Performance traceability of Photonic Integrated Circuits (PIC) devices within the supply chain: What is the appropriate interval for establishing a new optical reference?

By: Lawrence van der Vegt, Head of Photonics, MPI AST Division
May-2025
AN5525-1.0

EXECUTIVE SUMMARY

The rapid evolution and adoption of Photonic Integrated Circuits (PICs) have redefined performance benchmarks across a wide spectrum of next-generation technologies. From high-speed optical communication and artificial intelligence to quantum computing and advanced IoT (Internet of Things) architectures, PICs are at the core of innovation. Their application scope continues to expand, now extending into mission-critical and harsh-environment sectors such as autonomous transportation, aerospace, and medical diagnostics, where precision, durability, and miniaturization are paramount.
In response to this growing complexity and diversity of use cases, characterization of PIC devices has emerged as a mission-critical process in its development lifecycle. Comprehensive testing at multiple levels within the manufacturing process enables early detection of performance deviations, ensures long-term reliability, and supports traceability within its supply chain. As manufacturers scale production and integrate PICs into high-value systems, accurate, high-throughput metrology becomes indispensable—not only to reduce time-to-market but to maintain competitive advantage in a rapidly evolving supply system.

This document provides a detailed examination of the factors that can compromise the accuracy and repeatability of optical measurements and outlines methodologies to mitigate these risks. Understanding the variables that define stability, accuracy, and repeatability in a multifaceted test system is critical to correctly interpreting measurement results. Building preventive mitigations into the processes and system -as per MPI- ensures ongoing stability and minimizes downtime.

Content

INTRODUCTION

In the context of parasitic testing of PICs, the term “calibration” is often used to describe the process of making an optical “reference.” While the two are related, they serve distinct purposes in optical measurement workflows and should not be used interchangeably.

Optical referencing involves establishing a relative 0 dB baseline by transferring an absolute optical power level (dBm) to a self-created reference level. This is a local, system-specific operation that ensures consistency in comparative measurements. In contrast, calibration refers to adjusting or verifying a measurement against an external standard—typically an industry-recognized or national reference—to ensure traceable accuracy of absolute values.

In practice, optical referencing is typically limited to optical power, as wavelength calibration is handled internally by most (tunable) laser sources. Depending on the laser architecture, wavelength stability and accuracy are maintained through integrated referencing mechanisms, thereby eliminating the need for separate wavelength referencing in most test setups.

The stability of the optical power reference is a critical factor in qualification and validation of both passive and active PICs. This applies across various device types and interfaces, including:
- Optical-to-Optical (O/O) components (e.g., waveguides, filters)
- Electrical-to-Optical (E/O) devices (e.g., lasers, modulators)
- Optical-to-Electrical (O/E) devices (e.g., photodetectors)

Accurate and stable referencing underpins the reliability of test parameters such as insertion loss, responsivity, extinction ratio, polarization depended loss and return loss.

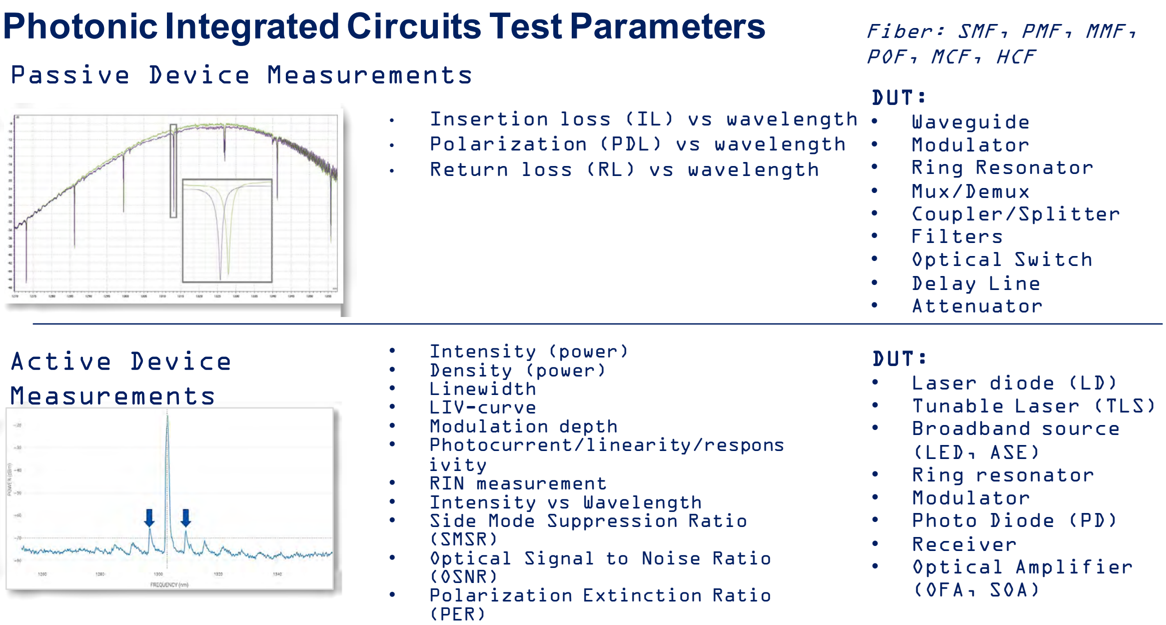

Fig. 1: Typical PIC test parameters

PICs are now widely deployed and have become the de facto standard in high-speed communication systems. The insatiable demand for greater bandwidth and higher data transmission rates has triggered large-scale mass production of PICs. However, this surge in deployment brings with it a critical challenge: every individual PIC device and port must be tested, placing immense pressure on reducing test times to an absolute minimum. Beyond telecommunications, PICs are also poised to become fundamental components in sensing, medical diagnostics, aerospace, and defense applications. As PICs continue to evolve, ensuring accurate device loss measurements and performance characterization becomes increasingly important.

Moreover, performance data must be traceable throughout the entire electronic and photonic component supply chain. This is especially vital as a PIC transitions from a Process Design Kit (PDK) layout to a packaged component or system-level circuitry ready for deployment. Ensuring traceability and accountability requires consistent characterization methodologies across the industry to enable comparable results, regardless of design or packaging variations.

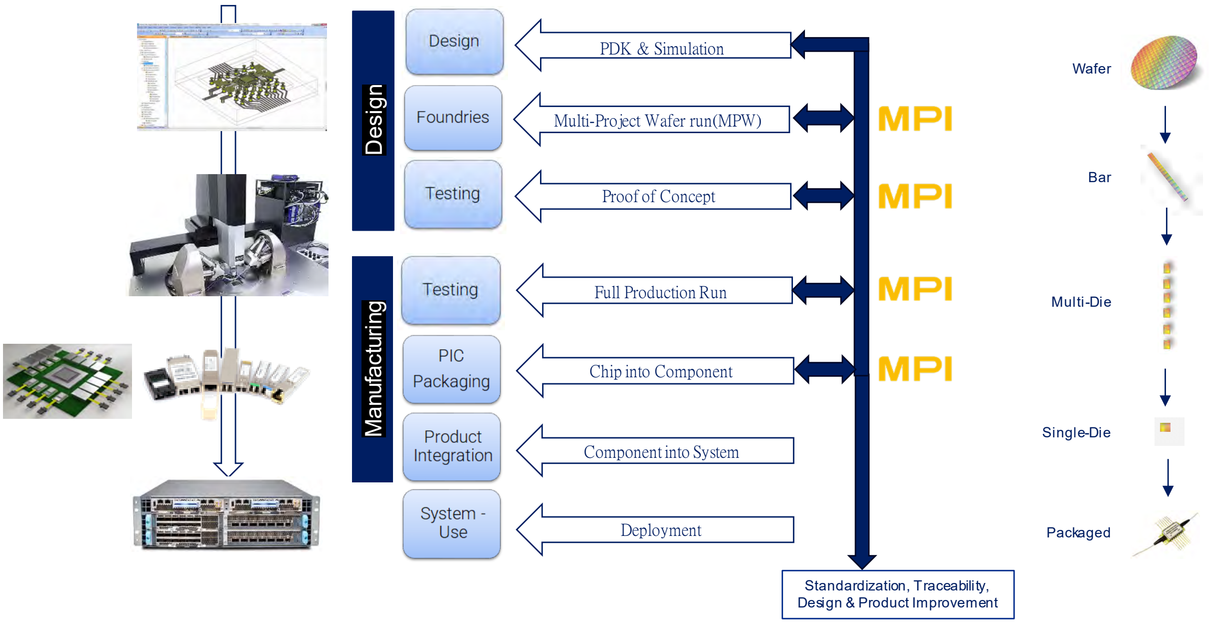

Fig. 2: Typical PIC Supply Chain

PROBLEM STATEMENT / TECHNICAL CHALLENGES

1. **Time requirements across the testing workflow.** Each phase of the PIC test process consumes valuable time. Keeping these to a bare minimum is essential to support high-throughput production environments:
   - **Hardware setup time:** Configuring test equipment to match the specific PIC design and port layout.
   - **Optical interface cleaning:** Ensuring cleanliness of fiber and probe tips, lenses, and couplers to avoid measurement contamination.
   - **Creating an optical reference:** Establishing an optical baseline (e.g., 0 dB reference) for accurate and repeatable loss measurements.
   - **Measurement execution:** Measurement acquisition of optical/electrical data from the PIC device under test with the right time-to-resolution ratio.
   - **Post-processing:** Analyzing and validating test results, storing data, and correlating with pass/fail thresholds.
   - **Throughput constraints:** Not having factored in time to re-reference in a production setting can turn into a time and resource catastrophe.
2. **Environmental condition variability.** Environmental factors—whether uncontrolled or deliberately introduced for stress testing—can significantly impact the repeatability and reliability of PIC measurements:
   - **Temperature variations:** Contraction and expansion of materials used in the test setup including the PIC device under test itself.
   - **Humidity fluctuations:** Can influence optical coupling and test instrumentation reliability.
   - **Mechanical vibration:** Destabilizes probe-to-PIC alignment and test instrumentation
   - **Dust and contaminants:** Degrades optical coupling efficiency and repeatability and introduces noise or measurement drift.

- **Ambient light interference:** which depending on the PIC testing wavelength can interfere destabilize measurement results. This is particularly applicable when testing PICs in the 200~1100nm range.

3. **Changes in hardware performance.** Over time, equipment drift or aging can lead to measurement inconsistencies:
   - **Probe system stability:** Changes in mechanical and optical alignment precision, affecting accuracy and repeatability.
   - **Laser source stability:** Includes output power fluctuations, mode hopping, wavelength drift, and polarization extinction ratio (PER) instability.
   - **Optical power meter and optical spectrum analyzer noise floor:** Variations and noise in detection systems can skew low-loss measurements.
4. **Optical power budget constraints.** Test setups (test instrumentation including probe system) should accommodate a wide range of PIC losses. The system's dynamic range must far exceed the expected PIC loss window.
   - **PIC insertion loss vs. test system dynamic range:** Adequate margin is necessary to measure both low- and high-loss components accurately and without damaging the PIC under test or connected optical test instrumentation.
5. **Operator-induced variability.** After establishing a baseline (e.g., 0 dB reference), several manual actions can unintentionally compromise test accuracy:
   - **Grating coupler alignment changes:** Slight probe tilt or shift alters coupling loss and wavelength.
   - **Test instrumentation setting adjustments:** Modifying power levels or wavelength post-reference negatively affects measurement results.
   - **Polarization control modifications:** Post-reference changes can introduce unpredictable measurement deviations.
   - **Hardware swaps:** Replacing fibers, connectors, or bulkheads post-reference leads to inconsistencies unless re-referenced.

SOLUTIONS OVERVIEW

Can be broken up in two groups, depending on the kind of testing required:

1. **Snapshot Testing** e.g., a one-time measurement requiring minimal time
   This is the most common method of testing PIC devices in a volume production setting, typically taking less than a minute to complete. Provided that a proper reference has been established, any fluctuations during the measurement period are negligible. However, fluctuations relative to the initial 0 dB reference can impact the measurement results, as illustrated in the example below:

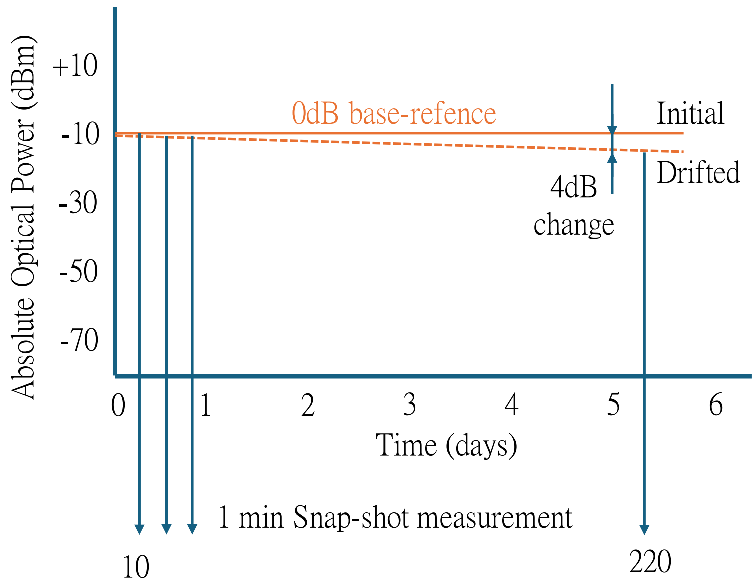

Fig. 3: Optical drift over time

Each snapshot measurement is taken from a different PIC port or device, making each result standalone and specific to that particular device or port.
In this example, a 0 dB baseline reference was established at timestamp 0. Without establishing a new reference over a span of 5 days, measurement #220 shows an insertion loss deviation that is 4 dB higher than it should be.
This drift is subject to the variables listed under the problem statement.

2. **Burn-in testing**, e.g. PIC device testing as a function of time, under optional stress conditions such as temperature/humidity and vibration.
Running burn-in type tests—either with or without stress testing—requires upfront knowledge of the standalone performance of the test setup hardware being used.
The setup and measurement process is similar to snapshot-type testing; however, the PIC device and port under test remain the same for the duration of the test. Burn-in testing typically runs over extended periods, typically ranging from 12 to 48 hours.
This setup does not allow for establishing new baseline references while the system is running. Therefore, the test setup should remain stable (within acceptable tolerances) for the entire duration of the measurement.

Steps to determine re-reference interval:

It's a given that any test setup will drift over time. This raises the question: How often should a new optical reference be established?
There is no one-size-fits-all answer—each test setup is different, and all relevant variables should be taken into consideration to determine the appropriate interval. The following four-step approach can be used to determine this number:

1. **Determine the environmental conditions under which measurements will be taken.**
   - What are the minimum and maximum temperatures?
   - What is the humidity range?
   - Is the environment clean and dust-free?
   - Is the location subject to vibration (e.g., traffic)?
   - Do the test instrumentation and probe system specifications fall within these environmental ranges?

2. **Determine the stability of the test instrumentation setup**
   Evaluate the system as a standalone setup. Directly connect the source and receiver of the test setup using two fibers and an optical bulkhead (for O–O type PIC devices) and run measurements over an extended period. The duration should be based on the equipment manufacturer's recommended reference interval and the interval the process operator intends to maintain. The deviation, as shown in the example below, should not exceed 0.6 dB.

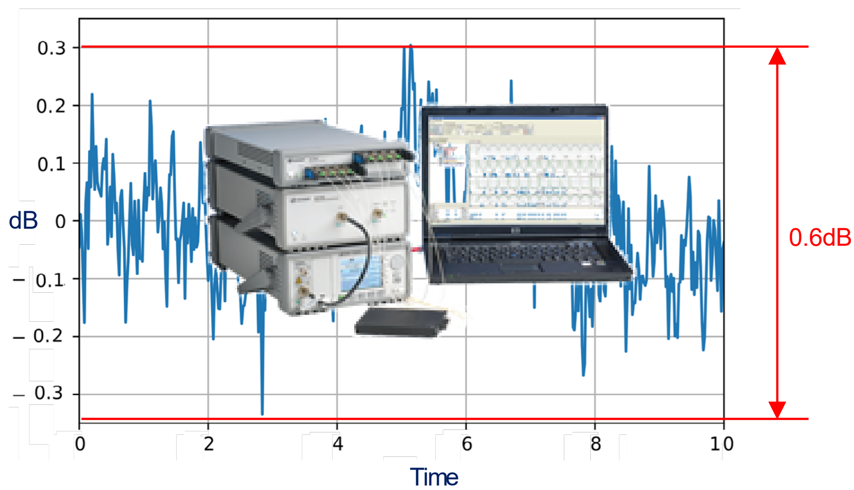

Fig. 4: Optical T&M deviation over time

Performance is highly dependent on the type, brand, and model of the test equipment, with some systems capable of maintaining stability within a 0.2 dB range.

3. Determine stability of the probe system

Once the performance of the test instrumentation used is confirmed, next is to test the stability of the probe system. The below setup represents the typical PIC probe system setup, including O-O, O-E and E-O test instrumentation.

Fig. 5: Default PIC probe system configuration

Once configured with PIC DUT compatible optical probes and with a 0 dB baseline reference established, the stability of the probe system can be evaluated by running measurements as described in Step #2. Key factors influencing probe system stability include the probe platen, to which the fiber probe positioners are mounted, the internal mechanism that holds the wafer or die on the chuck and maintaining probe positioning throughout the measurement. Depending on the optical coupling technique used, the latter components are subject to the fiber probe coupling variables outlined below.

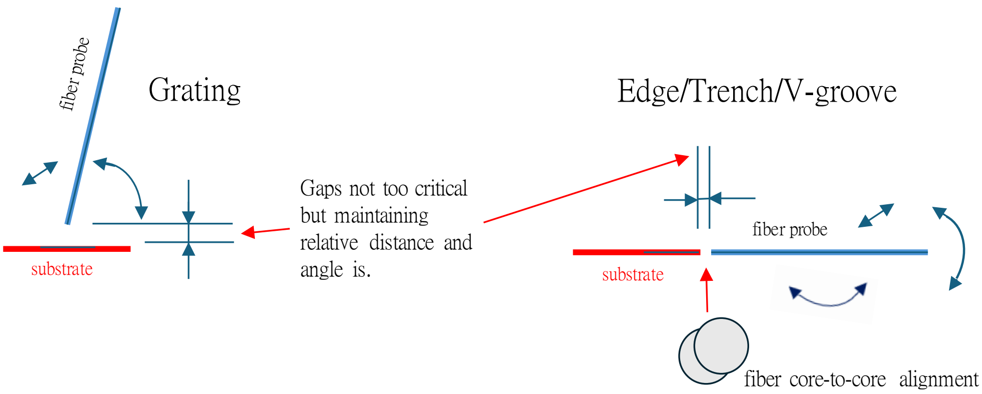

Fig. 6: Optical probe position variables

As with test instrumentation, probe system performance is entirely dependent on the brand, model, and configuration, with some MPI systems capable of maintaining stability within a 0.02 dB range using active control.

4. **Determining re-referencing interval**

Once the performance of the optical test instrumentation and probe system have been determined, next is to offset these values against the PIC under test. The sum of the two should fall within the pass/fail margin of the PIC under test as shown in the example below.

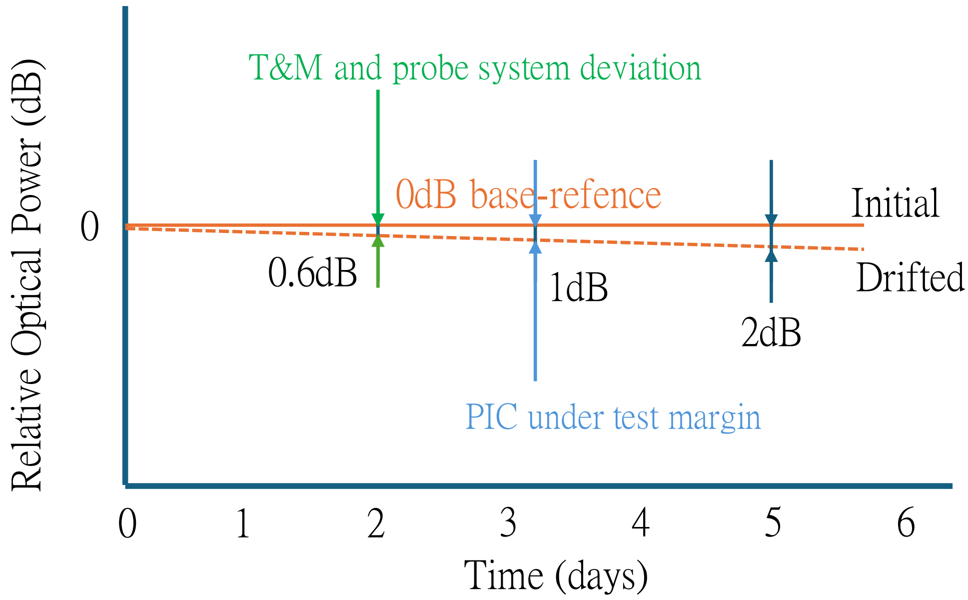

Fig. 7: Determining re-referencing interval

If the pass/fail margin of the PIC under test is, for example, 1 dB, and the overall drift of the combined test equipment and probe system setup follows the trend indicated by the dotted line, then the process operator should establish a new reference every three days.

SETUP MITIGATIONS

Prevention proactively avoids issues before they occur, saving time, cost, and resources that would otherwise be spent correcting them. In technical and manufacturing environments, such as PIC testing, seemingly minor issues like measurement drift can lead to inaccurate results, product rejection, or the need to repeat test cycles. Preventative measures ensure system stability, minimize downtime, and maintain data integrity. The mitigations below proactively address the variables listed under the problem statements.

1. **MPI Probe systems:**

   - Temperature control & compensation
   - **Probe arms:** Different material choices neutralize thermal contraction and expansion, maintaining consistent probe arm positioning.
   - **Chuck:** A wide range of field-exchangeable chucks is available, depending on the required temperature range. System-controlled integrated heating and cooling, coupled with probe system control SENTIO® software, minimize the effects of temperature variations.
   - **Auto fiber probe positioning:** Both the angle (for grating coupling) and the probe-to-DUT distance are methodically determined and set, eliminating operator interpretation.
   - **Calibration:** Dedicated calibration hardware and AI-driven process control software ensure accurate optical probe positioning as a function of temperature.

   - Vibration control
   - **Probe platen:** Features embedded software-controlled air cooling and efficient full thermal isolation.
   - **Internal mechanism:** Includes advanced vibration damping components.
   - **Hexapod with Nano-Positioner:** Provides active probe position compensation.
   - **Vibration-absorbing feet:** Further reduce external vibration impact.

   - Scalability
   - **All MPI probe systems are custom-configurable**, minimizing setup and reconfiguration time.
   - **Ambient light interference** is mitigated with an optical „dark box“ that can be mounted on top of the probe system.

   - Software automation, operator time is minimized through full software automation. SENTIO® manages probe system control, while Measmatic handles test instrumentation and external process control.

   - Throughput, volume wafer testing is supported through optional wafer feeders: the WaferWallet®, MAX, or ULTRA.

2. **Test instrumentation:**

   - Temperature/humidity control, since most lasers are sensitive to environmental conditions, maintaining a stable and controlled temperature and humidity is essential.

MEASUREMENT PROCEDURE

There are multiple test setup options to choose from, depending on the PIC device functionalities and the parameters to be tested. The sections below outline the most common setups and provide a step-by-step guide on how to establish a reference.
After selecting wavelength, power, and fiber-compatible components for the PIC under test, the first step—as described in the previous chapter—is to verify the performance of the test instrumentation that will be used to characterize PICs.

1. The first option is about testing a polarization independent Optical-to-Optical (O-O) PIC device on insertion loss as a function of wavelength with tunable laser source (TLS) and optical power meter (OPM)

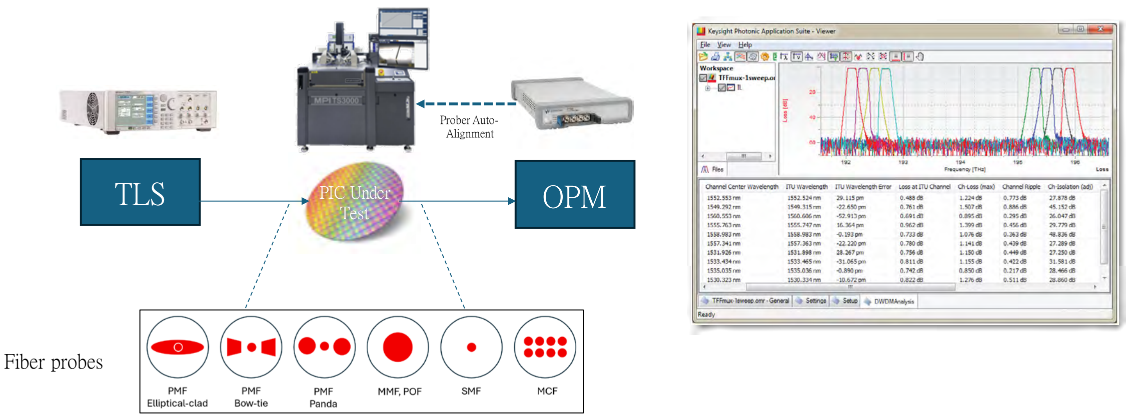

Fig. 8: Testing polarization independent PIC devices with a TLS and OPM

a. Establish a 0dB baseline reference by connecting the output fiber from the TLS to the input fiber to the OPM as shown below:

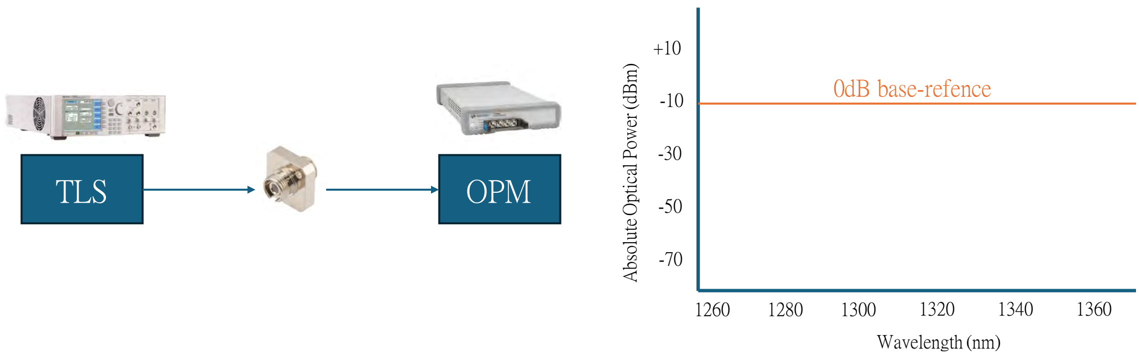

Fig. 9: Creating a baseline reference with a TLS and OPM

b. Once the performance of the test instrumentation is confirmed to be within acceptable limits, the next step is to include the probe system in the setup and perform a new 0 dB reference. For this setup, use a straight waveguide on the wafer under test and position both probes optimally. This can easily be achieved using the automated process in MPI's SENTIO® software.

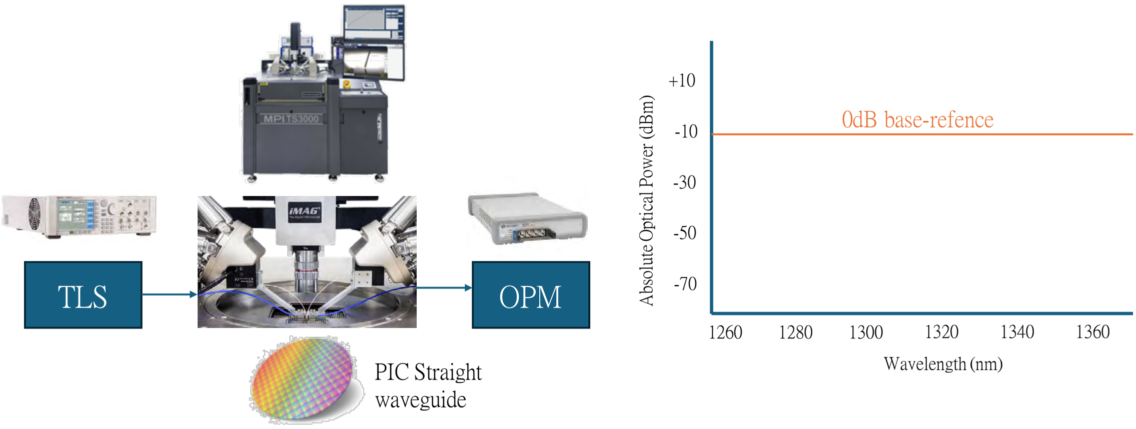

Fig. 10: Creating a baseline reference with a TLS and OPM on a probe system

c. Once the new 0 dB baseline reference has been established, move both probes to the input and output ports of the PIC device under test and perform a wavelength sweep on the test setup. The previously established 0 dB baseline reference will be replaced, and the characteristics of the PIC under test will be displayed as loss (in dB) as a function of wavelength.

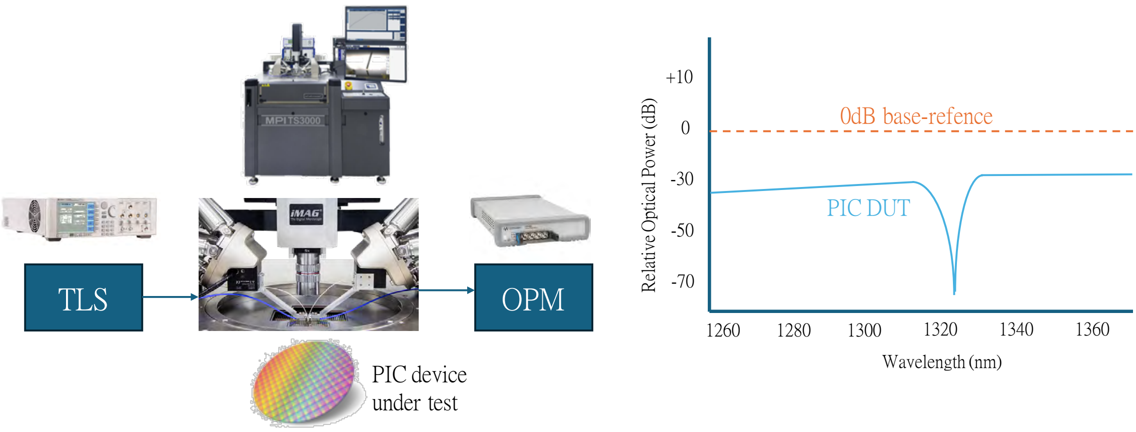

Fig. 11: Testing polarization independent PIC devices with a TLS and OPM

2. The second option is about testing a polarization independent Optical-to-Optical (O-O) PIC device on insertion loss as a function of wavelength with broadband source (BBS) like an LED or ASE source, and optical spectrum analyzer meter (OSA).

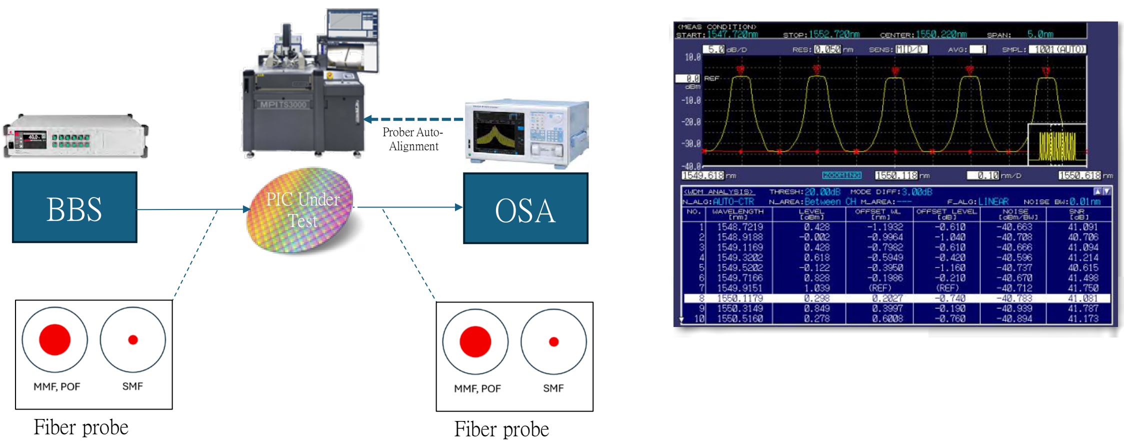

Fig. 12: Testing polarization independent PIC devices with a BBS and OSA

a. As with a TLS and OPM setup, the first step is to establish a reference by connecting the output fiber from the BBS to the input fiber of the OSA, as shown below. Instead of a flat 0 dB line, the optical spectrum of the BBS will be displayed. This spectrum serves as the baseline.

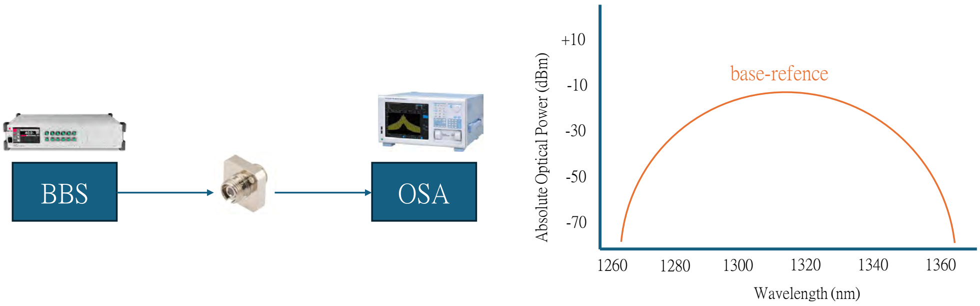

Fig. 13: Creating a baseline with a BBS and OSA

b. Once the performance of the test instrumentation is confirmed to be within acceptable limits, the next step is to include the probe system in the setup and perform a new reference measurement. For this setup, use a straight waveguide on the wafer under test and position both probes optimally. This can easily be achieved using the automated process in MPI's SENTIO® software.

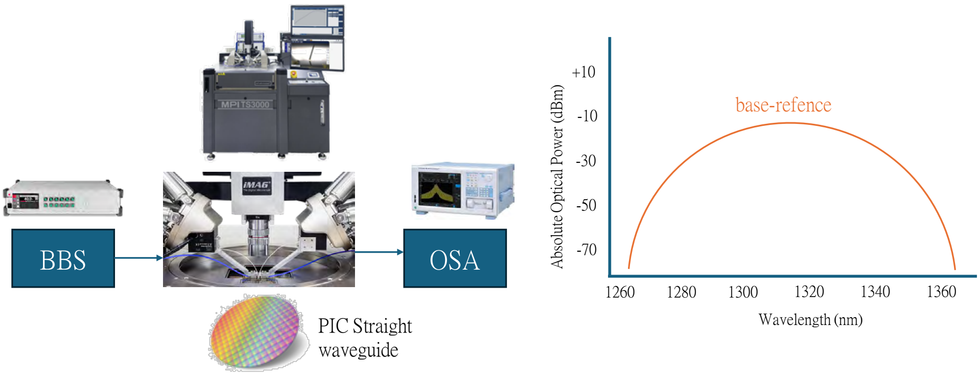

Fig. 14: Creating a reference with a BBS and OSA on a probe system

c. Once the new reference measurement has been made, move both probes to the input and output ports of the PIC device under test and perform a wavelength sweep on the test setup. Depending on the OSA used, both the first (reference) and second (PIC under test) measurements will be displayed as loss (in dB) as a function of wavelength.

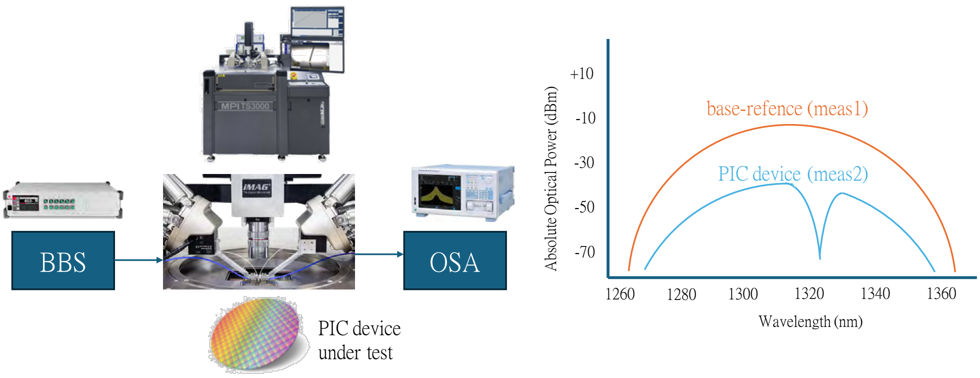

Fig. 15: Characterizing polarization independent PICs with a BBS and OSA

d. Last step is to normalize the results of the second measurement, which can be done by subtracting it from the first (reference) measurement. Actual loss characteristics of the PIC under test will be shown on the OSA as per the below:

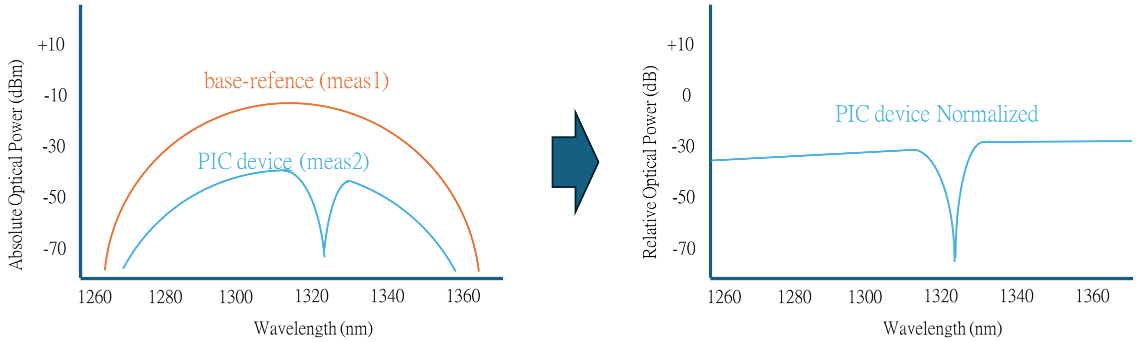

Fig. 16: Normalizing measurement results of a polarization independent PIC with a BBS and OSA

3. The third option involves testing a polarization-dependent Optical-to-Optical (O-O) PIC device for insertion loss and polarization-dependent loss as a function of wavelength, using a tunable laser source (TLS), polarization controller (POL), and optical power meter (OPM).

   Establishing a reference and performing measurements is similar to testing polarization-independent PIC devices; however, all measurements must be conducted as a function of the state of polarization.

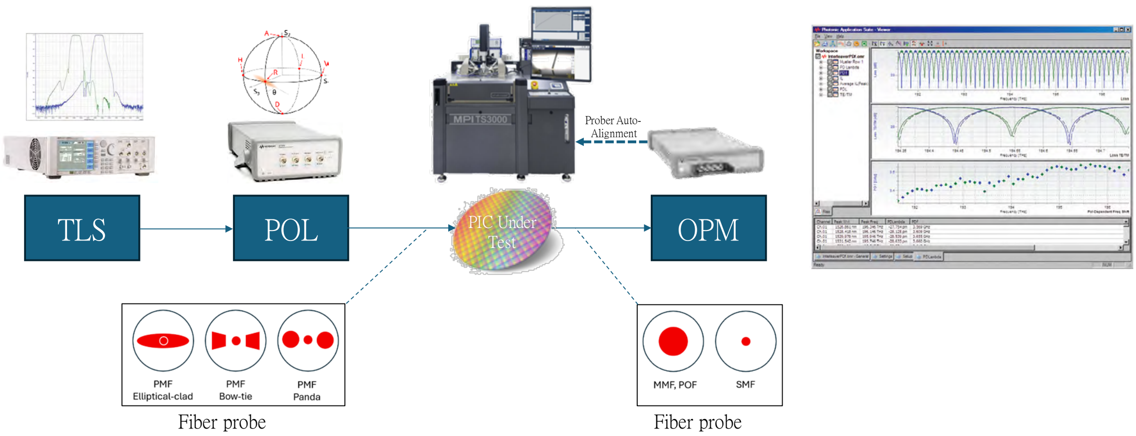

Fig. 17: Characterizing polarization dependent PICs with a TLS, POL and OPM

In summary:
As the above examples illustrate, there are many configuration setups and instruments available for performing PIC measurements. The selection depends on test parameters, PIC device functionality and design, required accuracy and repeatability, and acceptable measurement margins. However, in all instances the fundamental principle remains the same: always establish a known good baseline (reference) measurement before beginning PIC characterization.

Additionally, when performing temperature cycling (TCT) on photonic integrated circuits, it is necessary to run periodic reference measurements as a function of temperature to ensure maximum accuracy within the calibrated temperature range. As noted in the Setup Mitigation section, calibration hardware coupled with SENTIO® software can facilitate this process in a controlled and automated manner.

BACK to TOP

CONCLUSION

As explained in this application note, there is no one-size-fits-all answer to the question how often a new optical reference should be made, but taken all variables into consideration one can determine the appropriate interval by periodically measuring the performance of a known good PIC device. This could be a PIC on a die, bar of wafer. Making periodical measurements will show system drift over time (provided no change in environmental conditions) and once the threshold level has been passed one will know after how many hours/days/weeks a new optical baseline reference should be made.

Direct contact:
Asia region: ast-asia@mpi-corporation.com
EMEA region: ast-europe@mpi-corporation.com
America region: ast-americas@mpi-corporation.com

MPI global presence: for your local support, please find the right contact here:
mpi-corporation.com/ast/support/regional-sales-contact

MPI Global Presence