Fiber Characterization Test Requirements

The risks of failing to properly characterize the fiber before system turn-up are significant. If the fiber is not characterized beforehand, substantial delays in service provisioning or increased time to repair can occur, which can lead to project postponements and missed turn-up commitments. If the network fails to perform as promised, the network provider is required to test the network and pinpoint the trouble source. In addition, the verification of fiber performance and the comparison with commissioning/acceptance test values are useful for ongoing network analysis and trending.

For companies who are not network providers, test equipment is often needed to solve finger-pointing issues, especially when multiple contractors are involved. Companies can use their own test equipment, or they can outsource the testing to a third party for fiber characterization. Outsourcing is only feasible for troubleshooting purposes if a local company is available to respond to emergency requests.

This document is intended as a reference guide for fiber characterization requirements. It describes the various tests that are commonly referred to when discussing fiber characterization. These tests are typically performed on the fiber media prior to the installation of new network elements or the upgrade of existing network elements, including higher bit rates, longer distances, and additional wavelengths. Typical and/or recommended test results are also provided. Finally, a summary of tests that are recommended based on specific network criteria, including length and transmission protocol, is provided.

Fiber Characterization Prior to Network Element Installation

Recommended Tests for Fiber Characterization

Network operators are pushing the transmission capacity to its limits with the use of higher bit rates and coarse or dense wavelength division multiplexing (CWDM/DWDM) techniques to achieve greater bandwidth over longer distances. As a result, it is becoming critical that all of the key parameters of the installed fiber in an optical network are thoroughly verified in order to ensure optimum performance. The evaluation of installed fiber against a specified requirement is known as fiber characterization.

In the recent past, leading equipment manufacturers have begun to introduce a policy of insisting on full fiber characterization of any network that employs or plans to employ CWDM or DWDM technology. Fiber characterization ensures reliable network performance now and provides information for future upgrade decisions.

The arguments in favor of fiber characterization are strong. With detailed information about the fiber, the operator can ensure that the CWDM/DWDM equipment is optimized and can speed up troubleshooting processes when a problem exists. As older fiber will eventually be unable to support higher bit rates or denser multiplexing of wavelengths, problems can be anticipated and solved much earlier in the deployment process, providing significant time and cost savings. For the upgrading of a "vintage" fiber plant, fiber characterization tests can be used to define which individual fibers (even in a common cable sheath) can or cannot support higher bit rate transmission, permitting the operator to maximize the capacity of the plant. This technique is called "bandwidth mining". For an up-and-running network whose fiber has been characterized, the likelihood of requiring maintenance is reduced.

Therefore, fiber characterization testing, prior to network element installation, provides the following benefits:

- Fiber characterization provides a true picture of the network's performance and limits. Therefore, the operator knows the maximum bit rate for current or future upgrades.
- Fiber characterization enables the equipment provider to provide the operator with the most cost-optimized solution for a given bit rate. For example, an optimized network may not require an amplifier or CD compensator and would still be CWDM-enabled (supports transmission over the 1270 nm to 1630 nm wavelength range).

Although the concept of fiber characterization is already familiar to long haul carriers, leading operators are now demanding this level of detailed testing even for medium and short links.

In less dense systems and at bit rates below 10 Gb/s, the measurements of the insertion loss (IL) and the optical return loss (ORL) of events/splices provide an adequate check of network performance. As the number of wavelengths increases, especially at higher bit rates, polarization mode dispersion (PMD), chromatic dispersion (CD), and spectral attenuation profile (SAP) become critical parameters. Therefore, associated test equipment must be used. Other accessories, such as cleaning kits, talk sets, visual fault locators, fiber identifiers, microscopes, and probes, are often overlooked, but they can be highly useful and effective test tools.

Insertion Loss and Optical Return Loss Over the Complete 1270 nm to 1630 nm Wavelength Range

For many years, the only available transmission wavelengths were 850 nm, 1310 nm, and 1550 nm. Cable manufacturers designed their products for the best performance at those specific wavelengths.

With the advent of DWDM and CWDM technologies, more wavelength bands are required, providing a larger spectral band. For DWDM networks, network elements likely utilize the 1480 nm to 1625 nm spectral band; whereas CWDM network elements utilize the 1270 nm to 1630 nm spectral band.

A primary concern is that fiber becomes more sensitive to bending as the wavelength increases. Most installed fiber was not designed for use at wavelengths higher than 1550 nm, and the network was not tested at these wavelengths when it was first installed. As a result, installation issues, such as bend radius, splice trays, and patch panels, that were not so important years ago, can now become critical at wavelengths close to 1625 nm. For example, a fiber with a bend radius of 25 mm may experience a loss of 0.3 dB at 1550 nm. At 1625 nm, though, the same fiber with the same bend radius would suffer a loss of 2 dB.

Another concern is that fiber was not originally designed to be used in the spectrum between 1310 nm and 1550 nm. In "vintage" fiber, there are often a region of very high attenuation near 1385 nm known as the "water peak". This portion of the spectrum is now used in CWDM systems, and therefore attenuation measurements shall be performed to qualify the fiber in this area. Also, both CWDM and DWDM systems utilize the spectrum above 1550 nm, i.e., up to 1630 nm. Therefore, complete attenuation measurements along the broad 1270-1630 nm range are recommended. This method is called spectrum attenuation profile (SAP) characterization. New fiber designs and manufacturing techniques resolve this "water peak" issue, but fiber of "vintage" or unknown origin should be characterized.

In addition, for some applications, such as analog CATV (for RF Video), ORL testing at different transmission wavelengths must be verified.

Polarization Mode Dispersion

Polarization mode dispersion (PMD) is caused by the birefringence of the fiber. The birefringence generates dual refraction indices (one for each polarization mode), which are eventually affected by the quality of the fiber, which can either be not perfectly circular or suffer external stresses, such as bending, twisting, or temperature variations. The difference between the indices of the two opposing modes creates a time delay, causing the transmission pulse to broaden when traveling along the fiber. The result is distortion of the signal and an increased bit error rate (BER) of the optical system, limiting the distance of the fiber link.

The maximum distance permitted by the PMD coefficient depends on the type of fiber. It can be assumed, though, that at bit rates higher than 10 Gb/s, PMD may be the critical limiting factor for medium to long length links. Therefore, PMD should be measured. For some applications, such as analog CATV, even lower bit rates will be affected by PMD.

PMD is measured by using the time delay between the two polarization modes, also referred to as the mean differential group delay (DGD), and deriving the PMD coefficient. A series of measurements should be carried out over a period of time to compensate for the fact that PMD varies with temperature.

Early checking for the effects of PMD is especially important since there is no easy low-cost solution available for its correction. The only course of action available to the operator is to reduce the bit rate or shorten the link. Historically, PMD values vary statistically from fiber to fiber even within the same cable sheath. Verification of PMD performance of existing fibers can help identify those fibers that are capable of upgrade and those that are not. Then, the operator can effectively "bandwidth mine" by hand selecting ("cherry picking") individual fibers for upgrade.

Chromatic Dispersion

Chromatic dispersion (CD) describes one of the basic characteristics of the fiber. It is caused by the variation of the fiber index with the wavelength. Its effect is to generate a delay between wavelengths and to broaden the transmission pulse as it travels along the fiber. This, in turn, provokes distortion and increases the BER ratio of the optical system. As a result, it creates a distance limit for a given bit rate.

For example, when the bit rate is increased from 2.5 Gb/s to 10 Gb/s, the distance limit may be reduced from 640 km to less than 100 km. At 40 Gb/s, the same fiber may only operate over a maximum of 5 km. New network installations and upgrades designed to operate at 10 Gb/s or higher should be tested for CD.

CD is measured by comparing the time delay between the different wavelengths, for a given distance. It is then possible to calculate the dispersion coefficient, dispersion slope, and other specific values, such as the zero dispersion wavelength and the associated slope.

The only external parameter that can affect the chromatic dispersion is the modulation type of the signal itself. Chromatic dispersion compensators are commercially available and can be used in the network to the correct distance limiting effects of CD.

Spectral Attenuation Profile

The spectral attenuation profile (SAP or AP) provides the fiber attenuation, as a function of the wavelength, for a given link. On a DWDM network with amplifiers, it is important to use the same power level for all of the channels on the receiver side. Since the attenuation of the fiber is not constant over the wavelength spectrum, it is important to measure the SAP. Using the SAP results, the amplifier can be tuned so that all of the optical power levels of the channels are the same at the receiver side or at the next amplifier. Therefore, this measurement is vital to system optimization.

Required Typical Test Results Prior to Network Element Installation

Acceptable values for system loss budget, maximum ORL or event reflection, PMD, CD, and SAP are dependent on the specific network element and should be supplied by the network element provider. However, in general, there are expected typical values. The expected values are discussed in the following sections.

System Loss Budget Requirements

System loss budget is linked to the insertion loss for a given wavelength or to the spectral attenuation measurements for the full spectrum wavelength range of the fiber link. The system loss budget includes the fiber itself and also splices, connectors, and active/passive optical components.

Acceptable values for maximum splice loss are generally established during construction by the operator's construction group or are negotiated with the splicing contractor. These values can vary greatly depending on the length of the link and the intended transmission protocol. Splice losses are sometimes specified on a statistical basis. For example, 80% of splices below x, no splice greater than y, or the sum of all splices on a single fiber span not to exceed z.

Another source of extrinsic loss (and often reflection) is "pass throughs" of intermediate locations, such as central offices (COs), usually to create long SDH/SONET rings. Identification and elimination of high losses here can provide critical system improvements and savings. While splices are relatively stable, improperly installed or improperly handled patch cords can have losses of multiple decibels as opposed to either tenths or hundredths of a decibel for a splice.

For example, a network element provider offers a $6,000 metro laser and a $10,000 long haul laser. One is specified for link losses of about 9 dB and the other one for up to 14 dB. Several bad connectors on an SDH/SONET ring are located by testing with an optical time domain reflectometer (OTDR) and are subsequently replaced to remove 4 to 5 dB of excess loss from the span. The network operator is then able to use the lower-cost laser transmitter (TX) card instead of the more expensive one. These types of activities demonstrate how fiber characterization testing can pay for itself rather quickly.

The specification for maximum ORL and single reflective event levels from one network element provider may be stated as a maximum ORL of 20 dB for the span and no single reflective event over -27 dB. Since maximum ORL varies from manufacturer to manufacturer, though, there isn't a standard pass/fail for ORL.

The most basic optical tester is a power meter and a power source combination, which is often called an optical loss test kit or set. This test set is used to verify the system budget. For more detailed information regarding the calculation of the system budget, refer to the JDSU Guide to Fiber Optic Measurements.

The standard for maximum span loss is also system dependent. There is no set standard; it simply varies from system to system. The system budget will depend on the output power of the transmitter, the possible deviation of the output power, the receiver sensitivity, and the dynamic range of the receiver. The received signal must not be too high. If it is, this problem can be solved by using an attenuator. Also, the received signal must not be too low. If it is, either an amplifier is required, extrinsic loss must be removed, a repeater or regenerator is required, or long haul transmitter (TX) and/or receiver (RX) cards are required.

An even more powerful tool that can be used to characterize fiber is an OTDR. This instrument can be used to verify the system budget, but it can also be used to characterize each event of the fiber (splices, connectors, etc.) For additional information about the OTDR, refer to the JDSU Guide to Fiber Optic Measurements.

PMD Requirements

There are limits for the PMD of a system that cannot be exceeded based on the transmission protocol. Some companies "flex" or "guardband" the pass/fail for PMD as defined by the ITU. For example, the limit for PMD is 10 ps for OC-192/STM-64. In flexing the PMD requirement, an operator may designate that the system passes for OC-192/STM-64 if the PMD is less than 10 ps. The operator may further designate that if the PMD is between 10 ps and 13 ps, then one dB must be added to the system budget as a power penalty. And finally, the system fails if the PMD is greater than 13 ps.

PMD measurements can also be performed if the network elements are not known at the time that the fiber is tested. Table 1 can be used to establish maximum PMD values based on the bit rate.

Bit Rate Per Channel	SDH	SONET	Equivalent Timeslot (UI)	PMD Delay Limit	PMD Coefficient for 400 km
55 Mb/s	N/A	OC-1	19.3 ns	2 ns	<96
155 Mb/s	STM-1	OC-3	6.43 ns	640 ps	<32
622 Mb/s	STM-4	OC-12	1.61 ns	160 ps	<8
1.2 Gb/s	N/A	OC-24	803 ps	80 ps	<4
2.5 Gb/s	STM-16	OC-48	401 ps	40 ps	<2
10 Gb/s	STM-64	OC-192	100 ps	10 ps	<0.5
40 Gb/s	STM-256	OC-768	25.12 ps	2.5 ps	<0.125

Table 1: Maximum PMD values as defined by the bit rate

Figure 1 shows the correlation between maximum distance, PMD, and bit rate.

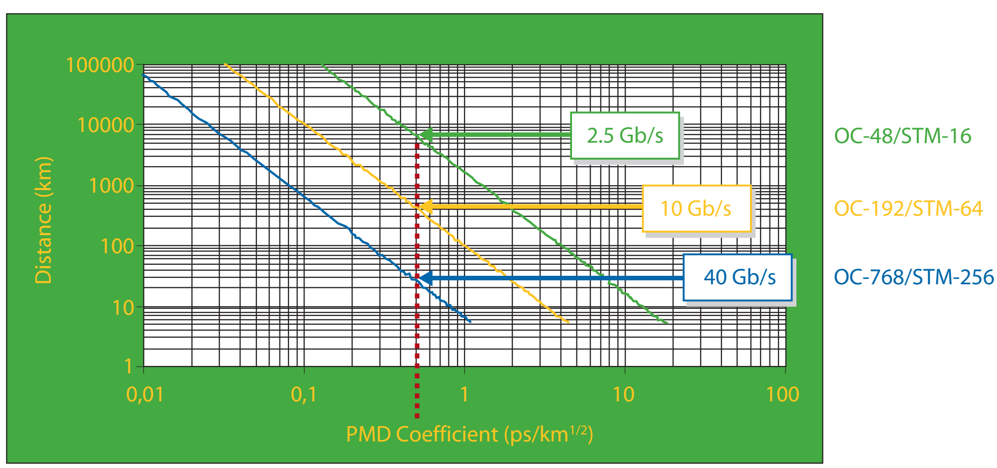

Figure 1: Maximum distance vs. PMD coefficient and bit rate

PMD can change over time due to temperature, stress, bends, or movement. While PMD compensators have been developed, commercially practical units have not yet been installed on a widespread basis. Today, fiber with an unacceptable PMD value for a particular bit rate indicates that the fiber cannot be used for that bit rate. As PMD is distributed statistically and randomly in existing fibers, this leads to "bandwidth mining". This technique recommends testing and qualifying existing dark fibers and designating them as either "10G acceptable" or "10G not recommended". By linking together individual spans of "10G acceptable" fibers to form SDH/SONET rings, for example, total system throughput can be maximized. This technique somewhat complicates plant administration, though.

CD requirements

There are expected values of CD based on the fiber type, such as standard, dispersion shifted, and non-zero dispersion shifted (Figure 2). If the CD level of a span is excessive for that particular manufacturer's network element, then dispersion compensation should be employed.

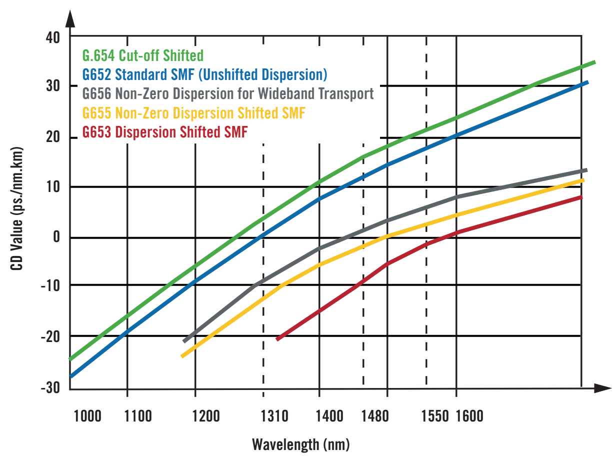

Figure 2: Expected CD values based on fiber type

The information in Figure 2 is provided by the ITU, and many manufacturers follow these or very similar recommendations. While nominal CD of the span can be measured, total system CD is dependent on the design of the TX and RX and varies by manufacturer. Typical limits for span CD may be 850 ps/nm, 1100 ps/nm, or even 1300 ps/nm. After these limits are exceeded, dispersion compensation modules are required. Typically, CD will not vary over time since it is based upon the physical properties of the fiber. Therefore, CD measurements are stable over the life of the fiber.

Table 2 lists expected CD coefficient values based on the bit rate, according to ITU recommendations.

Bit Rate Per Channel	SDH	SONET	Total allowable CD Coefficient at 1550 nm (not normalized to one km)
2.5 Gb/s	STM-16	OC-48	12,000 to 16,000 ps/nm
10 Gb/s	STM-64	OC-192	800 to 1,000 ps/nm
40 Gb/s	STM-256	OC-768	60 to 100 ps/nm

Table 2: Expected CD coefficient values based on the bit rate

For more information regarding the recommendations and standards for all of the previously discussed tests, including PMD and CD, from the ITU-T, IEC, TIA, and EIA, contact the particular organization or contact your JDSU representative.

Fiber Characterization for Maintenance, Monitoring, Troubleshooting, and Restoration

In the previous section, testing of the fiber and the typical test results prior to network element installation were discussed. The next aspect of fiber testing is during maintenance, monitoring, troubleshooting, and restoration. This testing can be used to isolate and sectionalize problems as well as to assign responsibility for the trouble.

As previously described, a basic optical loss test set will give the total loss of the system under test. If this total loss is acceptable, then no further testing is required. If the total loss is not acceptable, then a specific tool is needed to identify and localize the excess loss. This is the job of the OTDR. The OTDR will identify breaks, bends, bad splices, bad patch cords, and dirty connectors. The OTDR is the most common fault-finding tool for outside plant (OP) issues. Therefore, the OTDR is the ideal instrument for network maintenance, troubleshooting, and restoration.

For DWDM and CWDM network systems, troubleshooting can be performed on live channels using a portable optical spectrum analyzer (OSA) if there is fiber access on the network. The OSA is able to analyze the wavelength, the power, and the optical signal over noise ratio (OSNR) of all live channels. These critical measurements enable the operator to identify and localize the cause of the failure. For the OSA, network access will typically be on a network element, such as a common (tap) port on a multiplexer or EDFA. If there are no access points, splitters can be installed to provide monitor access points, where typically 5% or 10% of the signal is tapped for analysis. Some transmission engineers and system designers are reluctant to add splitters because they add loss, require labor to install, and must be stored somewhere in the CO. However, if a DWDM or CWDM system has no access points, then any attempt to troubleshoot, even one wavelength, is intrusive and requires "taking down" multiple wavelengths, which is an even less desirable situation.

For monitoring purposes, full-time OTDR-based monitoring systems that test the fiber link on a 24/7/365 basis can be implemented. These systems can perform OTDR testing on live and dark fiber from one central server using a remote fiber test system (RFTS). The RFTS should be set to alarm the end user automatically when preset thresholds are reached. Ideally, it will correlate the OTDR trace to a map for simple and exact fault identification and localization. An ideal RFTS will also have an OSA capability, which will monitor all of the system's channels 24/7/365 by analyzing the wavelength, power, and OSNR.

The cost of wavelength monitoring equipment should be based on the system requirements with respect to measurement capability and accuracy. For CWDM networks, for example, a low cost OSA or channel monitor can be used due to CWDM's wide channel spacing. One key specification on any OSA or channel monitor is its spectrum of operation. Many OSAs operate in the C + L band since that is the common range for DWDM networks. CWDM networks, though, may cover the entire optical spectrum from 1270 nm to 1630. In this case, a C + L band OSA will not be able to measure many of the CWDM channels.

Fiber Characterization Test Summary

Table 3 is a fiber characterization test summary table and is only meant to serve as a guideline to help establish a network test plan and strategy. It will help planners determine what tests they need and do not need so that they can focus on the required capability and optimize resources. The table can also be used to determine the test capabilities that they may need in the future.

Fiber testing depends on the network elements, age of the fiber, application, test equipment available, fiber location, type of fiber, fiber manufacturer, and operating company philosophy regarding testing. Therefore, the values provided in Table 3 are recommendations and can be modified to suit the system's requirements. Table 3 recommends tests for fiber based on wavelength, length of fiber, age of fiber, bit rate, and whether the fiber has DWDM channels or single channels on it.

Test	OC-48 1550	OC-48 DWDM	OC-192 1550	OC-192 DWDM	Equipment Req'd	Techs Req'd	Testing Recommended
Insertion Loss (IL)	1310/1550 nm	1550/1625 nm	1310/1550 nm	1550/1625 nm	PM & LS or OFI	2E	Bi
Optical Return Loss (ORL) (Note 1)	1550 nm	1550 nm	1550 nm	1550 nm	ORL meter or OFI (w/ ORL option)	1E (Note 7)	Bi (Note 9)
Physical Plant Verification (Note 2)	1310/1550 nm	1550/1625 nm	1310/1550 nm	1550/1625 nm	2 or 3 wavelength OTDR	1E	Bi (Note 10)
Spectral Attenuation Profile (SAP) (Note 3)	No	1480-1625 nm	No	1480-1625 nm	Broadband source and OSA	2E	Uni
Polarization Mode Dispersion (PMD) (Note 4, Note 5)	<80 km not required unless pre-1993 fiber	<80 km not required unless pre-1993 fiber	Pre-1993 required, '93-97 required if >50 km, post '97 required if >80 km	Pre-1993 required, '93-97 required if >50 km, post '97 required if >80 km	Broadband source, OSA, and Polarizer	2E	Uni
Chromatic Dispersion (CD) (Note 6)	Not required if <150 km	Not required if <150 km	Recommended	Recommended	4 wavelength OTDR/CD	1E (Note 8)	Uni

Legend:

- **PM** Power meter
- **LS** Light source
- **OFI** JDSU bidirectional loss test set
- **OTDR** Optical time domain reflectometer
- **OSA** Optical spectrum analyzer
- **1E** One-ended test
- **2E** Two-ended test (two technicians)
- **Uni** Unidirectional
- **Bi** Bidirectional

Note 1: This is the CW return loss test (direct measured). Sometimes, this test is not performed, and the OTDR return loss value (calculated) is accepted. Limit values are usually -27 dB.

Note 2: This test includes testing of connectors, splices, point reflectance, and localized loss.

Note 3: This test is often not performed provided that the "limits" of the wavelength spectrum are tested for insertion loss to ensure that there will be no adverse effects from bending loss. Therefore, if insertion loss is tested at one wavelength higher than the highest used wavelength, then this test may be omitted in many cases.

Note 4: The guidelines identifying testing requirements are for example only and may vary by application. In some caes, this test may be "guard banded" from the TIA recommendations. Or, the user may apply a power penalty to results, which is greater than the limits specified by the TIA. For example, if the PMD (OC-192) is greater than 10 ps but less than 13 ps, then one dB may be added to the system budget loss as a power penalty.

Note 5: This test is dynamic. It is recommended that multiple tests are performed over a period of time.

Note 6: Both CD test limits and cases where CD testing is recommended are highly dependent on the network element equipment specifications. Consult the network element provider for these limits and recommendations.

Note 7: While this test is generally one ended, at short distances, an "open" connector at the far end may generate enough reflectance to skew the results. In this case, a technician may apply a terminator or mandrel wrap at the far end during the test.

Note 8: While this test is normally one ended, at longer distances, a zero dB reflector may be required at the far end to increase the dynamic range of the test set. For low fiber count testing, zero dB reflectors may be applied in multiples and left in place during testing (as opposed to moved from fiber to fiber during testing) so that the test remains one ended.

Note 9: In most cases, this test only needs to be performed from the transmit end; however, at the time of the test, this information is not often known. Testing the ORL on fiber pairs that will be used for SDH/SONET transmission can lead the user to select the direction pair with the lowest ORLs for transmitter placement.

Note 10: While this test is one ended, it should be performed from both ends and the results should be analyzed using appropriate software, such as JDSU's OFS-100 or OFS-200 software. Testing from both ends, though, is not always done.

Table 3: Fiber Characterization Test Summary

For CWDM applications with OC-48 or OC-192 transmission rates, the recommended tests from column 2 (OC-48 DWDM) and 4 (OC-192 DWDM) can be performed with one exception. Eventually, CWDM operates in the range of 1270 nm to 1630 nm. Therefore, all tests should be performed over this extended range, and not only in the 1480 nm to 1625 nm range.

The following JDSU documents are available for your reference:

- Fiber Characterization in Singlemode Optical Networks poster
- Guide to Fiber Optic Measurements
- DWDM pocket guide
- FTTP Measurements white paper
- FTTX Test and Management Portfolio poster
- Polarization Mode Dispersion Requirements white paper
- Chromatic Dispersion Requirements white paper

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