Monitoring Hollow Core Fiber

A practical, layered approach: from proven cable surveillance to Hollow Core fiber-specific degradation assessment

Hollow core fiber (HCF) is moving rapidly from research into trials and early operational deployments. Operators rightly ask how their installed HCF links will be monitored over their service life. The encouraging news is that a credible foundation already exists. VIAVI's installed base of remote fiber test systems (RFTS) watches over thousands of fiber routes today, and the underlying methods — single-ended OTDR surveillance, alarming, and trending via ONMSi — extend naturally to HCF cables. This application note describes the recommended monitoring strategy for HCF — starting from what works today on standard fiber, then layering in the additional techniques needed to characterize the HCF itself as the technology matures.

Throughout, we make a deliberate distinction between two questions an operator may want answered. Is the cable healthy? — answered by surveilling a witness fiber inside the cable. Is the HCF link itself degrading? — answered by additional, complementary measurements on the HCF fiber. These questions need not be answered with the same instrument or technique, and in many deployments the simplest, most economical solution will combine them in layers.

1. The Witness-Fiber Baseline (Where It Applies)

Outside-plant fiber cables are most economically monitored by dedicating one fiber in the bundle as a witness fiber — a single fiber that travels with the cable and is continuously OTDR-monitored from a permanent fiber test head (FTH) at one end. This is the standard RFTS approach and it remains valuable for HCF cables. How it is applied depends on what fibers the HCF cable actually contains:

- **HCF-only cables** — Most HCF cables now reaching the field do not include single-mode fiber alongside the HCF; the cable is all-HCF. In that case the witness role can still be played by a dedicated HCF fiber that carries no live traffic, but it is monitored using the HCF-specific approaches described in the rest of this note rather than by standard SMF reflectometry. The witness layer here is more demanding and shares the maturity of those HCF-direct methods.
- **Cables with SMF alongside HCF** — Where the cable bundle does include a single-mode fiber, it is a convenient and immediately available witness because its OTDR signature is well understood and stable. This configuration delivers the full operational maturity of today's RFTS today, with no HCF-specific development needed. It cannot be assumed for every HCF deployment; it is an opportunistic advantage when the cable architecture provides it.

In both cases the monitoring signal is fully separated from any HCF fiber carrying live traffic, and — where the witness configuration is available — the model delivers the familiar operational advantages of RFTS:

- Continuous cable-health visibility with technology operators already know.
- Proven RFTS reliability across thousands of installed nodes
- Zero impact on HCF transmission — no in-band multiplexer, no insertion loss, no latency penalty on the live HCF fibers.
- Fast time to deploy using equipment, processes, and operator workflows that are already in place.

Cable-level events — fiber cuts, severe bends, crushing, abnormal temperature, and other physical damage — are common to all fibers in a cable and will manifest on whichever fiber is chosen as the witness. The HCF-specific monitoring topics discussed in the rest of this note are therefore important in their own right: on HCF-only cables they are how the witness role is actually delivered, and on cables with SMF they add the link-loss view that the SMF witness cannot provide for the HCF spans themselves.

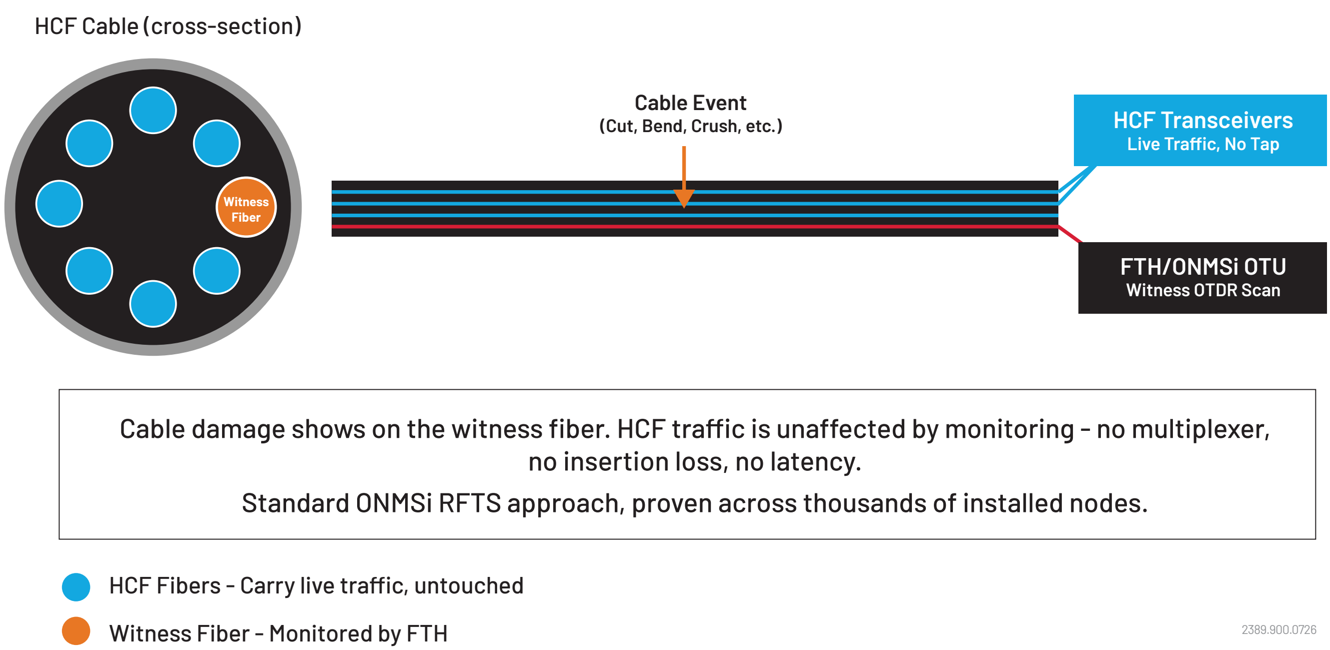


Figure 1. Witness fiber monitoring of an HCF cable. A single dedicated witness fiber rides with the HCF fibers in the same bundle; physical events affecting the cable manifest on the witness fiber, with no impact on the HCF fibers carrying live traffic.

2. The HCF Optical Signature: What We Have to Work With

When direct monitoring of the HCF fiber is required (for example, for degradation characterization, splice surveillance, or ready-for-service verification), it is important to be realistic about the signal an OTDR has to work with. These are facts about HCF reflectometry, not about HCF as a transmission medium. They affect how we monitor; they do not, by themselves, affect the operating health of the link.

- Backscatter is much weaker than in SMF. The Rayleigh backscattering coefficient itself is approximately 30–40 dB lower than in SMF; the resulting OTDR trace signal is on the order of 14–20 dB lower than for an equivalent SMF measurement. This compresses the usable dynamic range, so monitoring approaches that depend on resolving small backscatter variations along the HCF span are intrinsically delicate.
- The backscatter coefficient is non-uniform along the fiber, varying with microstructure and gas conditions. Trace shape can show variations that have nothing to do with link loss.
- SMF↔HCF transitions may exhibit high reflectance producing extended dead zones that obscure the immediate vicinity of each transition.
- Recent research has shown that the backscattering signature of anti-resonant hollow-core fiber depends on the gas content and pressure within the hollow core. As gas conditions evolve, the relative contribution of gas-molecule scattering and surface scattering may change, potentially affecting the measured backscatter profile over time. Crucially, backscatter drift in HCF does not by itself reduce the link budget or impact carried traffic — it is a measurement-side challenge for monitoring, not a transmission impairment.

3. Recommended HCF-Direct Approach: Single-Ended IL Surveillance

For deployments where direct monitoring of the HCF link is wanted in addition to the witness-fiber baseline, the recommended approach is single-ended and built around three elements:

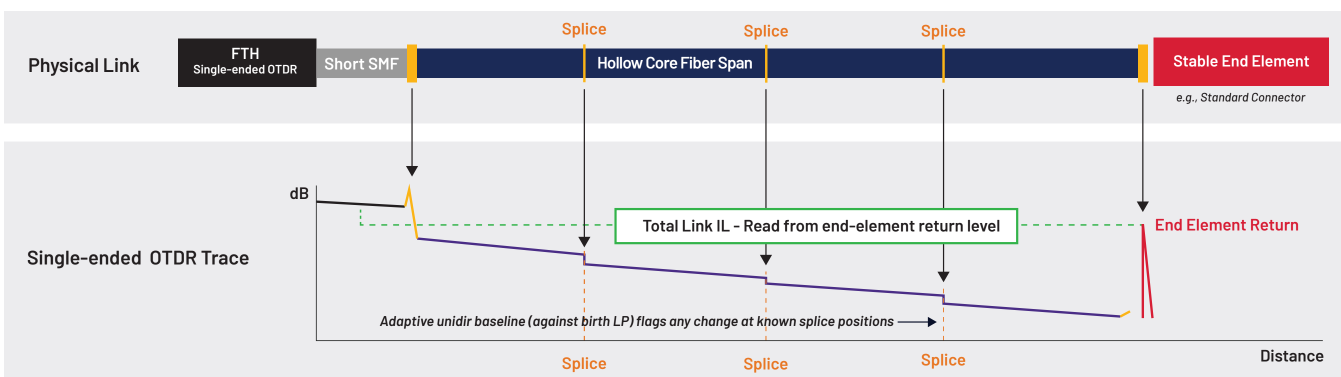
- **A stable end-of-link reference.** A stable, well-characterized element at the far end of the HCF link — typically a standard, properly installed connector or termination with measurable, stable reflection — returns a known signal back to the OTDR. Because that element's reflection is stable over time, the level of its return on each scan is a direct indicator of total link insertion loss. This is a robust, single-ended, HCF-agnostic measure of link IL — and it does not depend on the HCF backscatter signature.
- **An adaptive single-ended baseline.** A high-quality "birth" loss profile (LP) is acquired at commissioning to characterize the link layout and the initial event losses. The first in-service unidirectional trace establishes the operational baseline. The monitoring system then tracks total link IL via the return level of the stable end element on every scan. While IL is stable, the unidirectional baseline auto-refreshes; when IL begins to change, the baseline is locked so that the change can be localized against a meaningful reference.

- **Localization at known events.** Splices and transitions are the most likely sites of physical degradation in service. With the birth LP providing the link layout, the in-service trace is monitored for variations at those known event positions — a method analogous to splice-assistant logic on conventional fiber. As the HCF backscatter signature stabilizes in service, the residual trace becomes a usable indicator of localized loss change.

This single-ended approach, anchored on a stable end element, gives a stable, in-service IL trend without continuous bidirectional measurement and without depending on monitoring methods that are not yet field-proven on HCF. For long, lossy links a longer SMF launch cable may be needed to accommodate the OTDR pulse width; in most cases a short launch cable combined with a stable end element is sufficient. Absolute IL accuracy is on the order of 1 dB, compared with better than 0.3 dB achievable with full bidirectional analysis. The stability over time — which is what monitoring actually requires — is excellent.

Single-ended HCF Link IL Surveillance with a Stable End Element

Total link IL is read from a stable, well-characterized element at the link end; localization comes from the unidirectional trace.



Single FTH + stable end element → continuous total IL trend, no bidirectional measurement, no in-band multiplexer.

Absolute IL accuracy ~ 1 db; long-term stability (what monitoring needs) is excellent.

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Figure 2. Single-ended HCF link IL surveillance. A stable element at the far end of the link — typically a standard, properly installed connector or termination — returns a measurable signal to the FTH; its return level tracks total link IL directly. The unidirectional trace, which on HCF is noisier and shows distinct Fresnel events at each splice, is anchored on a birth Loss Profile to provide localization at known splice positions.

4. Where Bidirectional OTDR Fits

Bidirectional OTDR analysis combines acquisitions from both link ends to produce a true LP that is independent of backscatter asymmetries. It is a powerful technique, and while the simpler single-ended approach in Section 3 will typically be the most economical choice for continuous lifecycle monitoring of HCF links carrying live traffic, bidirectional measurement has several roles worth considering — and the right mix depends on the operator's architecture and operational priorities.

Bidirectional OTDR is appropriate in the following roles:

- **Diagnostic, on demand.** When single-ended monitoring detects an unexplained deviation, a bidirectional acquisition is the right way to determine whether the change is real loss or backscatter drift.
- **Range extension** for very long HCF links where the single-ended dynamic range is insufficient.
- **Commissioning**, run once at acceptance to establish a high-confidence baseline link loss profile.
- **Witness HCF fiber.** Where the operator reserves a dedicated HCF fiber as a witness — carrying no live traffic — bidirectional monitoring becomes practical without imposing any insertion-loss or latency penalty on the production fibers. This is a useful option for early HCF deployments where there is appetite to characterize long-term HCF behavior in depth.
- **Repair and fault isolation.** A permanent FTH at one end combined with a portable instrument (a handheld OTDR or optical network analyzer) at the other end is a practical hybrid for locating faults and confirming the repair, without requiring permanent bidirectional infrastructure on every link.

For routine in-service monitoring of production HCF carrying live traffic, the single-ended approach in Section 3 will typically be the most economical choice; the bidirectional roles above complement it where deeper characterization, longer reach, dedicated witness fibers, or fault diagnosis call for it.

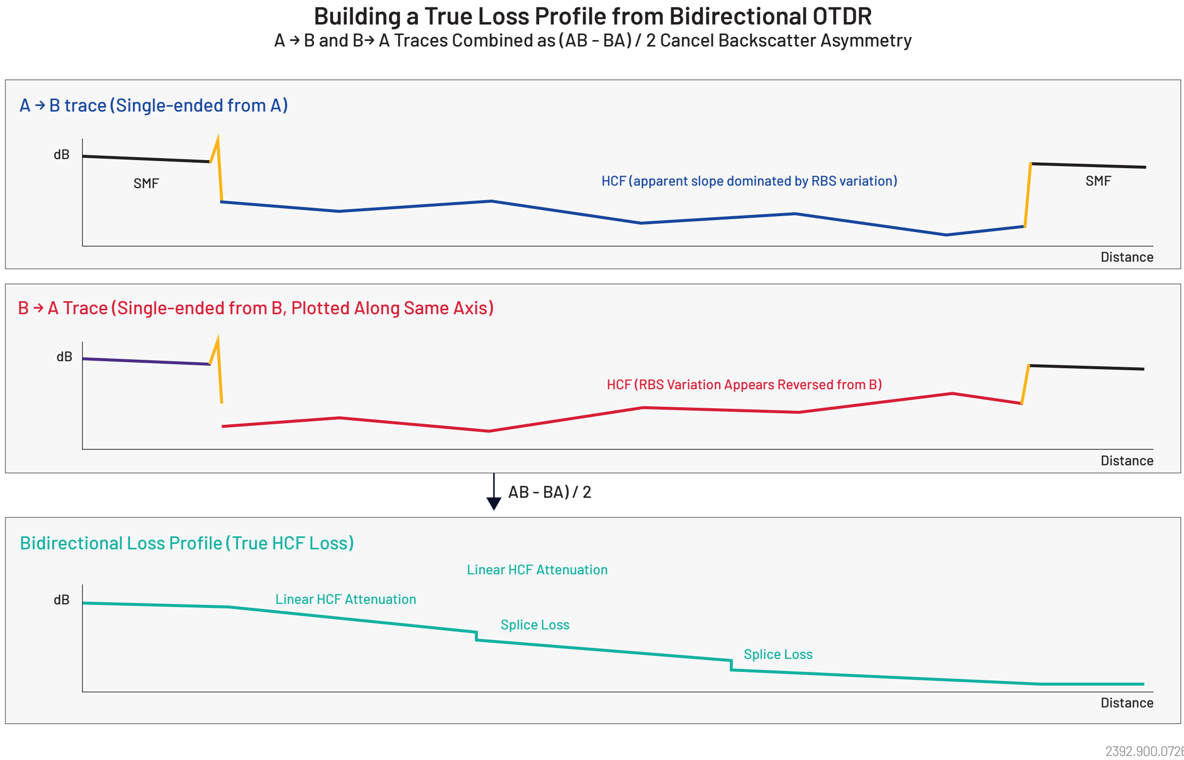

Figure 3. Bidirectional OTDR as a diagnostic and commissioning tool. Combining A→B and B→A acquisitions cancels backscatter asymmetry and exposes the true loss profile. Reserved for commissioning, on-demand diagnosis, and range-extension on long links — not for continuous lifecycle monitoring.

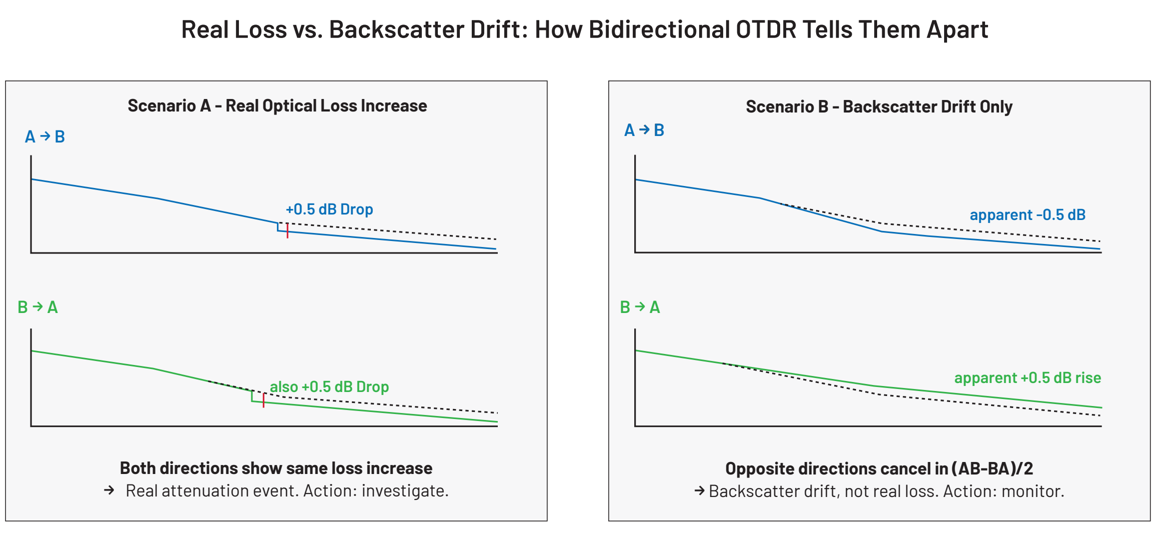

Figure 4. When single-ended monitoring flags an apparent IL change, an on-demand bidirectional measurement answers the diagnostic question: is it real loss (both directions confirm the change), or is it backscatter drift (the apparent changes cancel)? The verdict drives the operational action.

5. Loss vs Backscatter: Keeping the Right Question in View

A practical principle worth restating: the metric that determines whether an HCF link is healthy is end-to-end optical loss. Backscatter is the mechanism through which an OTDR sees the fiber, but a change in backscatter is not, in itself, an operational problem for transmission. Treating every apparent backscatter shift as a loss event will generate alarms that have no transmission meaning and will erode confidence in the monitoring system.

The single-ended IL surveillance approach in Section 3 is designed around this principle. The stable end element measures total IL directly and stably, the adaptive baseline keeps the unidirectional trace meaningful as the HCF gas signature settles, and bidirectional measurement is held in reserve for the rare cases where a deviation needs diagnostic confirmation. The result is a monitoring discipline that tracks what matters to the network — link loss — without chasing measurement artifacts that the network's transmission performance does not see.

6. Recommended Tiered Monitoring Strategy

The recommended strategy combines the four layers below in proportion to the question being asked. The foundation is the witness-fiber surveillance that operators already know and trust. HCF-specific layers are added only where they answer a real operational question that the witness fiber cannot.

Layer	Question It Answers	Method	Cadence and Status
1. Cable health	Is the cable physically intact?	Single-ended OTDR on a dedicated witness fiber inside the cable bundle. On HCF-only cables (the typical case), the witness is a dedicated HCF fiber monitored by the HCF-direct methods below. Where a separate SMF is present in the bundle, it can serve as the witness with the maturity of today's RFTS.	Continuous, 24/7. Proven and in service today on conventional cables.
2. HCF link IL	Has the HCF link's total loss changed?	Single-ended OTDR on the HCF, anchored on a stable end element. Total IL is read from its return level.	Continuous. No bidirectional measurement, no in-band multiplexer.
3. Localization	Where did an IL change occur?	Birth Loss Profile (LP) at commissioning + adaptive single-ended baseline; monitor variations at known splice positions.	Continuous. Splice-assistant logic on each scan; auto-refresh while IL is stable.
4. Diagnosis	Is an apparent change real loss or backscatter drift?	Bidirectional OTDR analysis, run on demand to combine A→B and B→A traces.	On demand only. Used to interpret a deviation, not for continuous monitoring.

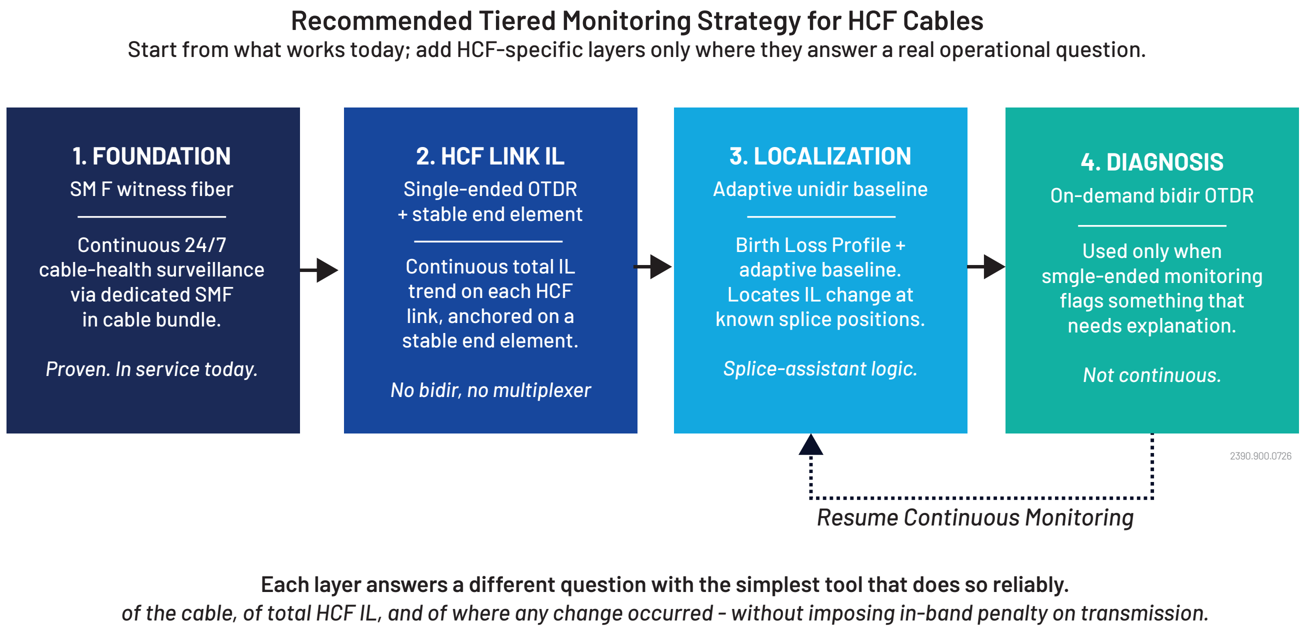

Figure 5. Recommended tiered monitoring strategy for HCF cables. The foundation is the proven witness-fiber surveillance; HCF-direct IL monitoring and adaptive localization are layered on top using single-ended OTDR; bidirectional OTDR is held in reserve for diagnosis and for the specific roles described in Section 4.

7. Practical Deployment Considerations

- **Witness fiber discipline.** Reserve one fiber per HCF cable for the witness role. Most HCF cables shipping today are all-HCF, in which case the witness is a dedicated HCF fiber monitored by the HCF-direct methods in Sections 2–4. Where the cable bundle includes an SMF, that SMF is the convenient and immediately mature choice — standard ONMSi configuration applies with no HCF-specific adaptation.
- **End-of-link reference.** Plan for a stable, well-characterized element (a standard, properly installed connector or termination) at the far end of each monitored HCF link; this is the anchor for single-ended IL monitoring. A short SMF launch cable is generally sufficient; for very long links, extend the launch cable as necessary to accommodate pulse width.
- **Adaptive baseline policy.** Configure the single-ended baseline to auto-refresh while link IL is stable, and to lock automatically when IL begins to change. This preserves localization sensitivity without generating nuisance alarms during the early-life backscatter settling period.
- **Wavelength.** HCF designs are typically optimized for 1550 nm and longer; monitoring at 1310 nm has limited diagnostic value for most HCF links.
- **Dynamic range at short pulse.** HCF splices are often 2–4 km apart, so usable dynamic range at short pulse width matters more than headline long-pulse figures.
- **Reflectance discipline at transitions.** Aim for SMF↔HCF transition reflectance below –50 dB at install; high transition reflectance produces dead zones that compromise both monitoring and diagnostic measurements.

- **Avoid in-band insertion where possible.** Direct in-band monitoring of a live HCF fiber requires inserting the OTDR signal alongside traffic via a multiplexer, which adds insertion loss and a small latency penalty. Wherever practical, prefer the witness-fiber and stable-end-element approach instead.

8. Bringing It Together

Monitoring hollow core fiber is not a search for a single, novel measurement. It is the disciplined combination of methods that already exist — witness-fiber surveillance applied to whichever fiber the cable provides (a dedicated HCF fiber on the typical all-HCF cable, or an SMF where the bundle happens to include one), robust single-ended IL monitoring anchored on a stable end element, adaptive unidirectional localization against a birth loss profile, and bidirectional measurement applied in the roles for which it is well suited — all framed by an awareness of HCF's specific reflectometry behavior.

Done well, this discipline gives operators the same operational confidence on HCF links that they expect on any other fiber asset: continuous visibility, a credible loss trend, and a clear escalation path when something changes — without imposing in-band penalty on the HCF transmission, and without depending on monitoring methods that are not yet field-proven on HCF.

VIAVI is actively working with HCF developers and operators to refine the HCF-specific elements of this strategy as the technology matures. To explore how it applies to a specific link or deployment, contact your VIAVI representative.

Related Materials

- Application Note: Testing Hollow Core Fiber (HCF)
- Resource site: What is Hollow Core Fiber (HCF) Testing?
- Platform: VIAVI ONMSi Optical Network Management System

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