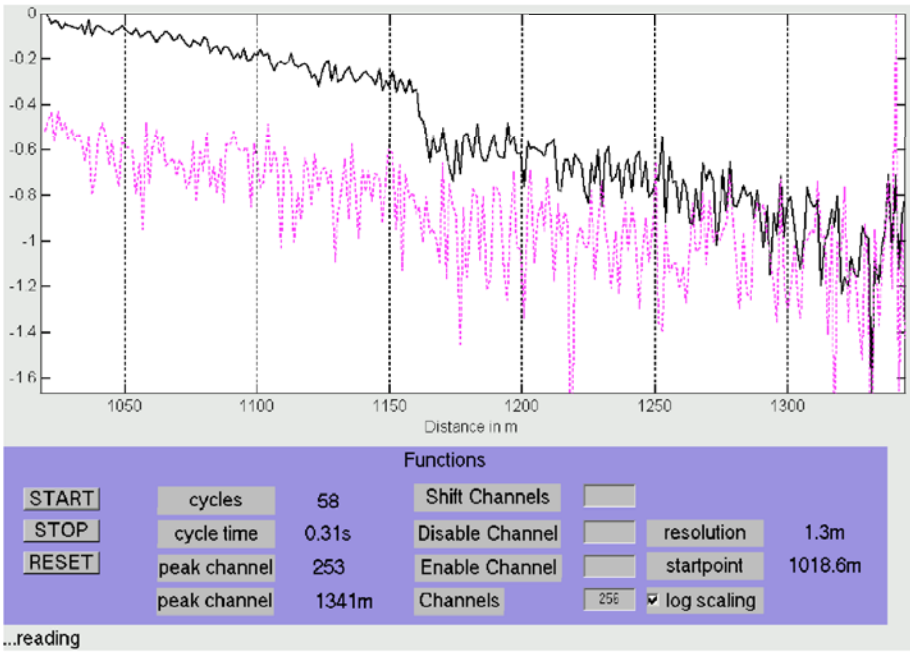

Fig. 4: 0,05 dB attenuation induced to a G62.5 fiber of 2.85 km length. The averaged signal (dark line) is observed at 1.3 m resolution

A standard FL module was modified prior to the test with the G62.5 fiber. Uncritical changes are the replacement of a single-mode coupler by a multi-mode coupler and the change to a multi-mode fiber-coupled laser diode at different wavelength. More critical to changes is the receiver side because any change in bandwidth influences the transfer function of the module. The convolution of signal and a non-flat transfer function deforms the measured signal shape. The chosen receiver at 850 nm is not as optimized as the longer wavelength receiver model. As a consequence one can observe stronger deviations in the exponential Rayleigh slope compared with the standard module. As an example see figure 5. Here the 0.05 dB attenuation of figure 4 is replaced by a 1 dB attenuation. Even though the actual Rayleigh level is reduced behind the attenuation, the Rayleigh signal visible in the graph increases because of the transfer function influence. Such behaviour has to be considered if it is planned to use or program automatic FL signal analysis software.

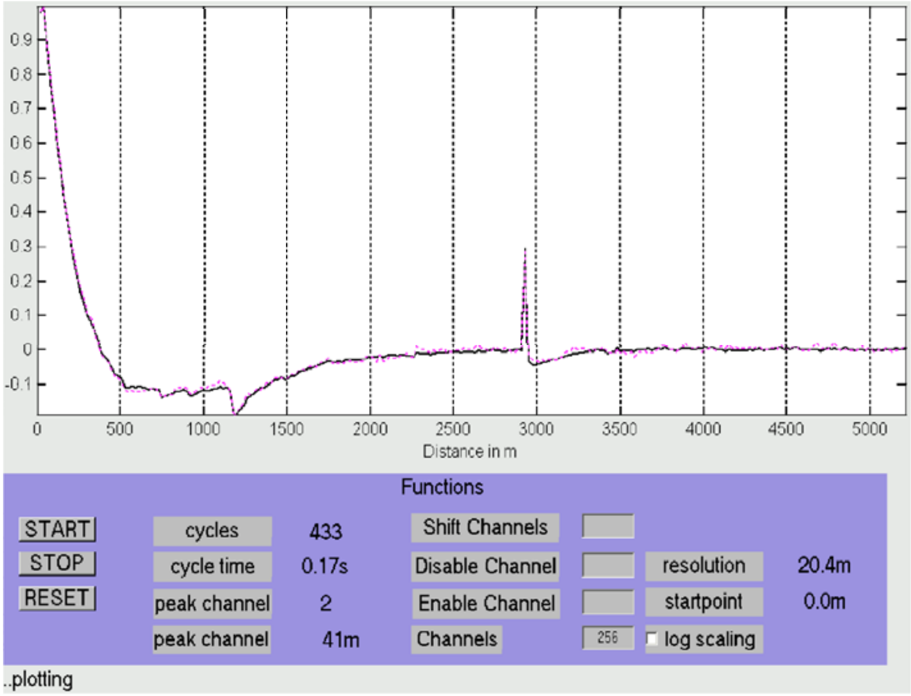

Fig. 5: 2.85 km of G62.5 fiber measured at low resolution. Notice the loss event at 1.2 km and the overall Rayleigh signal distortion caused by the device function.

Going back to standard single mode fiber: the FL module in the setup that is discussed below is operated with 1 mW laser power at 1300 nm. At this wavelength a total attenuation of 2.6 dB within 8 km length is resulting. The fiber is terminated with an angle-polished connector (E2000 HRL) that is either open (fig. 7-9) or connected to an additional length of fiber (fig. 6). Aim of the test is the investigation of measurement time and the influence of averaging on the signal performance.

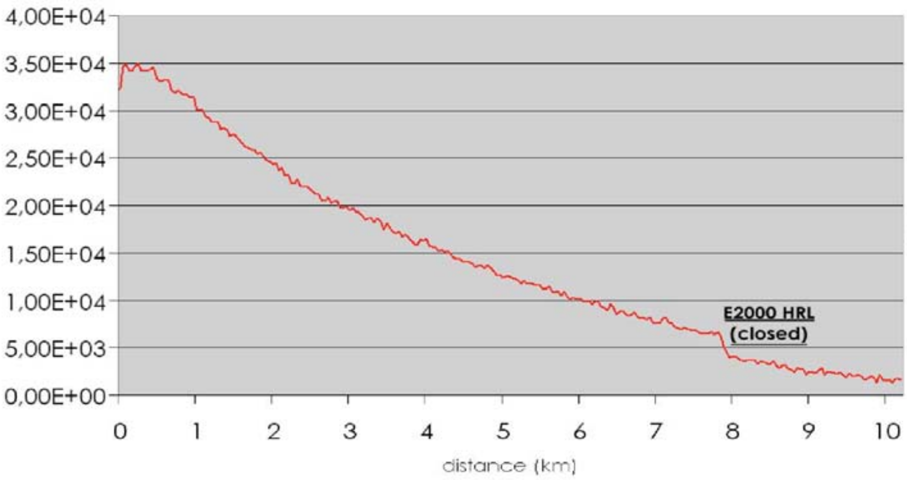

Fig. 6: 6 s measurement time (10 averages), raw data (y-axis in a.u.)

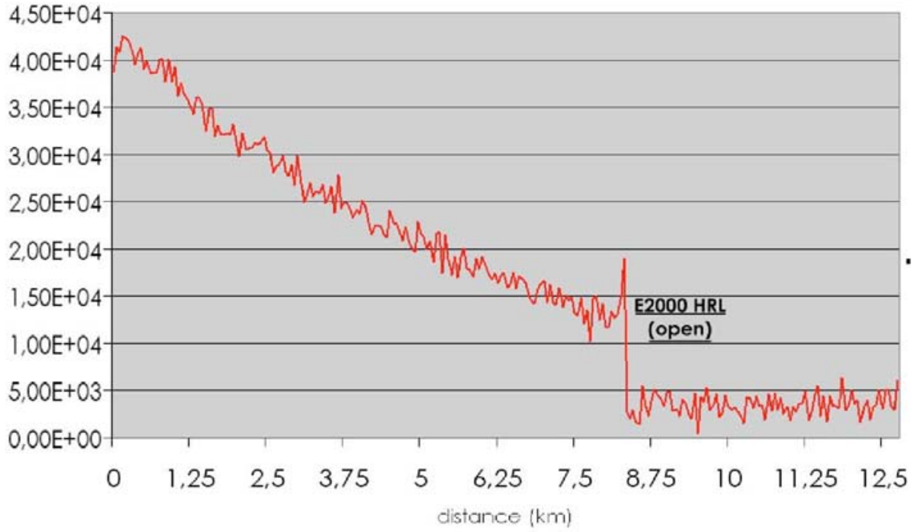

Fig. 7: 6 s measurement time (10 averages), raw data (y-axis in a.u.)

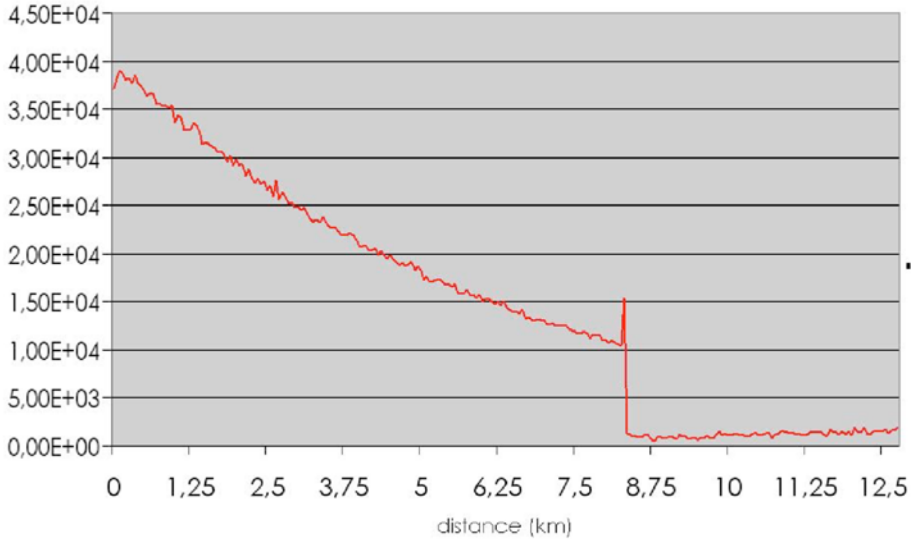

Fig. 8: 18 s measurement time (30 averages), raw data (y-axis in a.u.)

When zooming into the connector region the E2000 HRL fiber end (reflection plus loss) can be precisely located without averaging within 1 s (see fig. 9).

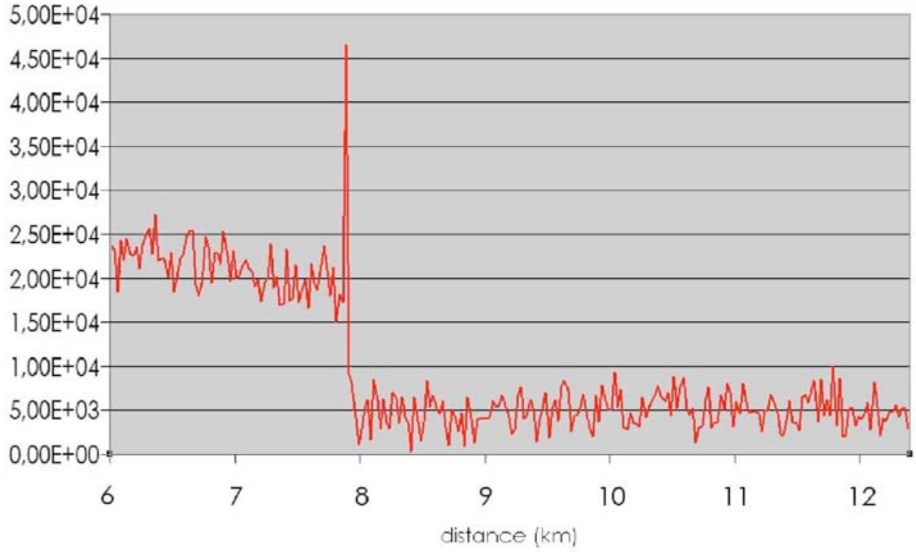

Fig. 9: 1 s measurement time (no averaging), raw data (y-axis in a.u.)

All these test results show that both reflective and absorptive events can be well detected because Rayleigh scattering is detected easily at a rather short measurement time in a distance up to 10 km.

Measurements at fiber lengths between 10 km-30 km

Using larger fiber lengths Rayleigh scattering and so attenuations are usually detectable only when signal averaging is introduced. Resulting measurement times are several seconds up to some dozens of seconds.

As an example a test with a 25 km fiber of SMF will be discussed. The measurement is again done with 1300 nm operation wavelength and 163 m resolution. The displayed signals arose from 50 averages with a total measurement time of 1 minute. Both pictures 10 and 11 show a 20 km fiber followed by a 5 km test length. All connectors are FC/APC, the second fiber end is kept open. In between both fibers a variable attenuator is placed: in fig. 10 a loss of approx. 0.4 dB and in fig. 11 a higher loss of approx. 1.2 dB is introduced.

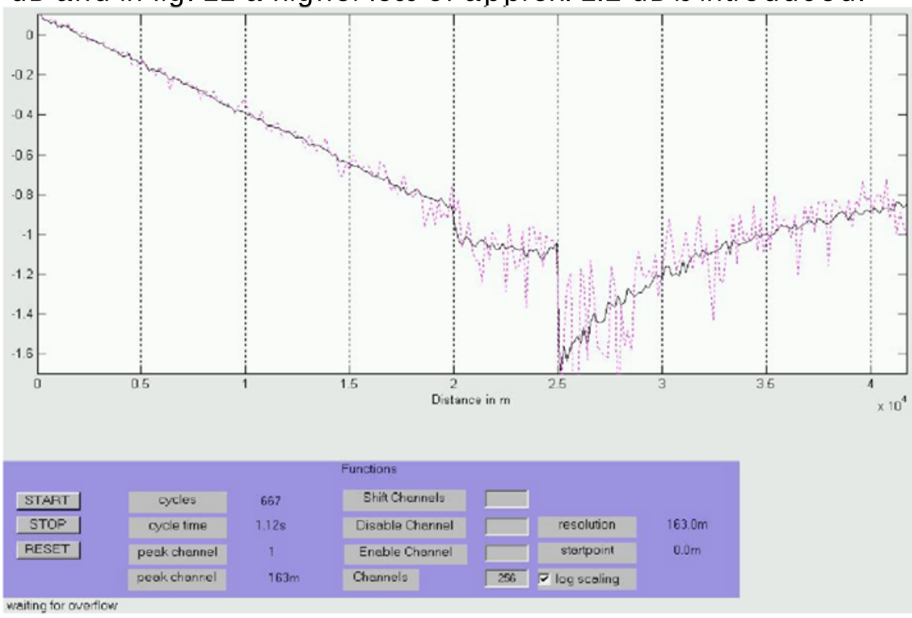

Fig. 10: 20 plus 5 km test fiber, connected with 0.4 dB loss (1 min ave, logarithmic scaling)

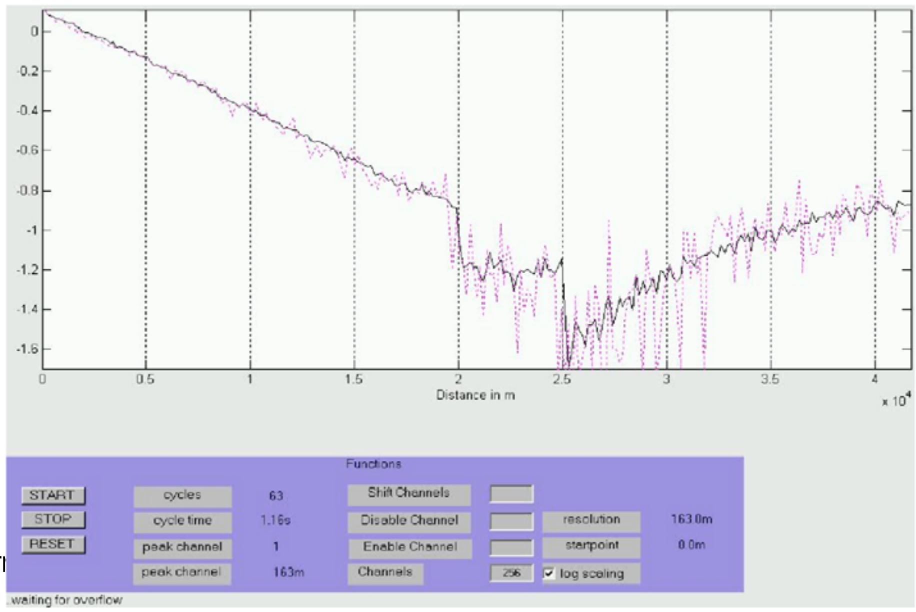

Fig. 11: 20 plus 5 km test fiber, connected with 1.2 dB loss (1 min ave, logarithmic scaling) Both the variable attenuator and the fiber end are clearly visible. The display modus of the GUI is a semilogarithmic scale. Please note that this modus has to be introduced carefully to the raw data. The actual zero line needs to be positioned a little below the minimum data level to gain from the logarithmic scale. Positioning too little below the minimum data level results in strong amplification of the signal noise level and in amplification of the transfer function. The artificial strong increase in Rayleigh signal just behind the fiber end at 2.5 km in figures 10 and 11 is a residue of this effect.

In summary it can be established that absorption still can be detected when observing an integral length of fiber in the range 10-30 km because Rayleigh scattering is detectable in a reasonable integration time. The Rayleigh slope may already be deformed near to the fiber end due to the receiver transfer function. Please note that small absorptive events may become invisible when large reflective events are present. Nonetheless in a large number of cases signals of such large reflective events can be eliminated by the FL's "disable channel" commands. This procedure then permits the search for absorptions.

In comparison with testing a fiber length smaller 10 km which often allows to locate absorptions in a single shot (measurement time is less than 1 s to a few seconds), for testing 10 km to 30 km fiber signal averaging is needed to see such events. This results in a measurement time of more than 10 s but typically less than 1 minute if a particular absorption event needs to be located in a distant section of the fiber.

Measurements at fiber lengths above 30 km

Further increase of the fiber length causes the device function becoming dominant when observing the whole fiber at low resolution. Due to the detection limit of -100 dB it is recommended to use an FL equipped with 1550 nm or 1625 nm laser diodes to allow a long measurement distance. The longer wavelength compared with e.g. a 1310 nm laser source produces less absorption per Kilometer.

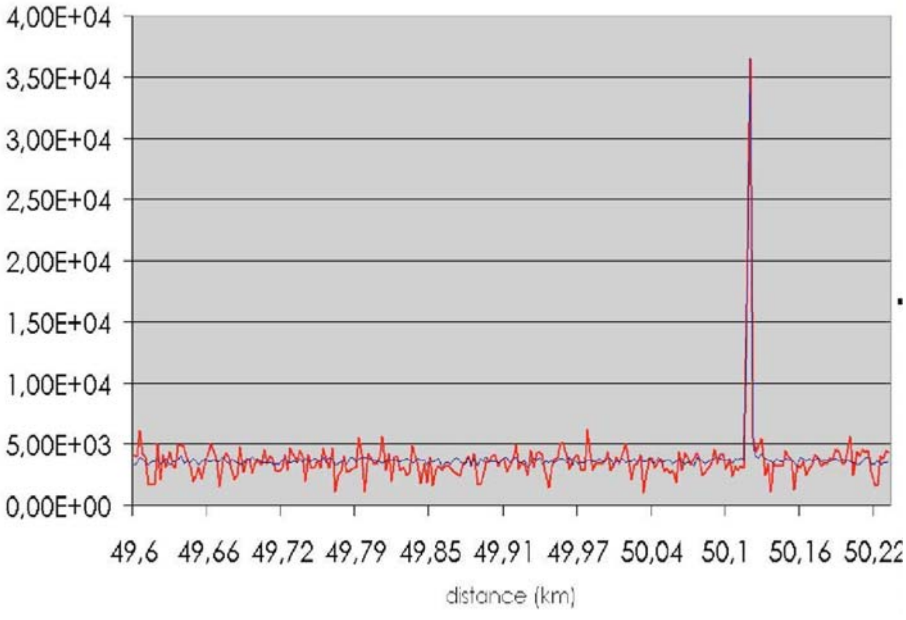

Fig. 12: open FC/PC connector at 2.5 m resolution in 50 km distance: 0.1 s measurement time per shot (red) and 30 averages (blue)

Figure 12 shows the signal of an open FC/PC connector at 50 km down the fiber. The measurement time for detecting such a reflective event at 50 km distance is still very short (0.1 s). The test is done at 1.3 µm wavelength and the total attenuation of the signal is -80 dB (assuming a 4 % reflection equals -14 dB and 100 km total length times 0.33 dB/km attenuation). Replacing the FC/PC end with an open APC connector and searching for its reflection is not successful. Within a reasonable integration time of 1-2 minutes the fiber end cannot be detected anymore.

Troubleshooting

It is expected that the manual gives all information about how to operate the FL module. However, when starting to work with the product there may arise difficulties. So some hints and comments about mistakes from other users may help. The following sections are intended to support the user in such a way. The subsequent comments will not spare from carefully reading the manual and also should not be considered being complete.

No signal

Receiving no signal after displaying the readout of the device can have different reasons that should be investigated (in the range of order according to the number of cases reported):

1) The laser diode power is too low because it is adjusted to a low value. This can be tested by sending a command through the interface that sets laser power to 100 %.
2) There is observed with high spatial resolution a section of the fiber that does not contain „events“ (reflections or absorptions). At high resolution Rayleigh scattering does not add up much as well and the integral signal assigned to a sample point is low: so far the signal is noisy and flat. To double-check against improper operation of the hardware make sure that an event signal is present e.g. by shifting the window of view or by producing a good Rayleigh slope via choosing less spatial resolution (minimum 10 m).
3) Finally there might be a hardware problem such as a broken fiber or a defect in the electronics. This cannot be fixed nor identified by the customer in all cases. Nevertheless it helps to clarify the situation if it is possible to measure the FL output power with a power meter: The average power at 100 % power level should be in the range of 0.2 mW to 2 mW (1300-1625 nm) for most of the standard products. Output power should be detectable independent of an FL measurement running or finished.

More experienced users may also note a difference in the measurement time until the device is ready for readout: Having no power (item 1 and 3) causes a longer measurement time then case 2 even if the signals may look similar.

No Rayleigh slope

Users having experience with pulse OTDR measurements usually expect a distinct Rayleigh slope over many orders of magnitude along the fiber. This generally can not be expected in case of FL traces, as discussed in the earlier sections.

Having the right fiber length but no Rayleigh slope at all may have different reasons:

1) There is actually no signal. Except a not yet observed case (looking at delivered products) that there´s a major defect in electronics „no signal“ is recognized by a random /noisy flat readout. Choose a longer span between sample points (see the discussion above).
2) There is a dominant reflection. This reflection dominates the available dynamic range collected signal compared to the Rayleigh signal floor so that this Rayleigh signal appears to be flat (see fig. 2). The best solution is to avoid such strong reflection. Open fiber ends (flat polished) or non-contact connectors (like SMA) should be replaced by physical contact (or angle-polished) connectors. This is most likely possible if FL modules are used in sensor setups or in case of fiber optic links are operated by the user of the FL module. In all other cases one should try to shift the window of view so that the strong reflection isn´t observed anymore or to apply the „disable channel“ command on the sample point of the strong signal. Then changes of this signal cannot be measured anymore but the dynamic range is better used so that lower signals like the Rayleigh slope become visible. If this also does not yet help or in case that the strong signal needs to be observed the laser power should be lowered or (absorbing) pre-fiber is a good trick. These measures of course also have disadvantages (like longer measurement time) and do not always make a Rayleigh slope visible. But the general test performance is improved.

Signal disturbance

The measured signal may be superimposed by artefacts depending on the signal size and internal and external influences. The following effects have been observed:

1) Large figures read out from the device and caused by a long measurement time often are misinterpreted as a noisy disturbance (actually this is the case „no signal“)
2) The correlation OTDR is a sensitive device that can be disturbed by other optical signals entering the receiver. Looking at small signals at the test signal wavelength the detector can be blinded by other than test signal light. The sensitivity on such interference is especially strong in case that the stray light signal pattern is correlated with the test signal pattern (see fig. 13).

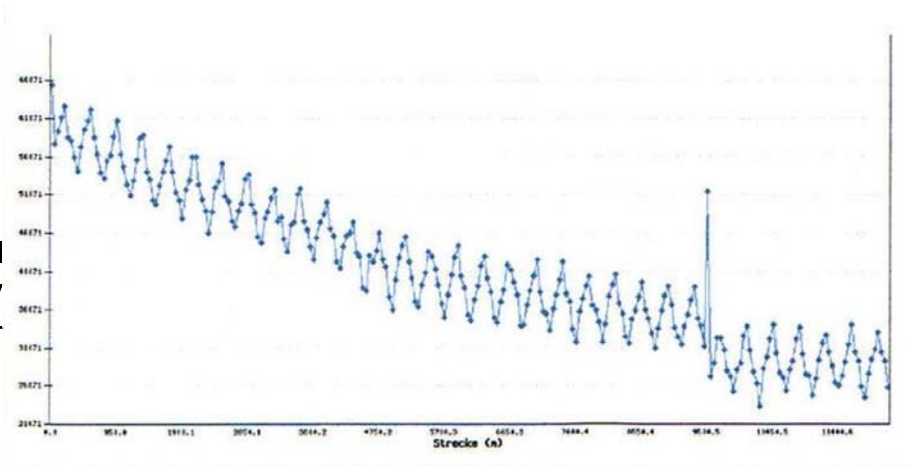

Fig. 13: Test signal superimposed by signals of counter-propagating communication lasers

The typical case for having optical cross talk to the test signal is having not enough isolation between the test signal and the communication signals within a fiber optic link. The WDM used to add/drop the test signal wavelength then should be replaced by a higher isolation version.