LPO-MSA

Link Diagnostics in LPO Applications

Abstract:
Network equipment comprised of Linear Pluggable Optics (LPO) modules and host ASICs provides a full suite of capabilities for link monitoring and analysis by leveraging diagnostic capabilities integrated within components along the signal path.

Introduction

LPO modules offer a lower power, lower cost, and lower latency solution compared to retimed/DSP-based modules by eliminating the discrete DSP from the optical modules, thereby maintaining a linear interface to the host ASIC. In LPO links, the host ASIC integrates the DSP functionality and is much more capable than the reference receiver assumed by standards such as IEEE at each segment of the link. This architecture difference is highlighted in Figure 1 as it relates to the Open Systems Interconnection (OSI) reference model.

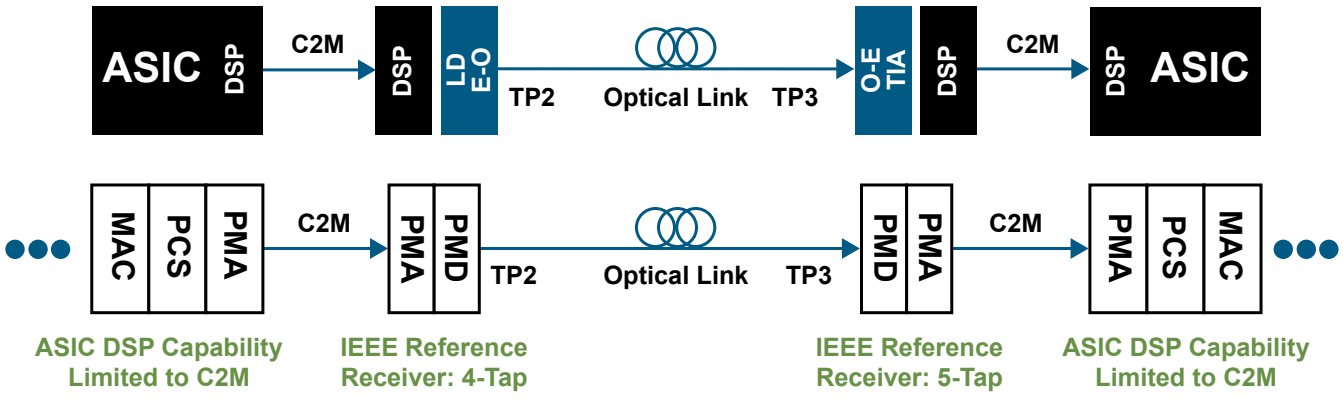

Figure 1a. Retimed Link

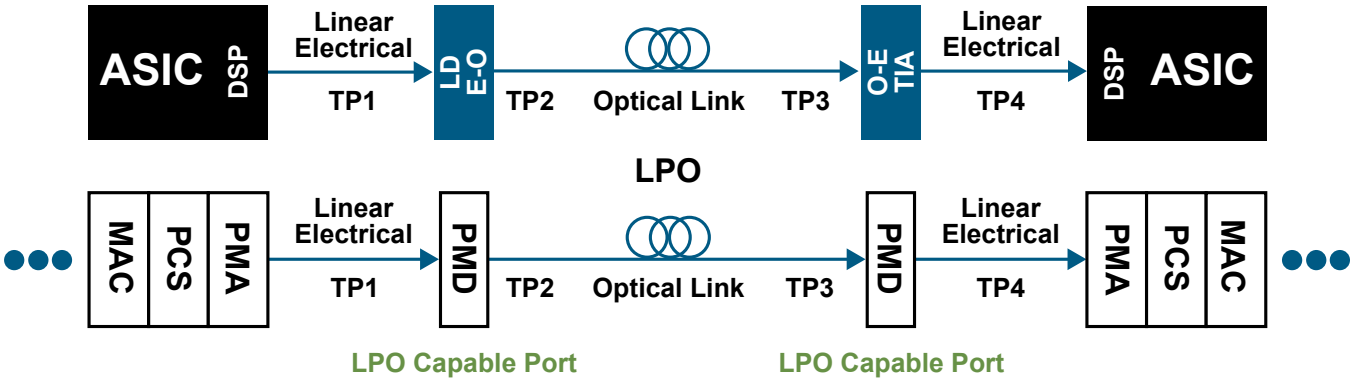

Figure 1b. LPO Link

Linear connectivity is also standard practice for Direct Attached Copper (DAC) cables, which is a passive solution (Figure 2). Diagnostic features in all three cases (Retimed, LPO, DAC) focus on the core functionality provided by the module, the host, and associated link elements to provide an indication of comprehensive link health. This paper outlines LPO capabilities that are available to end users as a part of link monitoring and diagnostics.

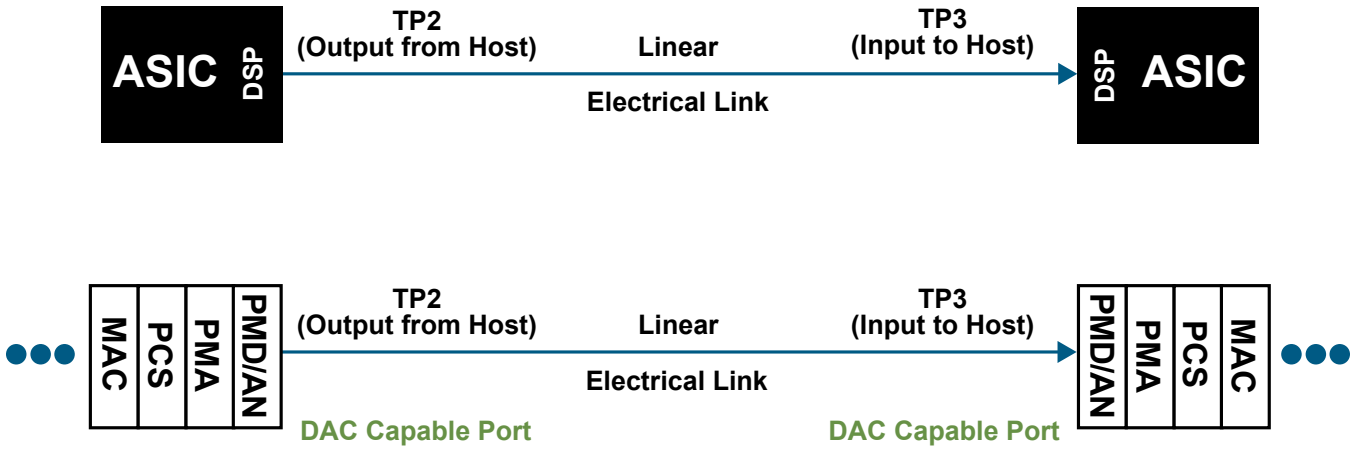

Figure 2: Passive Copper (DAC) Link

Linear Module Diagnostics

The simplest linear module is a DAC. The cable in this case is passive (no active electronics in the data path), and therefore high-speed active diagnostic capability is not available inside the module. Instead, host ASIC capability is leveraged to provide metrics for the health of the link. These capabilities may include end-to-end PRBS generation and checking, end-to-end channel loss estimation, and statistics for signal-to-noise (SNR), BER, and FEC. Example end-point ASIC capabilities is shown in Figure 3 which plots the received signal after equalization.

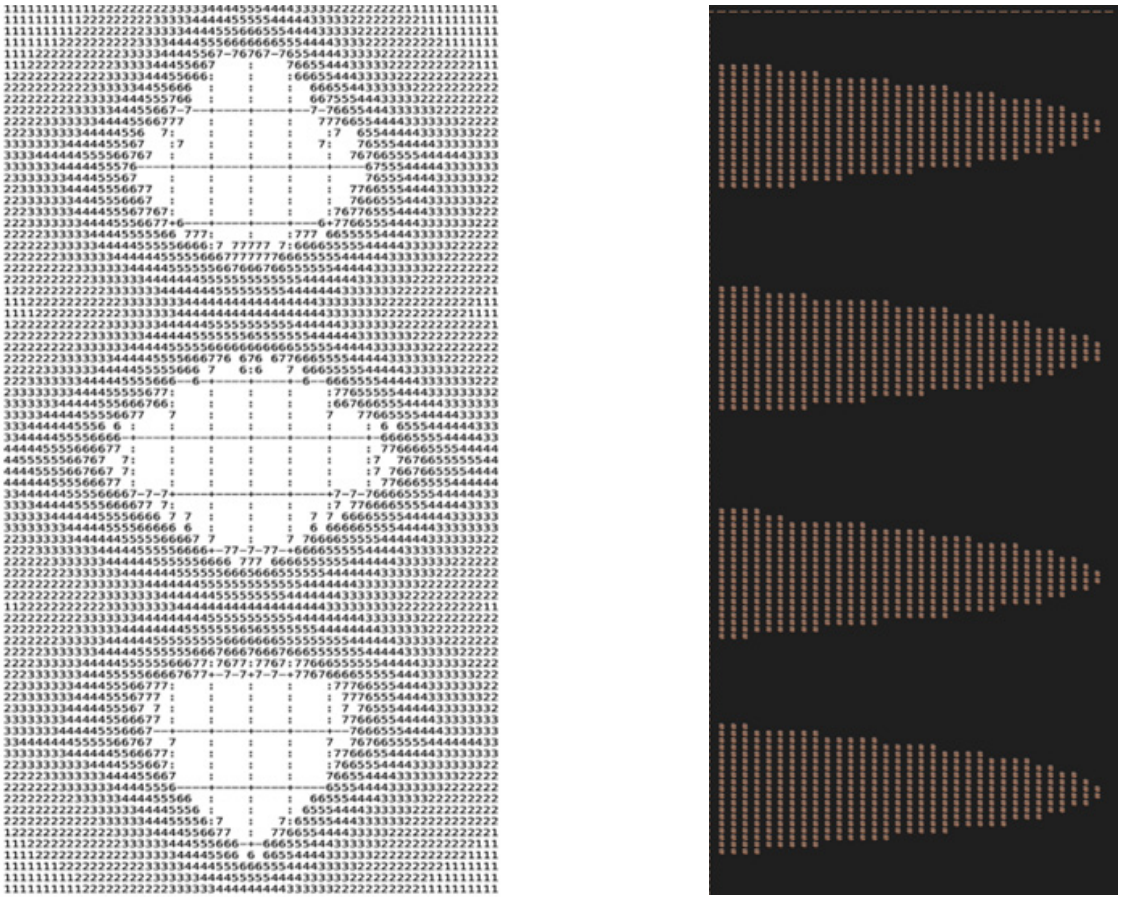

Figure 3: ASIC Diagnostic Plots

An LPO module can be considered an extension of the DAC use case in which the module performs linear communication over optical fiber and uses only a host DSP (the plot in Figure 3 was measured using an ASIC in diagnostics mode with an LPO link). Since there is a medium conversion via the PMD interface, active elements are required to perform E-O and O-E conversion. If one considers the IEEE model of a link in the LPO application:

- The Host ASIC corresponds to the Retimer Function (part of PMA)
- The Passive Egress Host channel corresponds to TP1
- The Optical Transmitter corresponds to the LPO module LD and E-O conversion
- The Optical Interface corresponds to TP2/3
- The Optical Receiver corresponds to the LPO O-E Photodiode and TIA
- The Ingress Host Channel corresponds to TP4

This IEEE 802.3 model is depicted in Figure 4.

From a link diagnostic perspective, IEEE 802.3 highlights SIGNAL_DETECT, which "shall be a global indicator of the presence of optical signals on all lanes." This diagnostic signal can be made available via the receive signal strength indicator (RSSI) associated with the LPO module and satisfies this core requirement.

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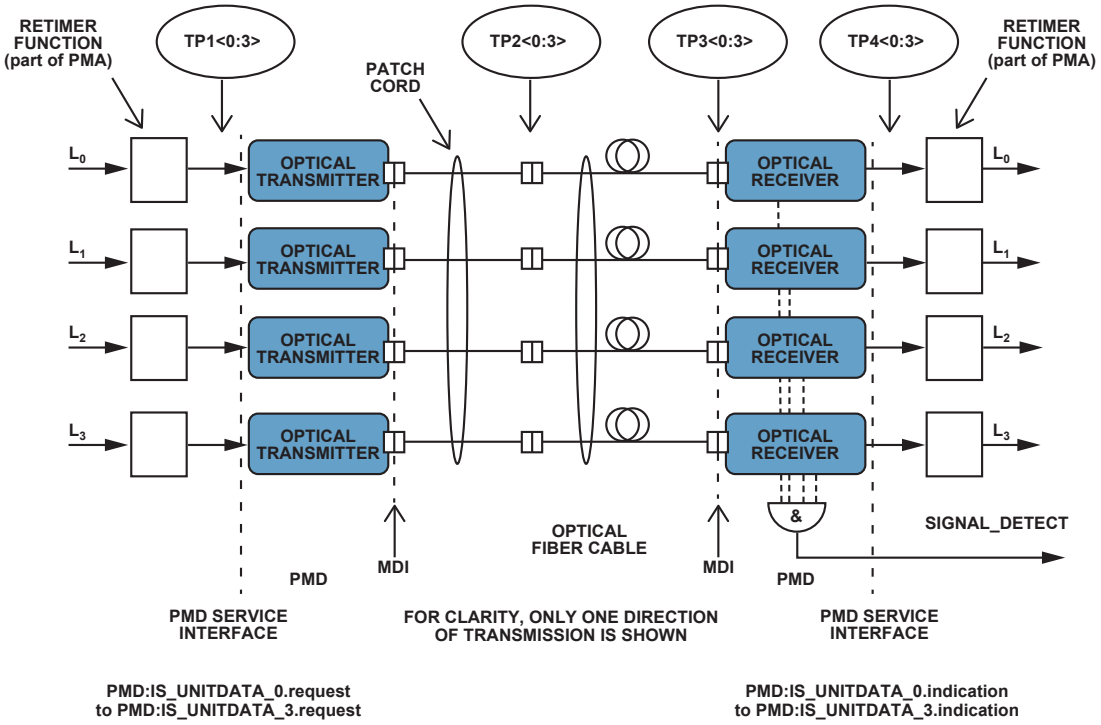

Figure 4: Example Block diagram 400G transmit/receive paths

Alternatively, IEEE 802.3 also provides the following diagnostics:

- PMD Global Transmit Disable Function. LPO modules support the requirement to turn off all optical transmitters by shutting down the laser driver and associated optical components.
- PMD Fault Detection. LPO modules can support this function by monitoring the operating conditions for components in the transmit and/or receive direction and triggering a fault when conditions fall out of expected ranges (including temperature, voltage, optical power out of range, etc.).

Beyond typical PMD diagnostics found in IEEE 802.3, LPO modules can leverage the active components in the transmit signal path to provide an indication of the signal presence from the transmit PMD service interface, similar to the SIGNAL_DETECT seen in the receive path. In this case, a module can leverage the signal amplitude seen at the LPO module driver to establish the presence of electrical signals on all lanes. This is additional optional diagnostic information not available in the DAC case and provides an indication of the presence of and health of the signal from the host.

The next diagnostic element in the transmit path is reporting of the transmit optical power. This data is available from LPO modules and represents an indication of the optical output power, which is equivalent to transmit power reported by retimed modules.

On the receive side, hosts can leverage the retimer capabilities of the ASIC capabilities to establish signal quality from the PMD service interface. Diagnostic information such as amplitude from the TIA, end-to-end PRBS generation and checking, end-to-end link loss, and statistics for signal-to-noise (SNR), BER, and FEC would again be available.

When optical modules introduced retimers, a Loss of Lock indicator (LOL) was added to establish if the retimer in the module was able to lock to the incoming data. Since an LPO module does not retime data, a Loss of Lock (LOL) indication is not meaningful, similar to how a DAC does not include an LOL indication. Removing the LOL indication from the module is a positive feature associated with LPO since the architecture obviates the need for module retiming functionality as well as associated diagnostic monitoring. Instead, an LOL indication can be signaled by the receiver retiming function, which is part of the local host ASIC. Taking this benefit one step further, the LPO architecture avoids multi-hop LOL sequence challenges seen at bring-up in retimed modules since only the endpoint ASIC locks to received data.

In LPO links, users can leverage the pattern generation and checking capabilities of the host ASIC since these represent signal endpoints analogous to the DAC case. In this case, the pattern generation and checking functionality of retimed modules is not needed. Signal detect functionality can be used by the LPO module to indicate the presence of the signal, and since the module is not making bit-level decisions, the pattern presented at an LPO module's input is what is available at its output.

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As discussed, the diagnostic capabilities from retimed modules are largely supported by LPO links as one considers the capabilities residing in each segment of the link.

LPO Diagnostics & CMIS

LPO modules and host ASICs offer a variety of diagnostic features and capabilities. The OIF Common Management Interface Specification (CMIS) Implementation Agreement documents the diagnostic registers supported by LPO modules, as highlighted in Table 1.

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CMIS Flag	Comments
LOSFlagTx	Latched Tx LOS Flag, Host Lane
OutputDisableTx	0b: Tx Output Enabled for Media Lane 1b: Tx Output Disabled for Media Lane
OpticalPowerHighAlarmFlagTx	Latched Tx Output Power High Alarm, Media Lane
OpticalPowerLowAlarmFlagTx	Latched Tx Output Power Low Alarm, Media Lane
OpticalPowerHighWarningFlagTx	Latched Tx Output Power High Warning, Media Lane
OpticalPowerLowWarningFlagTx	Latched Tx Output Power Low Warning, Media Lane
LaserBiasHighAlarmFlagTx	Latched Tx Bias High Alarm, Media Lane
LaserBiasLowAlarmFlagTx	Latched Tx Bias Low Alarm, Media Lane
LaserBiasHighWarningFlagTx	Latched Tx Bias High Warning, Media Lane
LaserBiasLowWarningFlagTx	Latched Tx Bias Low Warning, Media Lane
LOSFlagRx	Latched Rx LOS Flag, Media Lane
OpticalPowerHighAlarmFlagRx	Latched Rx Input Power High Alarm, Media Lane
OpticalPowerLowAlarmFlagRx	Latched Rx Input Power Low Alarm, Media Lane
OpticalPowerHighWarningFlagRx	Latched Rx Input Power High Warning, Media Lane
OpticalPowerLowWarningFlagRx	Latched Rx Input Power Low Warning, Media Lane
TempMonValue	Module Temperature Monitor (Current Value) internally measured temperature in 1/256 °C increments
V_{CC}MonVoltage	Supply Voltage Monitor (Current Value) internally measured input supply voltage in 100 µV increments
Module Active Firmware Version	Module Active Firmware Version number

Table 1: LPO CMIS Diagnostic Registers

Also described in CMIS are the optional Advance Management Features. These optional features include BER, frame error ratio or frame error count, signal-to-noise estimation, level transition (decision threshold) measurement that characterizes the received PAM eye, and FEC statistics. Focusing on the receive path, LPO solutions support these observables by leveraging the host ASIC. Instead of the module DSP reporting the optical ingress information, the host ASIC can provide a variety of diagnostic information for monitoring. This is depicted in Figure 5. Giving the host ASIC direct visibility to the quality of the link provides the added benefit of accelerating the reaction time to link diagnostic feedback via the management layer, which resides in the host.

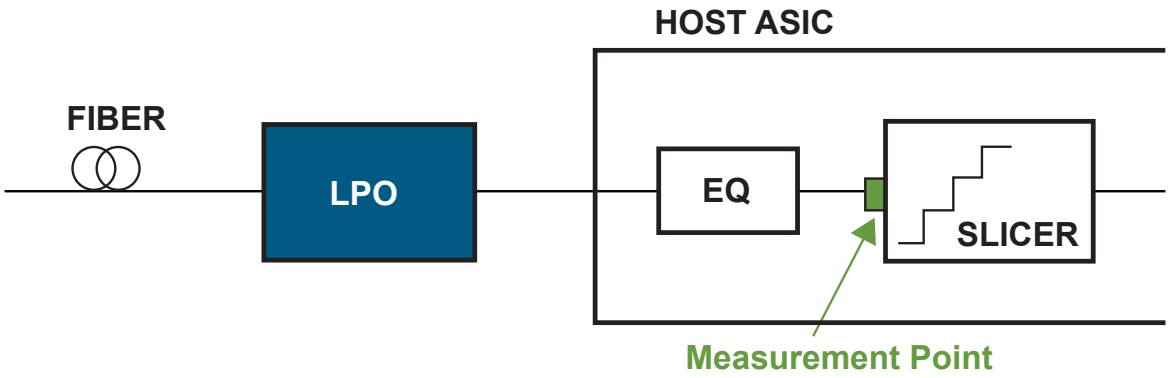

Figure 5: Advanced Management Monitoring Leveraging LPO

Example Diagnostic Cases in LPO

The LPO MSA solicited input from end users on the most likely diagnostic cases observed in the field when leveraging optical connectivity spanning multiple generations of deployment. While extremely rare, the top three diagnostic cases of interest are:

Poor Fiber Connection

It is always recommended to inspect and clean optical fiber before bringing up a new link. One can also use digital fiber scopes and optical time domain reflectometry (OTDR) equipment to verify the fiber link is operating as expected before bringing up the connection. Once the link is made, its health can be determined by the receive ASIC, typically reporting link SNR, pre-FEC BER, post-FEC BER, and input amplitude. If the ASIC is reporting a high BER/ poor SNR, one can check if the input swing to the ASIC from the LPO module is appropriate. If there is a poor fiber connection in the link, the output swing from the TIA may be lower than expected (since the module is not receiving sufficient light). One can then poll the transceiver to verify if it is receiving sufficient

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optical power via Rx flags. If the received optical power is lower than expected, this can be an indication of a poor fiber connection. This can further be identified if the transmit link partner is reporting a sufficient optical output power via Tx flags.

Laser Aging

A classic diagnostic case in optical communications is laser aging. LPO modules benefit from being lower power than retimed modules, which keeps components operating at a lower temperature and significantly increases the mean time between failures (MTBF). Network Operators can monitor the health of a transmit laser within LPO modules in the same way as retimed modules. In the laser aging case, an LPO module would generate an alarm based on Optical Power Low flag to alert the network of a reduction in output power. Module implementations can also adjust laser bias to compensate for the reduction in optical power (average power control). In this case, the laser bias warning flag may also alert users to unexpected conditions over the life of the module.

Multipath Interference (MPI)

MPI occurs when optical reflections are present in a fiber link. This can occur at optical connectors that are not properly mated and/or fiber interfaces at the connector being unclean, resulting in poor optical return loss. The reflected signal appears as added relative intensity noise (RIN), which can limit the overall link performance. In this case, the transmit and receive LPO modules may report the signal for the respective ends of the link are at appropriate levels. The host ASIC would, however, report that there is a lower than expected SNR in the link, which is similar to how the MPI would have been identified in a retimed module with DSP inside. An OTDR can then be used to confirm the fiber issue, and associated corrective action can be taken. This case is similar to how a FTTx PON network would identify an MPI issue. With PON, MPI is typically caused by the splitter-based distribution introducing optical reflections. It is worth noting that fiber-to-the-home networks, such as passive optical networks (PON), are similar to LPO from a diagnostic capability perspective and have successfully shipped in hundreds of millions of ports in an outside plant environment.

Conclusion

LPO-based hosts and modules support a variety of diagnostic capabilities for monitoring of both optical and electrical interfaces. Registers used for transmit and receive diagnostics in CMIS can be leveraged with LPO, as well as host ASIC capabilities to form a full suite of capabilities while minimizing link power, cost and latency. A summary diagnostic capability found in LPO links can be seen in Figure 6.

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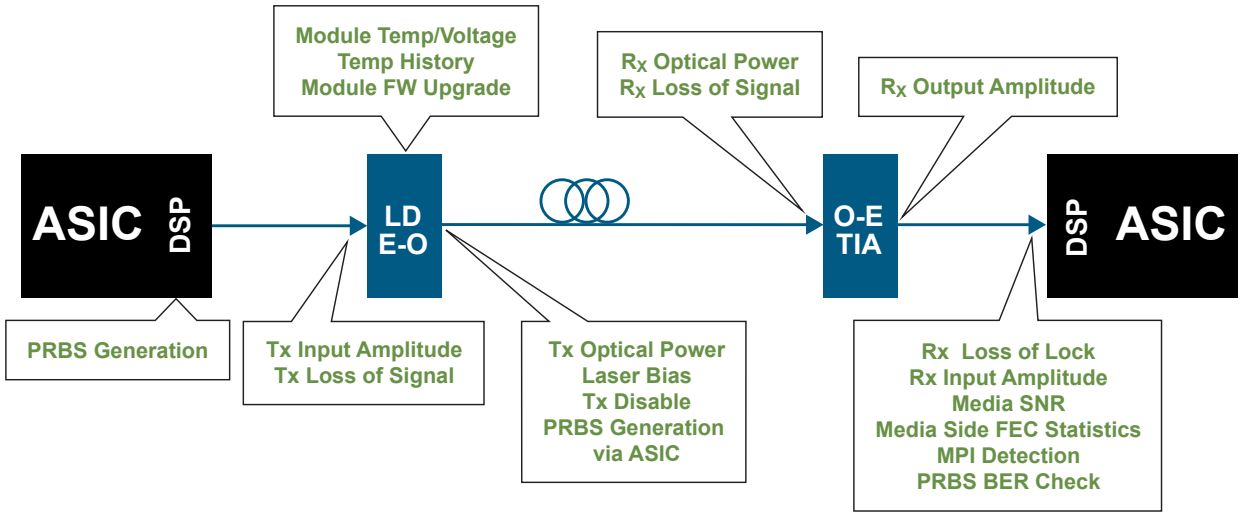

Figure 6: Summary of LPO Link Diagnostics

List of Terms Used in Article:

ASIC	Application Specific Integrated Circuit	**MAC**	Media Access Control
BER	Bit Error Ratio	**O-E**	Optical to Electrical
C2M	Chip to Module	**PCS**	Physical Coding Sublayer
DAC	Direct Attached Copper	**PMA**	Physical Medium Attachment
DSP	Digital Signal Processing	**PMD**	Physical Medium Dependent
E-O	Electrical to Optical	**SNR**	Signal to Noise Ratio
LD	LPO Driver	**TIA**	Trans Impedance Amplifier

References:

OIF CMIS Rev. 5.2

IEEE Std. 802.3-2022