Anritsu Advancing beyond

# Multicore Fiber-Optical Transmission Characteristics Testing

Multi Channel Fiber Tester MT9100A

## Introduction

In recent years, driven by the widespread adoption of AI and cloud services, transmission capacity in optical communications — such as submarine optical cables and inter–data center links—has continued to increase. Conventional single-mode optical fiber (SMF), which has been widely used to date, incorporates a single optical transmission path (core) within a single fiber, and therefore faces a physical limit on the transmission capacity per fiber.

As a technology to overcome this limitation, multicore fiber (MCF), a form of space division multiplexing (SDM), has attracted growing attention. By independently arranging multiple cores within a single optical fiber, MCF is expected to enable significantly higher transmission capacity compared with SMF.

However, when MCF is deployed in optical networks, suppression of inter-core crosstalk — which directly affects optical transmission quality — becomes a critical challenge. Consequently, reliable inter-core crosstalk measurement methods are required at every stage, from design and manufacturing to network construction and operation.

This document introduces the importance and challenges of optical transmission characteristics in MCF, and also explains the limitations of conventional methods as well as emerging measurement technologies.

## Optical Transmission Characteristics of Multicore Fiber and the Importance of Their Evaluation

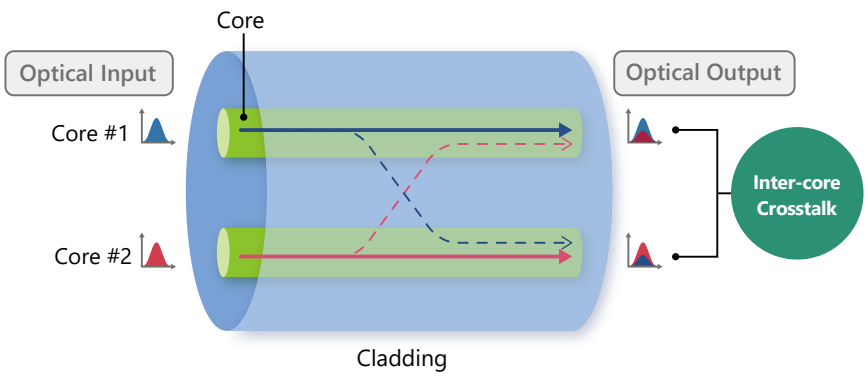



**Figure 1 Inter-core crosstalk in an MCF (two-core example).**

When deploying MCF in optical networks, inter-core crosstalk — an optical transmission characteristic unique to MCF — becomes a critical evaluation parameter. Inter-core crosstalk refers to the phenomenon in which signal light propagating through one core leaks into an adjacent core, resulting in degradation of signal quality in the neighboring core. To mitigate this effect, it is essential to quantitatively and accurately evaluate inter-core crosstalk at every phase, from the design stage through manufacturing and into network operation.

In addition to inter-core crosstalk, transmission loss, and reflectance are also key evaluation metrics in the assessment of MCF optical transmission characteristics. These characteristics are influenced not only by the intrinsic quality of the fiber itself, but also by various external factors such as bending and tensile stress during installation, as well as the precision of connector and splice processing. Accordingly, there is a strong need to establish measurement systems that enable rapid and highly accurate evaluation of these characteristics in both manufacturing environments and field applications.

# Inter-Core Crosstalk Evaluation Methods for MCF and Associated Challenges

As representative methods for measuring inter-core crosstalk in MCFs, the transmission method and the loopback method are commonly used. This chapter outlines these methods and describes a representative example of each.

## What Is the Transmission Method?

The transmission method is a technique for evaluating inter-core crosstalk (XT) in an MCF by launching light into one end of the fiber and measuring the output optical power at the opposite end using an optical power meter (OPM). This method is also referred to as the power meter method. In this measurement, the crosstalk evaluation procedure and achievable measurement accuracy depend on the type of light source used. This section describes methods using a tunable laser source (TLS) and a continuous-wave (CW) light source.

## Transmission Method — TLS Case[1]

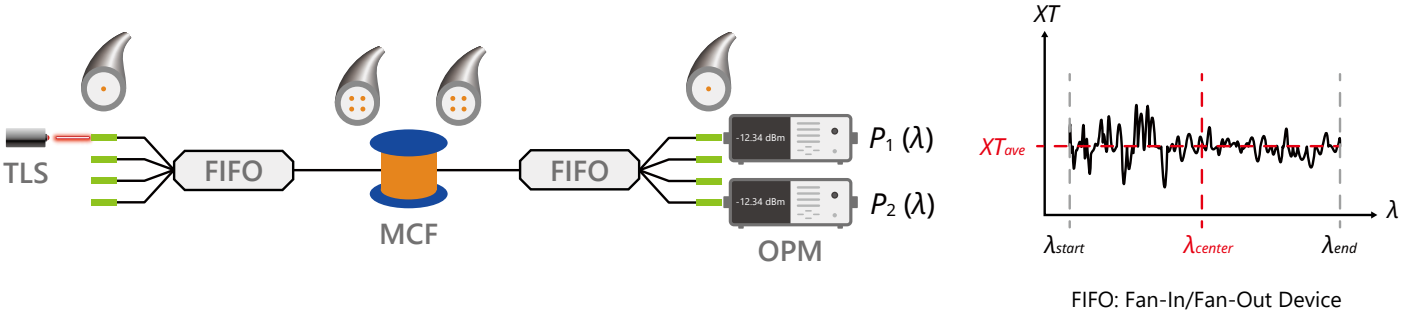
In the transmission method using TLS, the output wavelength of the TLS is swept over a specified range at fixed intervals, and the optical power at each wavelength is measured using an OPM. The XT in MCF varies as phase changes occur due to slight bending of the MCF and minor non-uniformities in the fiber structure. For this reason, XT is known to be an inherently stochastic physical quantity.

Conventionally, statistical data have been obtained by applying physical perturbations, such as rewinding the MCF or changing bending conditions. However, this approach has posed challenges in terms of both measurement reproducibility and operational efficiency.

To address this issue, Reference [1] focused on the fact that sweeping the wavelength of the light source can vary the phase difference between cores, and proposed a method in which the wavelength of TLS is swept. This approach makes it possible to obtain a large number of XT measurement values without the need for operations such as rewinding the MCF. By applying statistical processing to these XT measurement values, the study demonstrated that stable XT values can be obtained.

As an example, the procedure for evaluating crosstalk leaking from Core #1 to Core #2 is described below.

1. At each wavelength, measure the optical power P1 of Core #1 and the optical power P2 of Core #2.
2. At each wavelength, calculate P2/P1 and define this value as the inter-core crosstalk at the corresponding wavelength. Since P2/P1 represents the leakage ratio into the adjacent core, it corresponds to the definition of XT.
3. Calculate the arithmetic mean of the crosstalk values obtained over all wavelengths and evaluate it as the band-averaged XT of the MCF.
   The averaging process is performed to smooth out the measurement fluctuations of XT, as shown in Fig. 2 (b), and to obtain a representative XT value over the actual transmission band.

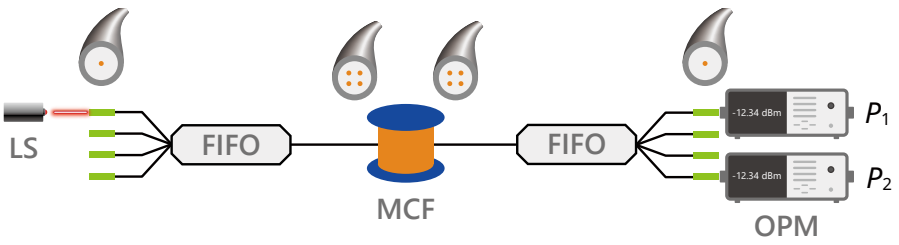



FIFO: Fan-In/Fan-Out Device

**Figure 2 Transmission Method Using a TLS:**
**(a) Measurement setup, (b) Example of inter-core crosstalk measurements at each TLS wavelength.**

## Transmission Method — CW Light Source Case

The XT can also be evaluated using a CW light source instead of TLS. When CW light sources such as Fabry–Perot (FP) lasers or superluminescent diode (SLD) sources are used, the optical power at the output end of each core is measured using an OPM, and XT is calculated from the ratio of these measured optical powers.




FIFO: Fan-In/Fan-Out Device

**Figure 3 Measurement setup for the transmission method using a CW light source.**

The transmission method is widely used and suitable for measurements during development, as it enables detection of extremely small XT values when a high-sensitivity OPM is employed. However, because both a light source and an OPM must be installed at opposite ends of the MCF, access to both ends is difficult in installations with long fiber lengths, making this method unsuitable for field maintenance or remote measurements. In addition, when the number of cores is large, switching connections requires significant time, which increases inspection workload during manufacturing. In such cases, alternative measurement methods should be considered.

## What Is the Loopback Method [2]?

The loopback method is a technique for measuring XT in an MCF with high sensitivity by using an OTDR and a dummy SMF. A key feature of this method is that, in addition to measuring transmission loss and reflection for each core with a conventional OTDR, it can also detect XT components. Furthermore, because XT is observed as a transmitted optical component, extremely small XT values can be measured with a high signal-to-noise ratio (SNR), second only to the transmission method.

The measurement setup consists of the following components:

**OTDR unit:** Pulse light $P_0$ is launched into the excited core and propagated through the MCF. The returned light from the MCF — primarily backscattered light — is acquired as a time-domain waveform.

**FIFO device:** An interface that splits and combines the single-fiber port of the OTDR into multiple cores of the MCF, enabling pulse light from the OTDR to be launched into a specific core and the returned light to be received from the appropriate core.

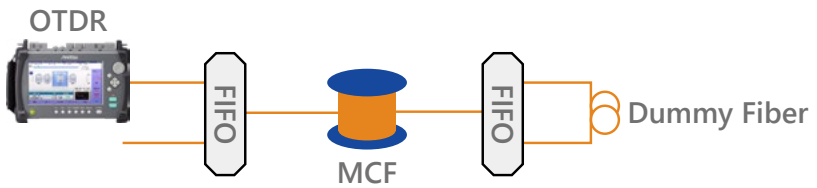
**Dummy SMF:** On the opposite end of the MCF, the excited core and the core under measurement are connected to both ends of the dummy SMF to form a loopback transmission path of the pulse light.

With this configuration, when pulse light $P_0$ from the OTDR is launched into the excited core (e.g., Core 1), inter-core coupling within the MCF generates an XT pulse light component Pxt in adjacent cores (such as Core 2). Both the main pulse component and the XT pulse component propagate through the dummy SMF after reaching the end face of the MCF. Within the dummy SMF, the main pulse propagates along the path Core 1 → dummy SMF → Core 2, while the XT pulse propagates in the opposite direction, Core 2 → dummy SMF → Core 1. As a result, the system is designed so that both signals arrive at the midpoint of the dummy SMF at the same time. At this midpoint, backscattered light inherent to the SMF is also generated simultaneously; consequently, the backscattered component and the XT component are superimposed and return to the OTDR. On the OTDR trace, this appears as a distinct XT peak at the midpoint position.

Because this method observes XT as a transmitted light component, it provides a high signal level and enables high measurement sensitivity even in low-XT regions. In addition, the loss and reflection distributions of both the excited core and the core under measurement can be obtained simultaneously. As the method can be implemented at relatively low cost, it is an effective approach for evaluating the characteristics of multicore fiber.

In the evaluation of MCF, not only inter-core crosstalk but also the measurement of loss distribution and reflection distribution are essential. These measurements are required to verify installation quality, identify the locations of defects, and diagnose transmission characteristics. However, with conventional measurement methods, it is necessary to switch the connections of the light source and receiver for each core, resulting in long measurement times. Consequently, there is a strong demand for measurement methods that can acquire these three characteristics of MCF within a short period of time.

Furthermore, similar to the loss distribution provided by an OTDR, it is desirable to obtain inter-core crosstalk as a spatial distribution. Because crosstalk in MCF varies along the fiber due to factors such as bending, manufacturing variations, and external forces, it is important in practical maintenance and operation to obtain position-resolved distribution information, rather than relying solely on a single overall value.




FIFO: Fan-In/Fan-Out Device

**Figure 4 Loopback Method.**

## Multi-Channel OTDR Method for Addressing These Challenges[3]

With the inter-core crosstalk measurement methods described above, there are challenges in that inter-core coupling cannot be evaluated while taking the position along the MCF into account, and that switching operations between MCF cores are required, resulting in increased measurement effort. To address these issues, a research group led by Distinguished Professor Masataka Nakazawa of Tohoku University proposed a multi-channel OTDR method. In this method, multiple OTDR units are synchronously operated using a common clock, enabling simultaneous acquisition of backscattered light from each core of the MCF. This makes it possible to non-destructively measure mode coupling along the longitudinal direction of the fiber.

### Principle of the Multi-Channel OTDR Method

The multi-channel OTDR method synchronously operates multiple OTDR units to acquire backscattered light from each core of an MCF on a common time axis. This enables measurement of mode coupling along the longitudinal direction of the MCF, and inter-core crosstalk can be calculated from the obtained mode-coupling data.

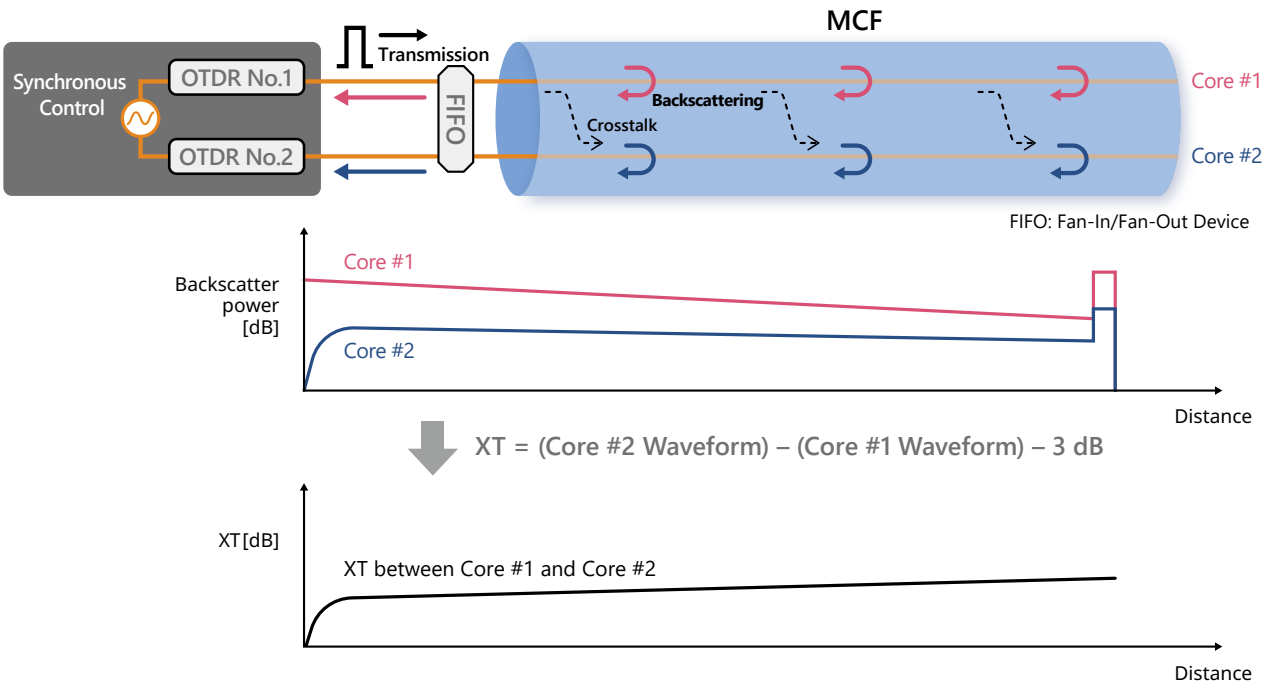



**Figure 5 Multi-Channel OTDR Method.**

To obtain inter-core crosstalk, pulse light is first launched from one OTDR unit into the excited core (Core #1). As the light propagates, slight coupling continuously occurs between adjacent cores, causing leakage into Core #2. As a result, backscattered light is also generated in the non-excited core (e.g., Core #2). In the multi-channel OTDR method, backscattered light from both the excited core and the non-excited core can be acquired simultaneously (Fig. 5). By using the ratio of these backscattered signals (mode coupling ratio), the strength of mode coupling as a function of position can be determined.

By comparing the two acquired backscattered signals, variations in mode coupling along the longitudinal direction can be identified. Because an OTDR measures round-trip light, the observed change in the mode coupling ratio appears as twice the actual value. Therefore, when calculating the coupling magnitude, a 3 dB correction is applied to convert the result into the correct increase in crosstalk.

In this way, the multi-channel OTDR method not only enables measurement of the crosstalk distribution along the distance axis — which is difficult to achieve with conventional methods — but also allows simultaneous measurement of multiple cores, resulting in a significant improvement in measurement efficiency.

## Test Solution for Implementing the Multi-Channel OTDR Method

As a test solution for implementing the multi-channel OTDR method, the use of Anritsu's Multi Channel Fiber Tester MT9100A enables efficient evaluation of the optical transmission characteristics of MCF from a single end while simultaneously measuring multiple cores. The MT9100A can measure up to four cores at the same time and visualize evaluation parameters such as loss distribution, reflection distribution, and inter-core crosstalk distribution along the distance (longitudinal) direction. This significantly reduces the need for per-core connection switching and complex measurement procedures required by conventional methods, thereby reducing the overall workload associated with MCF evaluation.

**Figure 6 Multi Channel Fiber Tester MT9100A.**

### Test Configuration and Measurement Overview

In the measurement setup, each core of the MCF is connected to the respective channels (ports) of the MT9100A via a FIFO device that enables branching from the MCF to SMFs. Because measurements using the MT9100A are completed with a single-ended connection, there is no need to place measurement instruments or operators at the far end of the fiber. This configuration is therefore well-suited not only for research and development, but also for use in manufacturing lines and field applications.

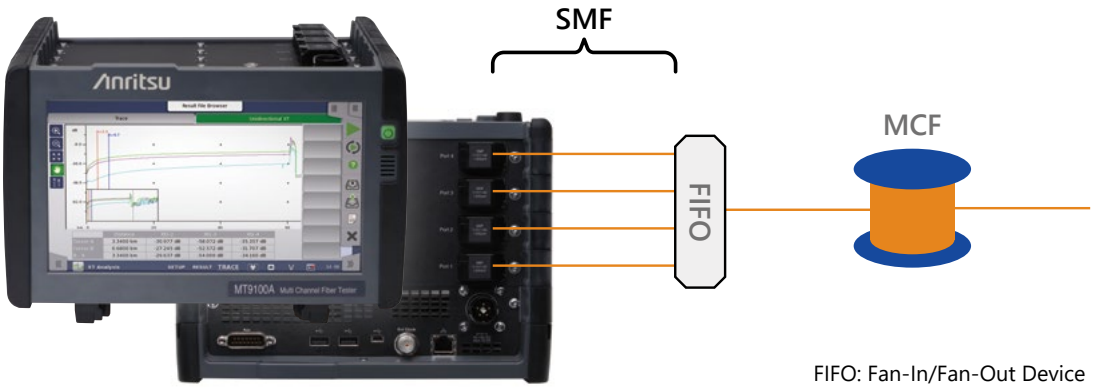
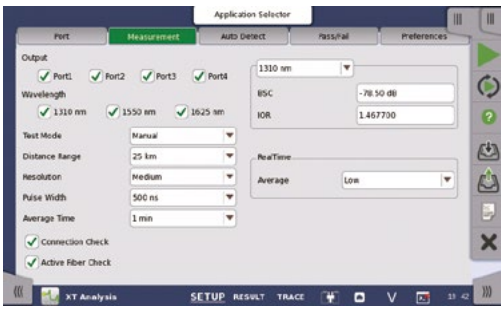



**Figure 7 Measurement image of MCF using the MT9100A.**

## Measurement Procedure

1. Connection:
   First, connect each core of the MCF under test to the respective channels (ports) of the MT9100A via a FIFO device. During connection, ensure that the optical fiber connector type (UPC/APC) is correct, and thoroughly clean the fiber ferrule end faces. This helps minimize variations in connection loss and inter-core crosstalk.

2. Measurement Condition Settings:
   Next, set the measurement conditions required for evaluation, such as the number of cores to be measured (up to four cores), the wavelengths to be used (1310/1550/1625 nm), and the averaging time (e.g., 30 s per wavelength).
   Setting level offsets and wavelength correction values can further improve measurement accuracy (see the Appendix for details).
   When measurements are required to be performed at wavelengths closer to the nominal values, use of the center wavelength accuracy option (±10 nm at 1550/1625 nm) is also recommended.




3. Single-Action Measurement:
   Once preparation is complete, start the measurement. The transmission ports are automatically switched within the instrument, and the backscattered signals from each core are acquired on a common time axis. No external optical switches or manual switching are required, allowing all cores to be evaluated simultaneously.

4. Result Review:
   From the acquired trace data, loss, reflection, and crosstalk can be visualized along the distance axis, enabling a comprehensive assessment of optical transmission characteristics. Measurement data can be saved automatically or manually in XTA format (waveform data) or CSV format (numerical data). The data can be transferred to a PC via USB memory or a network connection for use in quality records and traceability management.

5. Pass/Fail Judgment:
   Pass/fail threshold values can be set in advance. When a measured value exceeds a threshold, an NG judgment is automatically displayed, and abnormal sections and events (such as connectors and fusion splice points) are automatically detected. If necessary, distribution traces can be used to identify locations of increased inter-core crosstalk and to analyze the underlying causes. The summary screen allows inter-core crosstalk and loss distributions to be reviewed at a glance.

By introducing the MT9100A, highly accurate and efficient measurement and analysis can be performed across a wide range of scenarios, including research and development, manufacturing, and field applications involving MCF. In particular, the ability to handle all cores simultaneously reduces repetitive measurement tasks and directly contributes to improved evaluation throughput.

### Advantages of Visualizing Inter-Core Crosstalk Distribution

One of the key features of the multi-channel OTDR method is its ability to visualize inter-core crosstalk as a distribution along the distance axis. With conventional approaches such as the transmission method, crosstalk has typically been evaluated as an average value over the entire fiber, making it difficult to identify where along the fiber crosstalk increases.

In MCF, crosstalk varies from section to section due to factors such as bending radius during installation, tensile stress, fixing methods, and the precision of connector and splice processing. By acquiring backscattered signals from each core on a common time axis, the multi-channel OTDR method enables the locations where inter-core crosstalk occurs and increases to be identified with distance resolution.

This capability makes it possible to quantitatively define installation requirements, including:

- Verification of whether the assumed installation conditions at the design stage are appropriate
- Identification of quality variations caused by manufacturing processes or installation work
- Clarification of bending conditions and installation rules required to meet allowable crosstalk levels

Distribution-based measurements provide essential information for ensuring the reliability of multicore fiber.

### Convenience of Single-Ended Measurement

With conventional MCF evaluation methods, it has been necessary to install light sources and measurement instruments at both ends of the fiber, which has posed a significant operational burden in field environments after installation. This not only requires personnel deployment and equipment transportation to the far end, but also leads to increased work time and adjustment effort. In contrast, the multi-channel OTDR method enables evaluation of all cores through measurement from a single end (single-ended measurement). By using the MT9100A, there is no need to place measurement instruments or operators at the far end, significantly reducing the workload at the site.

This feature enables rapid and flexible evaluation in scenarios such as:

- Field verification and maintenance after installation
- Outdoor or underground environments where securing a power supply is difficult
- Sampling inspections and full inspections on production lines

Single-ended measurement provides a major advantage by transforming MCF evaluation from a “specialized task” into a routine verification activity.

### Significant Reduction in Measurement Time and Cost

Because the multi-channel OTDR method allows simultaneous measurement of multiple cores, measurement time can be significantly reduced compared with conventional methods. With the MT9100A, after measurement is initiated, the transmission ports are automatically switched within the instrument, and backscattered signals from each core are acquired sequentially. No external optical switches or manual connection switching are required.

For example, this method offers the following features:

- One-action measurement of all cores and all wavelengths
- Measurement time dependent on the “number of cores × number of wavelengths × averaging time”
- Automatic data saving and automatic judgment of measurement results

These features eliminate reliance on operator skill and enable standardization of the evaluation workflow.

As a result, the method achieves:

- Reduced measurement time
- Lower personnel costs and fewer operational errors
- Reduced operational costs in both manufacturing and field environments

The multi-channel OTDR method is a highly practical test solution that combines improved efficiency with high-precision evaluation of MCF.

## Conclusion

As the adoption of MCF continues to expand, improving the efficiency and accuracy of transmission-characteristic evaluation is becoming increasingly important. The multi-channel OTDR method is a powerful solution that enables simultaneous, distribution-based evaluation of all cores, thereby addressing the challenges of conventional methods. Looking ahead, further advances in MCF evaluation technologies are expected, including support for higher core counts, compliance with new standards, and progress in evaluation automation. Anritsu will continue to contribute to solving on-site challenges by strengthening its related products and support systems.

# Appendix

## Practical Points for Measurement

To efficiently and accurately evaluate the optical transmission characteristics of MCF, proper design of the measurement workflow and practical know-how in the field are essential. This section provides a detailed explanation of the overall evaluation process using the MT9100A, along with key points to consider at each step.

## Correction and Accuracy Management Points

**• Noise Floor Management**

To ensure reproducible measurement of inter-core crosstalk, the waveform level should be adjusted to be at least 4.5 dB higher than the noise floor by selecting appropriate pulse widths and averaging times. The waveform level depends on the pulse width and can be increased by approximately 1.5 dB or more by doubling the pulse width. The noise floor depends on the averaging time and can be reduced by approximately 0.75 dB by doubling the averaging time. In general, for step-index MCFs with relatively large inter-core crosstalk, a pulse width of 1 μs and an averaging time of 30 s are often sufficient.

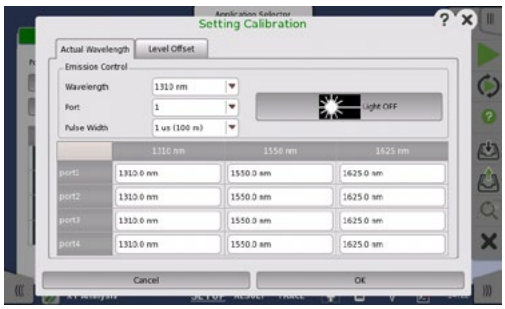
**• Dead Zone Mitigation**

When separation of closely spaced events is required, select a short pulse width, a short distance range, and high sampling resolution. Because there is a trade-off in which the dynamic range decreases as the pulse width becomes shorter, the minimum pulse width that allows crosstalk to be observed should be selected.

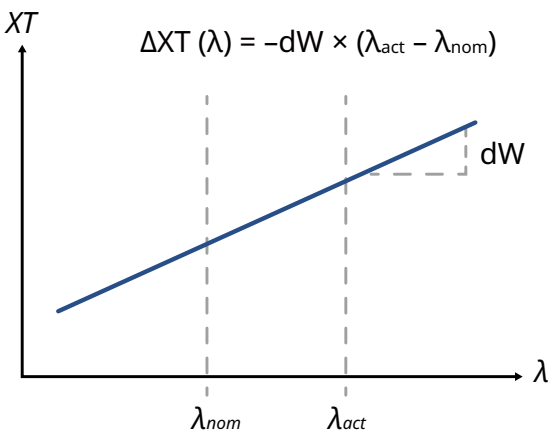
**• Wavelength-Direction Correction**

Crosstalk exhibits wavelength dependence and generally increases at longer wavelengths. When it is necessary to obtain crosstalk values corresponding to the nominal wavelength, the effective center wavelength of the MT9100A and the wavelength dependence of crosstalk of the MCF under evaluation are entered. The effective center wavelength ($\lambda_{act}$) is obtained by emitting optical pulses from the MT9100A and measuring them with an optical spectrum analyzer. The wavelength dependence of crosstalk (dW) can be derived, for example, from data obtained using the transmission method with wavelength sweeping. Once these values are set, the correction amount (ΔXT) is calculated according to the following equation, and the corrected crosstalk value ($XT_c$) is obtained from the measured crosstalk value ($XT_m$).

$$\Delta XT(\lambda) = -dW \times (\lambda_{act} - \lambda_{nom})$$
$$XT_c(\lambda) = -XT_m(\lambda) - \Delta XT(\lambda)$$




**Setting of Measurement Optical Pulse and Input of Effective Center Wavelength**




$$\Delta XT(\lambda) = -dW \times (\lambda_{act} - \lambda_{nom})$$

| | |
|---|---|
| $\Delta XT(\lambda)$ [dB] | XT Variation Amount<br>A smaller value indicates larger (worse) crosstalk. |
| dW [dB/nm] | Inter-Core Crosstalk Coefficient<br>For details, refer to the coefficient settings. |
| $\lambda_{act}$ [nm] | Effective Wavelength<br>Wavelength measured using an optical spectrum analyzer. |
| $\lambda_{nom}$ [nm] | Nominal Wavelength<br>One of 1310 nm, 1550 nm, or 1625 nm. |

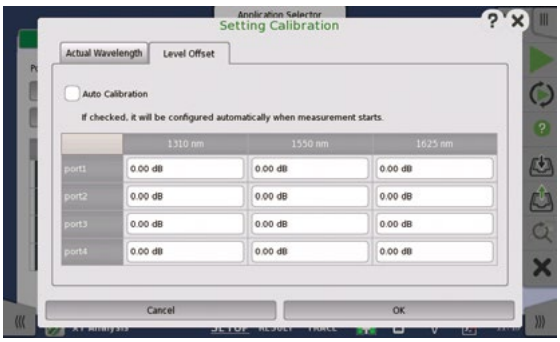
The corrected XT measurement value, $XT_c(\lambda)$, is expressed by the following equation.

$$XT_c(\lambda) = -XT_m(\lambda) - \Delta XT(\lambda)$$

| | |
|---|---|
| $XT_m(\lambda)$ [dB] | XT measurement value (before correction) |
| $XT_c(\lambda)$ [dB] | Corrected XT value |

• **Level-Direction Correction**

When the loss at the near end of the instrument differs between cores, the loss difference [dB] introduces an error in the measured crosstalk equal to twice that difference. If multiple connection points are present between the instrument and the MCF and large inter-core loss differences are expected, use of the level offset function is effective. By setting each connection loss as a correction value, measurement reproducibility can be improved. Selecting the “Auto Setting” function allows the individual connection losses to be calculated prior to measurement, thereby reducing operational effort.



## Related Product

### Multi-Channel Fiber Tester  MT9100A

The Multi Channel Fiber Tester MT9100A is the industry's first* OTDR capable of evaluating optical transmission characteristics of multicore fiber, including inter-core crosstalk between optical transmission paths (cores). By enabling simultaneous measurement of up to four cores and visualizing optical transmission characteristics — including inter-core crosstalk — along the distance axis, the MT9100A makes it possible to accurately identify fault locations in multicore fiber.

By introducing the MT9100A, highly accurate and efficient measurement and analysis can be performed not only in research and development and manufacturing processes, but also across all stages of network construction and operation involving multicore fiber. For engineers, it represents an ideal test solution that dramatically improves both work quality and productivity through innovative technology.

* As of November 2025, according to research by Anritsu.

Learn more

## References

[1] Tetsuya Hayashi, Toshiki Taru, Osamu Shimakawa, Takashi Sasaki, and Eisuke Sasaoka, "Characterization of Crosstalk in Ultra-Low-Crosstalk Multi-Core Fiber," Journal of Lightwave Technology, vol. 30, no. 4, pp.583-589, Feb 15, 2012

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