ENHANCED UNDERSEA LINE MONITORING TECHNOLOGY FOR COHERENT OPEN CABLE SYSTEMS

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Abstract: The monitoring of undersea systems based on embedded passive loopback paths is a cost-effective approach to wet plant monitoring that has long been used in amplified undersea systems. The latest generation of Line Monitoring System (LMS) for submarine cables provides higher detection sensitivity, simplified measurement scheduling across complex networks, automatic maintenance of reference data sets, and improved data analysis to track changes in amplifier parameters based on detected fault conditions. The improved sensitivity of these techniques enables users to more easily track slowly evolving localized impairments in the wet plant over time. To support the growing complexity of undersea OADM systems, management of the enhanced LMS has been centralized at the network management layer. The inclusion of ReST APIs enables the user to programmatically initiate and schedule measurement routines and retrieve system-wide measurement and alarm information.

1. INTRODUCTION

In the last decade, there have been significant changes in the undersea market driven by many factors, including coherent transmission technology. More recently, there has been a move to an open cable paradigm where transmission equipment is acquired independently from the undersea wet plant. There has also been a push for new higher capacity, higher fiber count systems with flexible grid reconfigurable nodes.

From a hardware perspective, open cable customers continue to seek a balance between high-tech monitoring solutions and cost, especially with new cables that incorporate higher fiber counts. In terms of software management systems, these customers are interested in an easily accessible LMS that enables improved tracking of key system parameters that better relate to the health and operating capacity of a system.

This paper reviews recent improvements in the overall wet plant monitoring process.

2. LOOP-BACK LINE MONITORING

Undersea cable systems require a fault detection and localization capability. When changes in the optical transmission path occur, system operators rely on the line monitoring capabilities of the cable management system to detect, locate and classify these changes. The passive optical loop-back LMS continues to thrive due to its simplicity, reliability and economy. Recent advancements have improved both the measurement capabilities and user experience.

Figure 1 shows a simple diagram of the loop-back line monitoring system provided by SubCom. The LMS uses optical side-tone signals at either edge of the data channel spectrum to “probe” the repeatered transmission cable from the shore station. At each repeater, a high-loss-loop-back (HLLB) taps a fraction of the arriving probe-tone signal and couples it back in the opposite direction. Terminal-based Line Monitoring Equipment (LME) houses the probe-tone transmitter and signal processing electronics to extract the loop-back signal (or loop-gain) for each repeater from the received channel spectrum. In-service fault monitoring with the loop-back system involves detection of temporal changes in the HLLB data collected by the LME over time.

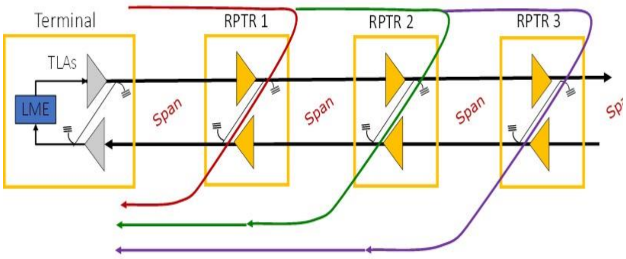

Figure 1a: Loop-Back LMS

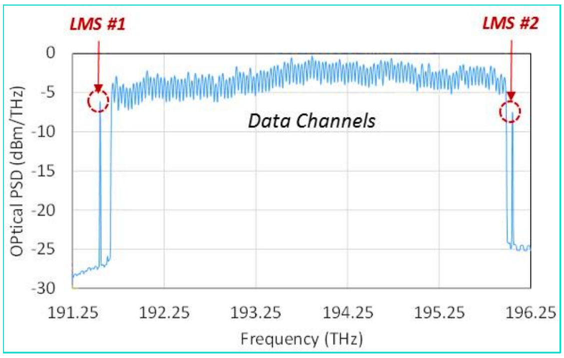

Fig 1b: LMS Probe Tones in the Tx Band

LME with an embedded Optical Time Domain Reflectometer (OTDR) capability for out-of-service fault localization within the undersea fiber spans was reported in 2007 [1]. Since its introduction, this LME has been widely deployed in more than two dozen SubCom undersea systems and the requirement for an embedded-OTDR capability has become the standard for new cable systems.

3. LME ADVANCES

Two key measurement metrics of the SubCom LME that were improved are receiver dynamic range and sensitivity. These improvements, arising from inclusion of the latest DSP technology and advanced correlation processing, significantly impact the HLLB and OTDR capabilities of the LME for both in-service monitoring and out-of-service localization of breaks. To address future dual-band systems use, both C and L band LME were developed with identical performance capabilities.

Embedded Optical Spectral Monitoring (OSM) and ASE loading have also been added to the SubCom LME along with other improvements expected to enhance the overall utility of the LME for testing and monitoring long undersea cables during all phases of deployment including manufacture, installation, initial turn-on and over the life of a system.

The increased receiver dynamic range enables the detection of weak OTDR signals returning from the furthest distance in a fiber span in the presence of high power signals returning from the near-end portion of the span. The Rx dynamic range of the SubCom LME was increased to 20 dB (one-way optical), enabling increased LME-OTDR repeater span visibility to greater than 100 km, with selectable spatial resolutions between 0.1 km and 5 km.

The receiver detection sensitivity of the SubCom LME was improved by 20x, resulting in reduced test time to recover the weakest, noisiest LMS signals with a given degree of measurement accuracy.

Figures 2 and 3 provide field evidence of the improved out-of-service LME-OTDR capabilities in terms of span visibility and tested system length. Figure 2 shows complete span visibility with 3 km spatial resolution after 1000 minutes of test time for the 103 km spans of a 4400 km trans-Pacific system. Figure 3, shows the 60 km spans with 5 km spatial resolution for a 28,000 km system (comprised of two concatenated 14 Mm fiber pairs) after just 3 minutes of testing.

The OTDR result of Figure 3 shows a round trip distance capability beyond that available in commercial C-OTDR equipment. And, unlike a Coherent-OTDR, the direct-detect correlating LME-OTDR result in Figure 3 shows no signal-fading effects from self-phase modulation over the entire 28,000 km system length.

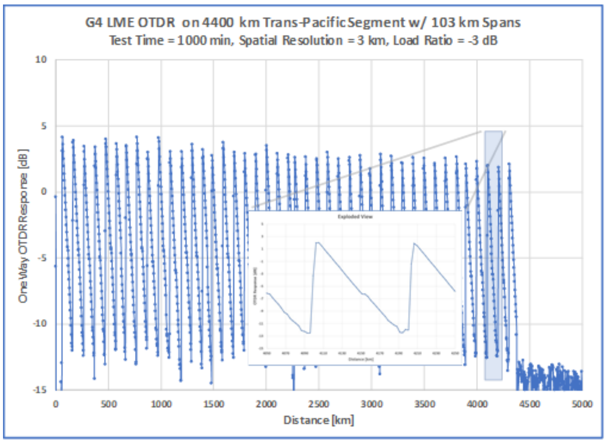

Figure 2: 103km LME-OTDR span visibility

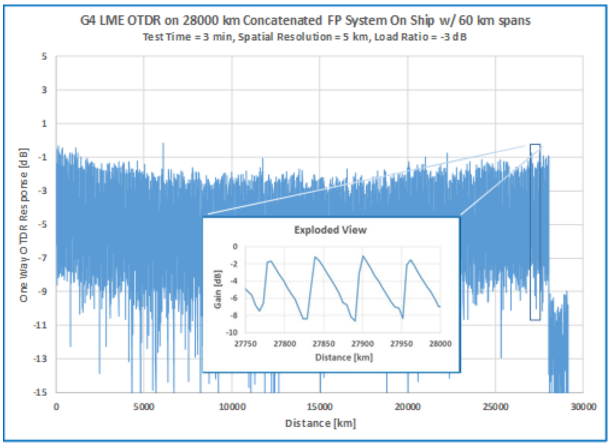

Figure 3: LME-OTDR on a 28000 km system

The Tx design of the SubCom LME was also improved, with higher probe tone launch power levels and a fast polarization-spinning probe-signal format that provides little interaction with adjacent coherent data channels during in-service HLLB measurements [2]. The LME also provides +15 dBm full-band ASE loading for dark-fiber pair measurements. Figure 4 shows an OSA trace of the LME ASE Loading source for dark-fiber measurements.

The OSM capability of the SubCom LME may be used in both dark and in-service fiber pair LME-HLLB and LME-OSNR (Optical Signal-to-Noise Ratio) measurements.

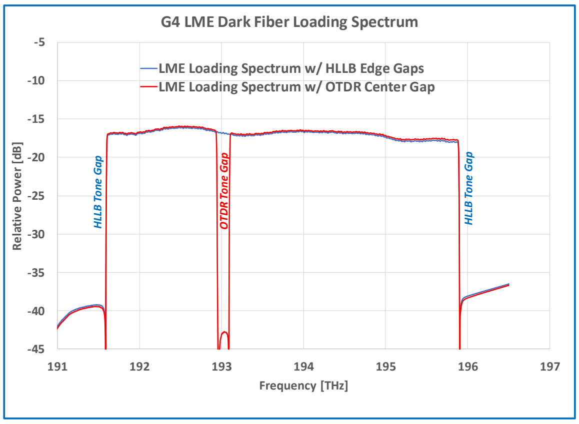

Figure 4: Embedded ASE Loading spectra for dark-fiber measurements

Changes in transmit OSM spectra into an undersea cable enable the detection of terminal or loading changes, while changes in the receive OSM spectrum can be used to diagnose fault or far-end loading issues.

Changes in measured OSNR can also be used to track system health over time. The combining of both Tx and Rx OSM measurements from both sides of a fiber pair can be used to make LME-OSNR measurements. For dark fiber pairs, the LME provides both the wet plant loading and OSNR test tone. For in-service fiber pairs, the LME provides only the test tone in a customer provided loading gap. An analysis of both Tx and Rx OSM data provides a measure of the wet plant OSNR at a defined spectral location.

4. ANALYSIS IMPROVEMENTS

The objective of the LMS fault classification process is to detect significant changes in the undersea wet plant by interpreting temporal changes in LME in-service HLLB and OSM data. The challenge is to resolve small stationary changes within the random fluctuations present in the LMS data.

Recent improvements in the detection and classification algorithms provide even greater fault detection sensitivity with reduced incidence of false positives. The development of Neural Network algorithms is underway for future use. These advanced algorithms show enhanced ability to extract fault information at elevated noise levels.

5. LMS MANAGER & SCHEDULER

The collection, analysis, and display of results from all LME circuit packs in a system are used to provide robust overall system monitoring. The LMS Manager is the software component that manages this function.

To accommodate the more complex reconfigurable OADM systems and the desire for open access, the LMS Manager has been designed as a centralized Network Management System (NMS) process rather than a local element management process. This provides many benefits, including the ability to coordinate complex LME measurement routines and combine measurement data obtained at diverse stations into a single analysis process.

The SubCom NMS includes Ocean Control - ReST API interfaces that provide support for undersea repeater and BU configuration. The ReST APIs provide a path for customer access and control of the entire LMS. If desired, customers can now integrate wet plant LMS monitoring processes into higher-level Software Defined Network (SDN) orchestrator functions, producing a shared monitoring view of the undersea system together with connecting terrestrial networks.

As each LME circuit pack provides a measurement capability for up to ten fiber pairs and each fiber pair might have different owner, the LMS Manager provides secure partitioning between user domains. Only authorized users can execute measurements and view results on a specific fiber pair, circuit pack, or wet plant element (any of which can be partitioned per user, per customer).

LMS measurement capabilities require synchronized measurement processes in all LME circuit packs (at diverse locations) associated with a single fiber pair. This close coordination of LME operations enables a pre-configured loop-back and or loading state to be set up on the far-end LME prior to making a near-end LME measurement.

The LMS Manager includes a measurement scheduling function that allows measurement routines to be organized, defined and scheduled (including simultaneous events) for all stations of a network. This feature provides the necessary coordination between LMEs and provides system owners with significantly more control and the ability to determine exactly what paths are being measured, and what measurements are being executed on those paths.

6. eLMS RESULTS

Presentation of wet plant health and status is also a key capability of LMS which has evolved since previous generations. To accommodate customers with differing interest levels in in-service LME-HLLB measurement results, the LMS Manager provides optional capabilities to view wet plant status and LMS results.

A new approach to interpreting raw LMS data, called "eLMS," simplifies understanding of the in-service measurements by automatically translating changes in LME-HLLB "loop-gain" data into expected changes in individual repeater and span parameters. This is possible because pump power and insertion loss events found during LME-HLLB data analysis can be related to changes in adjacent amplifier operating points.

Using an appropriate amplifier model, the relative changes in LMS data can be used to find the change in input and output power, gain and tilt of repeater amplifier. These amplifier parameter changes can then be tracked over time to enable an amplifier-based interpretation of the LMS data.

In previous LMS generations, reference LMS data needed to be manually reset (re-baselined) for the entire fiber pair after any significant loading or wet plant event. This need has been reduced dramatically with the new eLMS which autonomously manages and updates the reference data used for in-service LME data analysis.

7. LMS WITH OPEN CABLES

Upon delivery of an Open Cable System, SubCom will generally enable the LMS on all dark fiber pairs - which is possible because the LME provides embedded ASE loading. Later, separate suppliers of Submarine Line Terminating Equipment (SLTE) will add data capacity to the Open Cable fiber pairs.

SLTE providers are expected to connect with the SubCom wet plant and LMS via the standard equipment configuration shown in Figure 5. This configuration enables the LME to monitor the transmit launch spectrum and ensure regulation of the LME power levels. SubCom provides a Common Optics Unit to facilitate this connectivity.

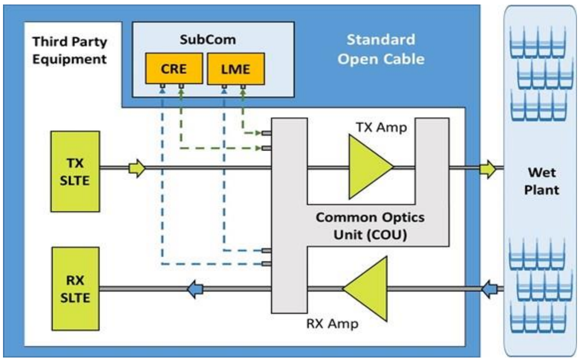

Figure 5: Open Cable SLTE configuration.

Recent experience with SLTE integration on SubCom installed systems has produced a few lessons-learned. To maintain high-quality LMS monitoring the interconnection architecture and optical characteristics provided by the third party SLTE, including the relative power levels and terminal amplifier gain bandwidth, must support the operational needs of the LME.

Since LMS tones occupy the outer edges of the data spectrum, transmit loading effects that cause spectral overlap with the LMS tones or cause tilt and/or excessive shape in the transmission spectrum must be avoided even if data channels might have satisfactory performance.

8. CONCLUSION

Trends in undersea system design continue to show a growing complexity of OADM networks with reconfigurable nodes, higher capacities and greater fiber counts. A new generation LMS based on passive loopbacks was developed and deployed in 2018, providing new measurement capabilities. New analysis techniques provide improved fault detection to address the growing complexity of undersea networks and the future needs of the open cable customers.

The new LMS technology delivers higher detection sensitivity, reduced measurement times, simplified measurement scheduling, automatic maintenance of reference data sets, as well as improved analytical methods for tracking repeater amplifier and system changes based on detected faults.

9. REFERENCES

[1] Brian Jander et.al., "Novel Undersea Line Monitoring Technology Enables Improved Performance and OTDR Capability," SubOptic 2007, WeB1.4.

[2] Lothar Moeller, Robert Behringer, Bamdad Bakhshi, Miguel Rodriguez, Dean Pappas, Brian Jander, "Mitigating Nonlinear Crosstalk from In-service Line Monitoring Equipment for Undersea Communication Systems", ECOC 2017, M.2.F.5.

