Why hollow-core fiber is the next big leap in optical connectivity

app note

EXFO

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Introduction

Hollow-core fiber (HCF) is a breakthrough technology poised to revolutionize the telecommunications industry. With hollow-core fiber, light propagates through a central air-filled core, surrounded by a microstructured cladding, instead of through solid glass. With the latest advancement in nested antiresonant nodeless fiber (NANF), the attenuation challenges of traditional photonic bandgap fiber have been overcome.

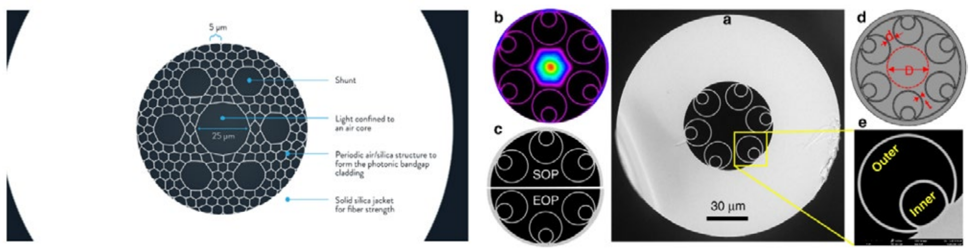

Figure 1. Comparison between photonic bandgap fiber (left) and NANF (right).

NANF maintains the key latency advantage of photonic bandgap fibers, since light travels through a medium with a refractive index close to 1.00—significantly lower than the 1.5 index of conventional ultra-low loss SMF-28 single-mode fiber. In addition, NANF achieves a lower attenuation coefficient than SMF-28, which typically exhibits attenuation about 0.16 dB/km in the ultra-low loss SMF variants. HCF is now being trialed in both field and laboratory settings, achieving record-low attenuation levels below 0.1 dB/km—marking a critical step toward real-world adoption. Some researchers anticipate that HCF could reach attenuation levels as low as 0.05 dB/km, making it a strong choice for long-distance communications. Additional benefits of HCF include minimal nonlinear effects, which allow the use of higher-power transceivers, along with inherently low chromatic and polarization mode dispersion (CD and PMD) that help extend transmission range.

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HCF is gaining traction in segments where ultra-low latency and high data rates are critical—most notably data center interconnects (DCI), high-performance computing, and specialized telecom networks. In DCI environments, where massive volumes of data move between data centers, HCF can provide a competitive edge by lowering signal delay, with the added benefit of reducing power consumption for amplification over longer spans. Beyond DCIs, emerging use cases include precision timing distribution, high-frequency financial trading, and advanced sensing applications.

EXFO developed a patent-pending method to decouple the GFE signal from the fiber trace, enabling accurate splice loss assessment.

EXFO at the core of HCF testing

As a global leader in fiber optic testing, EXFO is closely tracking the evolution of HCF technology. Our close collaborations within the industry allowed us to test our equipment on NANF HCF. These trials validated the readiness of our solutions and provided valuable data to further enhance our software capabilities. Today, EXFO offers a comprehensive portfolio of HCF-optimized test solutions, including the Hollow-Core Fiber OTDR Test Kit, which delivers precise fault location and loss measurements in scenarios where traditional OTDRs fall short. Its high dynamic range makes the hardware inherently well suited for HCF characterization.

Complementing this, the dedicated uni- and bi-directional analysis software extracts critical fiber parameters such as loss, ORL, and length. It also enables splice loss and reflectivity measurements—capabilities that required specific innovation for hollow-core fiber—making it a unique and essential tool for advancing this new fiber technology.

- **NS-348X – Hollow-Core Fiber OTDR Test Kit**
- **FTBx-570 – Advanced CD/PMD analyzer**
- **FTBx-88810 Series – 1G-800G solution with BERT application**
- **CTP10 – Attenuation profile**
- **FTBx-5255 – Optical spectrum analyzer**
- **MaxTester 945 – Compact OLTS for field use**

OTDR testing

In today's datacenter interconnect (DCI) environment, ultra-low latency and high bandwidth are critical for supporting cloud services, financial transactions, and AI workloads. As operators push for longer spans and higher speeds, fiber characterization becomes essential to guarantee performance and reliability. Optical time-domain reflectometer (OTDR) testing plays a key role in validating fiber integrity, splice quality, and overall link performance—especially when deploying advanced technologies like hollow-core fiber (HCF) to reduce latency.

Challenges

Hollow-core fiber introduces two unique challenges for OTDR testing, primarily due to its distinct physical properties.

1. **Low Rayleigh backscatter (RBS)**
   The first challenge is low Rayleigh backscatter (RBS). HCF exhibits RBS levels about 15 dB lower than standard single-mode glass fiber, which significantly reduces the strength of return signals over long distances. To overcome this, a high-dynamic-range OTDR is essential. EXFO's bi-directional OTDR, optimized for hollow-core fiber and featuring the industry's highest dynamic range, has demonstrated exceptional performance in field trials for accurate HCF characterization.
2. **Splice assessment and gas filling events (GFE)**
   The second challenge involves splice assessment and gas filling events (GFEs). Unlike standard SMF splices, HCF splices display a unique signature: an RBS elevation on either side of the splice that can extend for kilometers. This occurs when environmental gases enter the hollow core during cutting and gradually equalize over several months, making accurate splice loss measurements difficult. To address this, EXFO developed a patent-pending method that isolates the GFE signal from the fiber trace, enabling precise splice loss evaluation. Furthermore, HCF splices often exhibit reflectivity unrelated to actual splice loss. EXFO's advanced analysis software captures both loss and reflectivity values, ensuring complete splice characterization.

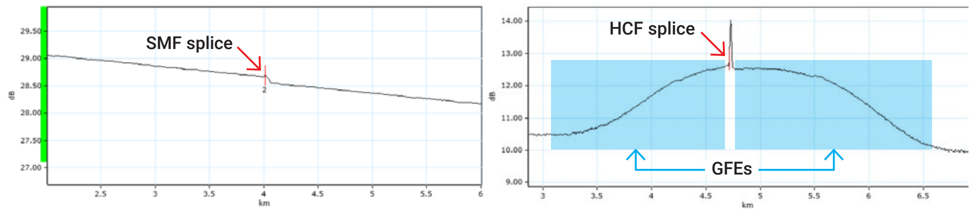

Figure 2. Comparison between SMF splice (left) and HCF splice (right) RBS signature.

Finally, hybrid cables combining HCF and SMF present an additional complexity due to their differing indices of refraction (IOR). EXFO's software accounts for these variations by supporting traces with dual IORs, guaranteeing accurate length measurements for each fiber section.

With EXFO's OTDR and patented analysis method, technicians can confidently assess splice loss—even on fibers exceeding 100 km in length, as illustrated in the following figure.

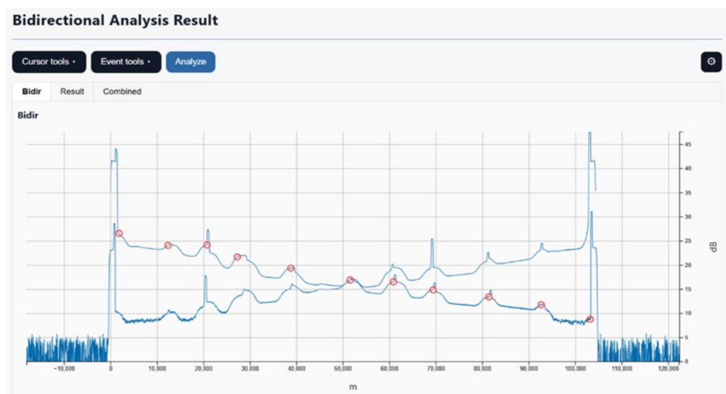

Figure 3. Raw trace acquired in both directions.

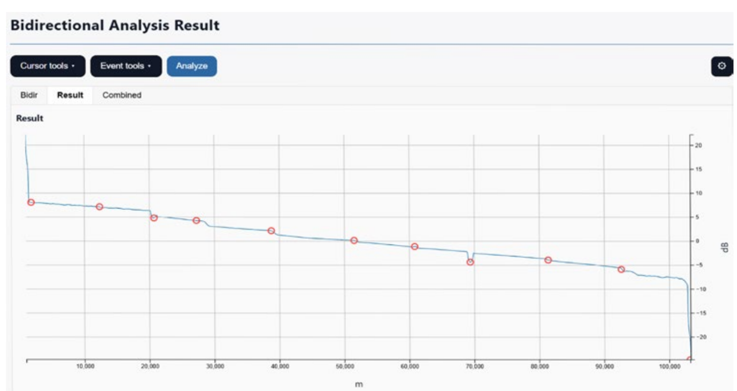

Figure 4. Splice loss assessment resulting from the HCF OTDR analysis.

For operators deploying data center interconnections, the promise of HCF goes beyond technological innovation—it's a direct business performance driver. By combining a high performance OTDR with a patented method to remove GFEs, EXFO turns a challenging testing environment into a reliable, repeatable, and scalable process. The result: verified end to end latency reduction, accelerated link qualification, accurate length measurements even on hybrid cables, and lower operational risk during deployment and maintenance. For latency sensitive applications—distributed AI, high frequency trading, multi site synchronization—this translates into a tangible competitive advantage: greater uptime, fewer surprises, and predictable performance over spans of 100+ km. In short, EXFO empowers DCI teams to deploy HCF with confidence, meet stringent latency SLAs, and accelerate time to revenue.

CD-PMD and latency characterization

Chromatic dispersion (CD) and polarization mode dispersion (PMD) testing are fundamental for validating high-capacity optical links, and this requirement extends to hollow-core fiber (HCF) deployments. HCF typically exhibits negligible chromatic dispersion due to its air-guided structure, while PMD values can vary significantly depending on the manufacturing process and fiber geometry.

In hybrid configurations where single-mode fiber (SMF) segments are combined with HCF, an additional performance metric becomes critical: wavelength-dependent latency. This parameter ensures that latency reduction objectives are achieved when replacing SMF with HCF. Since SMF delay characteristics are wavelength-sensitive, comprehensive testing across the operational spectrum is mandatory to guarantee compliance with end-to-end latency requirements.

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The FTBx-570 single-ended dispersion analyzer is inherently optimized for CD and PMD characterization on HCF. Its advanced software architecture supports refractive indices down to 1.00, enabling precise dispersion measurements on air-core structures. Furthermore, due to the lower attenuation coefficient of HCF compared to conventional SMF, the FTBx-570 achieves extended measurement ranges. Field validation has demonstrated successful operation on HCF spans exceeding 80 km using a standard UPC patch cord as the end reflection point. When equipped with the integrated mirror accessory, this range can surpass 200 km. Importantly, the FTBx-570 leverages end-of-fiber reflection for CD and PMD analysis, rendering the inherently low Rayleigh backscatter (RBS) of HCF inconsequential—only the reflection intensity dictates measurement feasibility.

Network type	Global link attenuation (dB/km)	Achievable distance UPC reflector	Achievable distance mirror reflector
Metro	0.25	120	150
Core	0.20	150	185
Longhaul	0.16	190	230
HCF	0.13	215	270

Table 1. Theoretical range of the FTBx-570 according to the global attenuation coefficient of the fiber.

A key differentiator of the FTBx-570 versus competitive dual-ended solutions lies in its ability to certify wavelength-dependent latency. This capability is essential for hybrid links where only a portion of the SMF infrastructure is replaced by HCF. By validating delay performance across the entire transmission band, the FTBx-570 ensures compliance with stringent latency specifications, safeguarding the integrity of ultra-low-latency applications.

Transmission measurement

Hollow-core fiber dramatically reduces propagation latency by guiding light primarily through an air-filled core. However, this same characteristic introduces increased sensitivity to specific gas absorption lines—particularly in parts of the L-band—which can impact signal quality.

The FTBx-88810 Series (1G–800G) test solution addresses these challenges by going beyond latency measurement alone. In addition to accurately measuring end-to-end latency which is critical for validating the ultra-low-delay benefits of hollow-core fiber, it supports full-rate bit error rate (BER) testing as well as pre-FEC BER measurements, providing visibility into physical-layer error performance prior to FEC correction.

BER

Alarms	Seconds		
No Traffic	0		
Pattern Loss	0		
Errors	**Seconds**	**Count**	**Rate**
Bit Error	0	0	0.00E00
Mismatch '0'	0	0	0.00E00
Mismatch '1'	0	0	0.00E00

Figure 5. BER/Errors tab showing clean link: no traffic alarms, zero bit errors, pattern loss, or ‘0’/’1’ mismatches with BER rate at 0.00E00.s.

By combining latency and bit error performance validation in a single test workflow, network operators can identify wavelength-dependent degradations potentially linked to gas absorption effects, determine which channels deliver robust performance at 100G, 400G, and 800G Ethernet rates, and validate that the hollow-core link meets both stringent latency targets and bit error performance requirements from end to end.

Latency

	Current (ms)	Average (ms)	Minimum (ms)	Maximum (ms)
Round-Trip	0.00537	0.00538	0.00535	0.00605 ✓
Round-Trip Threshold (ms)	0.10000		Unit	ms

Figure 6. Round-trip latency performance summary showing current, average, minimum, and maximum delay, all well below the 0.1 ms threshold.

Attenuation profile measurements (AP)

The attenuation profile describes how optical signal power decreases as light propagates through a fiber, depending on the wavelength and whether the fiber is a hollow-core fiber or a single-mode fiber. This profile is essential because it determines which wavelength bands can support long distance, high capacity transmission with minimal amplification. By understanding the attenuation profile, network designers can select optimal wavelengths, maximize transmission reach, and ultimately improve the efficiency and effectiveness of fiber optic communication systems.

Within EXFO’s portfolio, the CTP 10 combined with a tunable light source such as the T-500 provides the ideal laboratory solution. This setup offers the highest wavelength resolution across the full C+L bands. As a field alternative to the CTP 10, an optical spectrum analyzer like the FTBx 5255 can provide valuable insight into the attenuation profile of the installed fiber. When paired with a broadband source like the FLS 5834B, the FTBx 5255 can characterize the attenuation profile of hollow core fibers in the C+L bands with a resolution of 0.035 nm and wavelength uncertainty of 0.01nm.

For hollow core fiber, contaminants—often in the form of trapped gases resulting from gas filling events—create extremely narrow absorption bands. To accurately measure the total absorption within an optical channel, it is critical to use the narrowest possible resolution and uncertainty, which is achievable only with a dedicated OSA. By contrast, commercially available devices that combine CD/PMD and attenuation profile measurements are typically limited to an uncertainty of 0.1 nm, which may be insufficient to properly quantify the impact of narrow gas absorption lines present in hollow core fibers.

For more information

[Hollow-Core Fiber OTDR Test Kit]

[FTBx-570 – Single-ended dispersion analyzer]

[MaxTester 945 – Fiber certifier optical loss test set (OLTS)]

[FTBx-88810 Series – 1G-800G test solution]

[CTP10 – Passive optical component testing platform]

[FTBx-5255 – Optical spectrum analyzer]

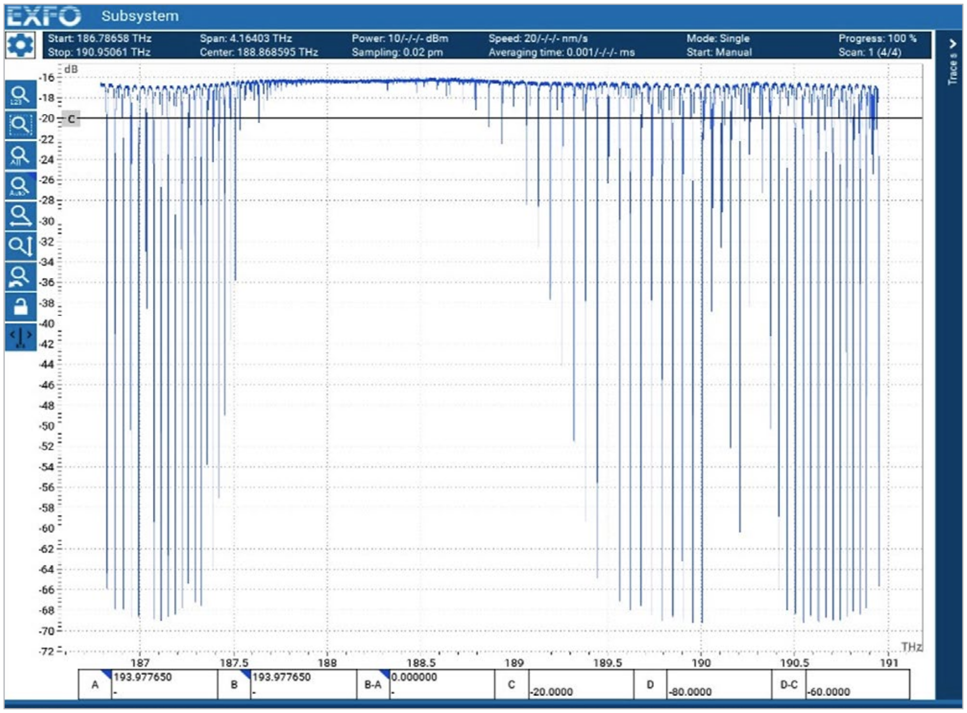

Figure 7. Spectral loss test results for CO2 and Hydrogen absorption of a typical long-distance HCF.

OLTS measurements

Among other applications, OLTS measurements are used to measure fiber continuity within hollow-core fiber. This is useful to ensure that the correct fiber is plugged in and that the optical path is intact from end to end.

In testing, paired MaxTester 945 units successfully measured fiber length, total loss, and reflectivity, and confirmed fiber continuity—making them ideal for field verification tasks or short cable with no splice to verify.

Why EXFO?

At EXFO, customer satisfaction is paramount—especially as new technologies emerge. By collaborating early with customers and partners, we ensure our solutions address real-world challenges and lead the market in usability and performance. Characterizing HCF is no small feat, but EXFO brings unmatched expertise in fiber testing ensures we get it done—delivering reliable, first-time-right results with tools trusted across the industry.

Conclusion

EXFO is proud to offer a suite of solutions for HCF testing and characterization. Whether you're in R&D, deployment, or troubleshooting, our solution are ready to help you get the most from hollow-core fiber. Contact your EXFO representative for more information or request a live demonstration—and see how EXFO can support your next HCF project with confidence and precision.