

# TESTING PROCEDURE FOR NETWORK DEPLOYMENT

## 086

### ■■■■ APPLICATION NOTE

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It is a widely recognized fact: demand for bandwidth keeps growing. The problem is, laying out new fiber is extremely expensive, so alternative solutions are looking increasingly attractive. As they strive to reduce total network costs, network operators are considering options such as speeding up the per-channel data transfer, lighting up new communication channels or even finding ways to transmit farther without having to regenerate or reshape the signal.

However, all of this is easier said than done. Sending more data down a fiber, over greater distances, brings into play various network characteristics, previously irrelevant, that can cause serious problems if not analyzed, understood and controlled. Carriers are looking ahead, and even though they are only using a few wavelengths now, they see the bottom-line benefits of a system capable of transmitting at 40 wavelengths or more. These large, powerful systems can take network performance to the next level, but they require proper installation, tuning and maintenance.

This application note reviews the critical parameters (and the order in which they should be tested) and the general criteria for quality transmission.

#### **Connector Inspection and Cleaning**

In each of the test procedures described hereafter, you should inspect and clean the connectors before hooking them up to the test equipment or another device. Dirty connectors can induce errors during network testing or commissioning; so you should also clean the test patchcords and the patch panel. Both ends of every fiber junction need to be squeaky clean.

Failing to do this can cause high loss and high reflection, as well as contaminate the equipment to which the connectors and patchcords will be connected. In addition, when inspecting a patch panel with tools such as EXFO's FIP Fiber Inspection Probe series or FOMS Fiber-Optic Microscope, finding defects can lead to believe that the rear mating connector has been dirtied or damaged. Therefore, it should also be inspected.

A recurrent problem might indicate that the cleaning procedures were not well understood or consistently applied. This is why following Telcordia recommendations is a safe way to go. Be careful if you are using compressed air, for it is not always perfectly pure and will sometimes leave dirt on the connector's endface.

When removing the protective caps, be sure to place them where they will not get contaminated themselves. Once cleaned, the connector should be inspected again to double-check the cleaning.

#### **Key Parameters**

##### **Event and Splice Loss Measurement**

With an optical time domain reflectometer (OTDR) such as EXFO's FTB-7000B or FTB-7000C, performance-inhibiting factors can be identified and located for later repair. These factors include bad or dirty connectors, fiber bends, bad splices, mismatched mode-field diameters, etc.

The OTDR plots the backscattered signal power as a function of distance within the fiber. It easily locates all events (bends, bad splices, etc.) that contribute to the overall loss and calculates the overall reflectance level. In addition, the OTDR accurately measures the fiber's length, so cuts or misrouted connections can be found.

Because unplanned events can and will affect overall performance, performing this test is essential, and problems must be corrected before any other test (loss, PMD or chromatic dispersion) can be conducted. Here is how the test works:

- The OTDR launches a pulse of light through the fiber at a wavelength within the transmission band of interest, and then measures the intensity of the returning power as a function of the departure time of the pulse.
- Taking into account the speed of light at the pulse's wavelength, the OTDR plots the pulse power vs. the fiber length. Ideally, and to cut testing time, you should perform a measurement each time a splice is done, as well as when fiber installation is completed (provided that the OTDR has a sufficient dynamic range).

Certain events, such as mismatched core sizes, cause an amount of loss that is different whether the light comes from one direction or the other—which is why it is recommended to test the link in both directions.

Also, some events incur higher loss at higher wavelengths. Testing in the C band (transmission band) will reveal what the DWDM signal will “see”, but testing in the L band can help reveal defects that would otherwise remain undetected. You should use the shortest possible pulse that will reach the end of the fiber with a good signal-to-noise ratio (SNR). This ensures the highest resolution and the shortest dead zone possible.

As for connector cleaning, OTDR test results should be evaluated by matching them against Telcordia specifications.

### Backreflection Measurement

Fiber and optical components exhibit a certain amount of backreflection; too much of it can affect the transmission quality. The reflected power comes mainly from Fresnel reflections, as well as local changes in the index of refraction—partly caused by components, connectors and splices. What's more, several components are naturally reflective, thus contributing significantly to the total backreflection. The last contributor to backreflection is the fiber itself, which creates backscattering as the light travels through it. The fiber's contribution is smaller, but it must be accounted for and minimized.

Too much optical return loss (ORL) can dramatically degrade system performance by corrupting data and destabilizing the laser cavity, increasing overall noise. It also affects the laser's linewidth and central wavelength. The end result: higher bit error rate (BER).

The testing methodology is similar to OTDR testing. A stable, continuous signal is sent down the fiber, and the power of the returning signal is measured. To ensure accurate testing, we recommend a reference measurement be taken to null the reflection of the launch patchcord and of the unit itself; this should be done before each test. To avoid high reflection from the fiber end, it is also recommended to terminate it with a mandrel. Since ORL is directional, measurements should be performed from both ends of the link. Testing in the transmission band is often enough—something EXFO's BRT-320A ORL Test Set is perfect for.

Telcordia sets a total ORL objective of  $-40$  dB, but this assumes that all components are newly installed and meet the latest Telcordia recommendations. In reality, targeting the  $-30$  to  $-35$  dB range is sufficient; of course, lower ORL contributes to avoiding further signal degradation. Values greater than  $-30$  dB should trigger corrective actions. An OTDR can help locate the high-ORL splices, connectors or other events.

### Power and Loss Measurement

The transmitting laser sends a certain amount of power. While the light is traveling through the fiber, absorption and scattering effects will slowly attenuate the original signal. If the power becomes too low, the receiver will not be able to analyze the signal, thus generating errors.

As discussed in the introduction, achieving more distance between regenerators reduces costs. This is why attenuation is becoming an increasingly critical parameter. On the one hand, increasing the power can lead to receiver deterioration or to undesired non-linear effects. On the other hand, too much attenuation limits the receiver's ability to process the input signal. Tolerances become tighter.

Optical loss testing uses a source (such as a handheld FLS source) at one end, and a power meter (such as a handheld FOT meter) at the other end. Taking into account the source power, previously referenced, link loss is obtained from the power reaching the power meter. Again, testing in both directions is a must.

To simplify this, use an instrument that includes both the source and power meter, such as EXFO's FOT-930 MaxTester. This enables you to perform bidirectional loss testing in a much shorter time. The high-end FOT-930 also offers a self-referencing feature, avoiding the hassle of bringing an additional source and power meter, again saving time. And since it can send and receive at many wavelengths, there is no need for continuously disconnecting and reconnecting the test equipment, making for quicker testing. Other FOT-930 options include an ORL test feature.

### Polarization Mode Dispersion (PMD) Measurement

Due to local changes in the index of refraction (called birefringent sections), the two polarization states of light travel at slightly different speeds, which results in a pulse spreading over time and distance, eventually increasing BER. In recent years, fiber manufacturers have dealt better with PMD—even though certain new fibers can show very high PMD—but older fibers generally exhibited small irregularities contributing to increasing the overall PMD.

Also contributing to increasing PMD are the physical stresses on the cable creating local changes in the index of refraction. Types of stresses include the stretching and bending that occurs during installation, as well as vibration and temperature variations. Because all these factors are random, PMD is a statistical phenomenon by nature.

Increasing the bit rate is one of the most popular ways to increase total data flow. As transmission speed increases, acceptable values of PMD and BER become smaller. High PMD corresponds to a power penalty on the total link budget. Although some fiber types (e.g., aerial fiber) are more at risk, high PMD can be found in all types of fiber. Effective measurement techniques and conscientious engineering are becoming increasingly critical.

In the field, PMD measurement is performed using the interferometric method, as described in the Fiber-Optic Test Procedure FOTP-124. This method is the only one that is stable and fast enough for tough field conditions, and the only one recommended by standards for installed links. Due to the statistical nature of PMD, several measurement points have to be determined and averaged out. A quick test over a broad spectral range, which is what the interferometric method enables, ensures high sampling and accurate statistics.

A broadband polarized LED is placed at one end of the fiber under test, and a PMD analyzer, such as the FTB-5500B, acts as receiver. This test only needs to be performed in one direction, as PMD is not direction-dependent. However, each fiber has to be tested.

Since PMD affects the bandwidth capacity of the fiber, standards prescribe what is the maximum acceptable PMD over a link for a given transmission rate. Being under the recommended value does not imply that PMD will never be a problem though, again because of the statistical nature of it. The standard means that on average, no PMD problem should occur.

Bit Rate (Gbit/s)	Max PMD* (ps)	PMD Coefficient* (ps/√km)
2.5	40	< 2.0
10	10 (with no FEC**)	< 0.5
40	2.5	< 0.125

\* Standards suggest a value for 10 Gbit/s only. Values at other data rates are nonetheless accepted by the industry.

\*\* Most long-haul instruments perform forward error correction (FEC).

### Chromatic Dispersion Measurement

Chromatic dispersion (CD) is the variation in the velocity of light (group velocity) as a function of wavelength. It causes pulses of a modulated laser source to broaden when traveling within the fiber, up to a point where pulses overlap and bit error rate increases. CD is therefore a limiting factor in high-speed transmission and must be properly compensated, which implies proper testing.

As stated before, with faster transmission comes smaller acceptable BER. This is even true with CD, as a data rate four times faster reduces the acceptable CD by a factor of 16. The good news is that CD is not affected by environmental factors, and is not a statistical phenomenon. Once it is tested and known to be higher than acceptable, wavelength-dependent compensation can be easily applied.

Since compensating CD over a wide wavelength range can be costly, it is key in optimizing the expense with accurate CD measurement—including dispersion and dispersion slope. An instrument based on the phase-shift method (a method described in FOTP-169 and application note 073), such as the FTB-5800, offers by far the highest accuracy and flexibility, due to the huge amount of testing points possible in the transmission bands and the higher wavelength accuracy.

To ensure coverage of the entire bands, a broad spectral source is used at one end, and the CD analyzer is placed at the other end; there is no need to measure CD in both directions. Because the source is modulated and the phase difference is measured as a function of wavelength, synchronization between source and receiver is required. Using an instrument based on optical referencing simplifies the test, since it is not necessary to have a second fiber, as is the case with electrical referencing.

Since CD affects the bandwidth capacity of the fiber, there are maximum acceptable levels of CD over a link, according to transmission rate. Here are examples:

Bit Rate (Gbit/s)	Max CD (ps/nm)
2.5	18 817
10	1176
40	73.5

### Spectral Attenuation Measurement

When attenuation becomes too high between regenerators, often an optical amplifier is used to increase the reach. Because it is important that all channels have similar power, amplifiers have to be as flat in gain as possible. And even if the amplifiers are flat, there often is wavelength-dependent loss throughout the transmission bands. Power level across these bands must be measured to avoid sending a channel at a high attenuation wavelength. Measuring loss as a function of wavelength provides crucial information for a good link-budget evaluation.

The data gathered can also eventually be used to estimate the potential danger of non-linear effects that can greatly increase BER, such as phase modulation and four-wave mixing. The present test does not measure such effects, but their impacts can be mathematically computed by simulation.

This is done by using a high-power broadband source, such as the FLS-2300B or the FLS-5800, to send a signal through the system and analyzing the signal with an optical spectrum analyzer (OSA) such as the FTB-5240B. An OSA is basically a wavelength-selective power meter. Using the source as a reference enables the OSA to record the source spectrum and compare it with the spectrum of the same source at the link output. This allows you to take the test equipment out of the link loss measurement equation. The resulting data is used to plot the final loss against wavelength traces.

Testing the fiber with an OTDR prior to measuring spectral attenuation will tell you the exact length of the fiber and enable the calculation of the link loss in dB per km. It will also provide the loss value at approximately 1550 nm, which can be used as a reference, or to validate the OSA test.

Because no two fibers are identical, testing all the fibers within the cable will help avoid bad surprises.

### DWDM Measurement

Once the above tests have been successfully completed, the next step is to light up channels to simulate real transmission. At this point, the ideal instrument for testing the channels is an OSA or a multiwavelength meter (MWM). Initial network commissioning should include the measurement of several key parameters and the recording of the results, in order to verify start-up performance and provide a baseline for future troubleshooting and upgrade management. OSA/MWM testing parameters vary according to the network characteristics, system specifications and approved standards.

The objective of the commissioning tests is to validate the general performance and integrity of the system. Although testing the whole system at once is often the quickest way, testing it per stage can avoid potential problems by isolating the source of nuisance, which contributes to optimizing network performance.

When testing the whole link, critical parameters such as channel power, wavelength and isolation need to be verified at each wavelength. Using the system's sources, the OSA or MWM placed at the end of the link will characterize the general behavior of each channel. Testing per stage implies testing the transmitters, receivers, amplifiers and multiplexers.

When testing at the transmitter level, you must ensure that each laser's power and wavelength match system vendor specifications and, most importantly, meet ITU standards. The OSA or MWM will test this directly.

As for the receivers, they must be able to detect the channel power to which they are each dedicated, without experiencing crosstalk from other channels. One of the most important parameters at this stage is the optical signal-to-noise ratio (OSNR) of each channel. System providers specify the acceptable OSNR limit for each channel (two values are often specified, respectively with and without FEC).

The amplifier's gain is measured in its active region by using the system's sources and the OSA or MWM. Amplifier (e.g., an EDFA) flatness, as well as its noise level, are measured using the same setup.

When multiplexing and demultiplexing, it is very important that every channel be stable and of equal power (both at the launch and at the separation). Connecting the OSA or MWM to the output port of the multiplexer or at the entry port of the demultiplexer will validate this.

Once the system parameters are optimized and stabilized, there is one more test to be performed with the OSA or MWM before lighting up the system: long-term monitoring. This will help you ensure that central wavelength, peak power and especially OSNR do not drift over time.

At the end of the link, the evolution of the signal parameters over time represent the sum of each individual reaction, which is the worst-case situation. The best system monitoring point is the demultiplexer input port. Having an instrument that allows remote control is a great feature at this stage.

### **Bit-Error-Rate Measurement**

As stated earlier, any parameter—loss, backreflection, dispersion, etc.—that doesn't meet specifications will affect the bit error rate (BER). BER is defined as the ratio of the defective bits received to the total amount of transmitted bits.

Basic test parameters include error seconds, block errors and unavailable seconds. However, the BER test is the way to check if a system's performance falls within tolerance. This critical test is a final proof that the system is ready to transmit. There are ITU standards defined for various transmission rates. According to the system vendor's specifications, BER can be judged acceptable or not. Achieving a BER level that is well below the maximum accepted level ensures a buffer zone in case of future BER increase.

BER measurement is performed with end-to-end testing (or loopback). A known pseudo-random bit sequence (PRBS) signal is sent down through the network and received at the far end by the BER tester. To provide cost savings, BER testers are often combined with SONET/SDH testers, as is the case with EXFO's FTB-8000 module (see next section).

The receiving unit will compare the transmitted pattern with the received pattern and detect if there was a bit error with respect to time. Typically, a BER test runs between 24 and 72 hours.

This test is critical. In a live network, if a system's bit error rate is too high, the information transmitted will not be reliable (a binary value of 1010001 may end up as 1010111).

**SONET/SDH Measurement**

Once the BER test has proven successful, it is time to send real structured information down the link. For most long-haul applications, this information is transmitted using a network transmission topology called SONET or SDH. SONET is the American National Standards Institute standard for synchronous data transmission on optical media. The international equivalent of SONET is synchronous digital hierarchy (SDH). Together, the SONET and SDH topologies enforce standards ensuring that international or intercontinental digital networks can interconnect and that existing conventional transmission systems can take advantage of optical media through tributary attachments. Irregularities in the structure can, for instance, prevent different parts of the network from communicating.

BER testers provide crucial information as they detect bit errors in a network. However, they cannot pinpoint a fault in a network—which a SONET/SDH analyzer (such as EXFO’s FTB-8000) can. A SONET/SDH network is split into various sections, starting from the Path section to the Multiplexsection and ending with the Regenerator section. Each of these sections will have its own overhead, which will be decoded by the analyzer, thus enabling it to detect if there are any errors or alarms. By monitoring these errors and alarms, an operator will be able to accurately determine the location of a fault.

Once the network is running, it is quite unlikely for a user to perform an intrusive test. However, monitoring the overheads is still needed. Most new-generation network elements offer optical taps that allow transmitted DWDM signals to be analyzed in a non-intrusive monitor mode. These taps contain all the channels transported by the fiber. Since the detector port of a SONET/SDH tester is a broadband device, it will detect all the channels without being able to isolate one. Isolating a channel can be achieved by using a tunable optical filter, such as EXFO’s FTB-9310.

**APS Measurement**

One of the main advantages of SONET/SDH networks is their ability to recover from catastrophic faults. Whether it be a fiber cut, a circuit pack failure or a human error, SONET/SDH networks can recover through a process known as automatic protection switching (APS).

When a network is commissioned, the APS capabilities must be thoroughly tested to ensure proper functionality and maximum resilience. Standards dictate that a SONET/SDH network must completely switch all traffic to a protection line/path in less that 50 ms. There are many ways in which APS measurements may be acquired, but the two most popular methods are AIS time and K1/K2 byte capture.

The AIS time test has the advantage of being easy to set up, as the test set is merely attached to a tributary off the main ring or line. The switch is then initiated and the tributary AIS time is measured and interpreted as the time it took to complete the switching. This gives a quick pass/fail result that simplifies the APS test.

The K1/K2 byte capture method, on the other hand, is more of an in-depth procedure in which the test set is placed on the protection path, inside the ring/line to be tested, either in “through” mode or attached to an optical splitter. The switch is then initiated and the K1/K2 bytes are analyzed to determine the time it took to complete the switching. This method’s advantage is that if there is a problem with the APS function, the K1/K2 bytes will allow you to troubleshoot the root cause of the issue.

**Conclusion**

Bringing a network up to speed requires several important steps, none of which should be neglected. Using highly accurate instruments at every stage of the testing cycle will ensure error-free and, more importantly, surprise-free transmission. Choosing a common supplier and a common chassis for all your test equipment will, in turn, contribute to bringing you key benefits: reduced instrument costs, minimal equipment deployment cost and effort, as well as shorter training and testing time for field technicians.



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