A NEW GENERATION OF SUBMARINE LINE TERMINAL EQUIPMENT

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Abstract: A new generation of Submarine Line Terminal Equipment has been developed and deployed into revenue-generating service. Within this product line are Transponders, Muxponders, Terminal Line Amplifiers, Initial Loading Equipment and Line Monitoring Equipment. All SLTE products operate in an extended-range NEBS or ETSI environment. The Transponders and Muxponders use strong FEC and the RZ-DPSK modulation format, have tunable laser sources, and support multiple client-port protocols. The Terminal Line Amplifiers have redundant, hot-swappable pump laser modules and are field-configurable to constant power or constant gain operation. The Initial Loading Equipment is field-configurable to support flexible in-service addition of new wavelengths while maintaining near-constant power spectral densities in the wet plant. The Line Monitoring Equipment supports in-service, terminal-based detection and classification of wet plant impairments. The Line Monitoring Equipment also performs OTDR evaluation of fiber-segments with performance superior to commercial C-OTDR products.

1 INTRODUCTION

Economic challenges in the commercial submarine telecommunications industry over the last 4-5 years have necessitated the introduction of new cost-reduced Submarine Line Terminal Equipment (SLTE). This equipment must fulfill the cost requirements of “thin” regional systems offering only one or two wavelengths per fiber at initial installation as well as the performance requirements of large global systems offering many wavelengths at initial installation. The same efficiencies must be available for incremental upgrade of wavelength count in extant cable systems originally installed with older generations of SLTE. The development challenge for this next generation of terminal products has been to decrease cost, reduce power dissipation, reduce size, and increase reliability, while improving transmission performance and user friendliness in ways that lead to lower wet plant costs and quicker installations.

All members of this new SLTE product family are single circuit packs designed to fit into any slot position of a new 8-slot intelligent Common Shelf that fits into a 4-shelf Common Bay. All circuit packs are managed by common Element Management Software (EMS). The primary members of this new product family are: (1.) multiple variants of a Transponder and Muxponder (the “HPOE”) offering RZ-DPSK modulation and identical forward error correction coding (FEC); (2.) a broadband, gain-flattened, low-noise Terminal Line Amplifier (the “TLA”) suitable for DWDM; (3.) Initial Loading Equipment (the “ILE”) that loads the unused optical spectrum to maintain near-constant power spectral density of channel wavelengths over the life of the undersea plant as additional wavelengths are deployed; and (4.) Line Monitoring Equipment (the “LME”) that remotely detects and classifies impairments in undersea fibers and repeaters using optically incoherent correlation techniques.

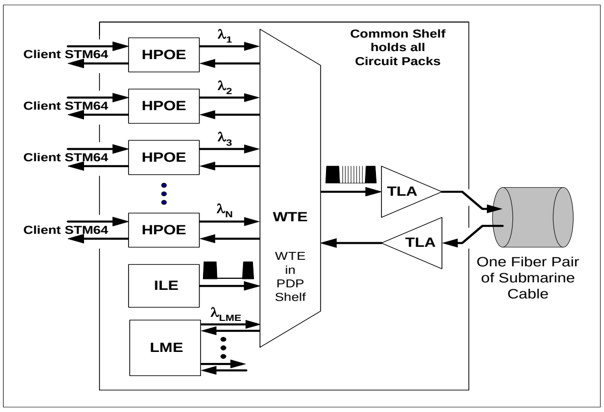

Figure 1: Architecture of complete Submarine Line Terminal Equipment

Figure 1 is a simplified schematic of the architecture of the SLTE within a cable station. The individual members of the SLTE circuit pack family are connected optically together to the submarine cable through the Wavelength Terminating Equipment (WTE). The WTE is the collection of mostly passive, packaged and modularized DWDM components which functionally aggregate or separate the individual channel wavelengths. These components are mounted in their own high density shelf that facilitates ease of installation and management of dense fiber interconnection.

2 ENVIRONMENTAL

All members of this new SLTE, including the intelligent Common Shelf and Common Bay, meet environmental standards summarized in Table 1. This table indicates that all circuit packs and the Common Shelf and Bay are compliant with NEBS GR-63-CORE and ETSI 300-019 standards for extended operation from -5°C to +50°C, seismic stress to NEBS Zone 4, and electromagnetic emissions and susceptibility performance to IEC EN300-386 and CISPR22.

Environmental Test (Stress)	Specification or Standard
Operational Temperature & Humidity	NEBS G-63-CORE, ETSI 300-019-1-3, class 3.1E
Extreme Temperature Exposure & Thermal Shock, High Relative Humidity Exposure	NEBS G-63-CORE, ETSI 300-019-1-1 & -1-2, classes 1.2 & 2.3
Damp Heat Cycling	ETSI 300-019-1-1 & -1-2, classes 1.2 & 2.3
Safety	EN60950
EMC (summary of many stresses) Harmonized standard for emissions Harmonized standard for immunity Electrical fast transients Electrostatic discharge Radiated immunity Conducted susceptibility Conducted interference Conducted emissions Surge immunity Radiated emissions, electric field Radiated emissions, magnetic field	EN300-386 EN55022 EN50082 IEC 801-4, IEC 1000-4-4 IEC 801-2 IEC 1000-4-3, ENV 50204 IEC 1000-4-6 CISPR22 IEC 1000-4-5 EN55022 CISPR22
Seismic & Office Vibration	NEBS GIIEC 1000-4-2EC801-3R-63-CORE
Packaged Transport Shock & Vibration	NEBS G-63-CORE, ETSI 300-019-1-2, class 2.3
Packaged Handling Drop	NEBS G-63-CORE, ETSI 300-019-1-2, class 2.3

Table 1: Summary of Environmental Stress Tests and Standards

3 TRANSPONDER

Transponder and Muxponder HPOE circuit packs support data transmission of different full-duplex client port protocols (STM64, 10GbE LAN PHY, OTU2 OTN, 4 x STM16, 8 x 1GbE) through the proprietary line interface operating at approximately 12Gb/s. A block diagram of the most commonly used Transponder HPOE is shown in Figure 2. This variant supports one full-duplex SDH STM-64 client port interface.

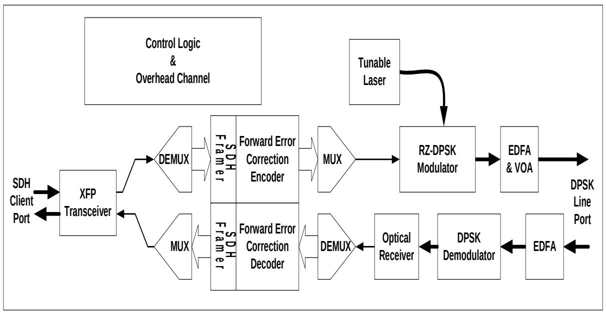

Figure 2: Transponder Block Diagram

All HPOE variants have these common features:

1. Strong FEC: 9.9dB net effective coding gain at 1E-15 corrected BER on user data. A plot of FEC performance compared to two previous product generations is shown in Figure 3. One can see that FEC performance shows no evidence of unwanted flaring down to 1E-15 BER.

2. A tunable CW laser source covering the entire C-band, thereby eliminating the need for multiple spare circuit packs, each covering a separate sub-band of wavelengths.

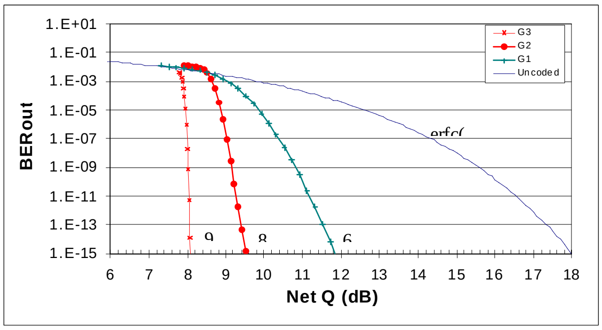

Figure 3:Transponder FEC Net Effective Coding Gain for 3 Generations of Product

3. RZ-DPSK optical modulation format which offers nearly the full 3dB theoretical improvement in "Q vs. OSNR" Line Receiver performance over conventional RZ-OOK modulation.

4. Optical pre-amplification within the line receiver and optical booster amplification within the line transmitter to facilitate flexible spacing to the first off-shore repeater, flexible implementation of dispersion compensation, and widely tunable launch power pre-emphasis.

5. An out-of-band 10BaseT order wire or service channel aggregated into the FEC frame overhead.

6. High density: eight single-slot HPOE's fit into the Common Shelf or 32 HPOE's per 300mm X 600mm common bay.

7. Performance Monitoring is provided for line Q and client port protocols.

Power dissipation of the STM64 Transponder is 50W per wavelength. Power dissipation for a fully-connected 8 X 1GbE Muxponder HPOE is 65W.

4 TERMINAL LINE AMPLIFIER

A perfectly designed low-noise TLA has provisionable gain, output power and tilt performance that is transparent and unappreciated by the end customer. This same performance flexibility, however, is most valued by the systems designer who must manage the WTE design and ensure transmission performance from initial deployment to full deployment of all channels. Figure 4 is a simplified schematic of the TLA. This new TLA provides 35nm bandwidth of low-noise, gain-flattened, low-PDL, temperature-invariant optical gain. The TLA can be field-provisioned to operate in either constant output power or constant gain mode and can be provisioned between operational modes without unwanted output transients. TLA gain and output power can also be provisioned over wide ranges as necessary to compensate for the insertion loss of various forms of terminal dispersion compensation, WDM filters and splitter/couplers, and for insertion loss growth in the WTE as channels are added. The TLA may be provisioned to provide positive and negative tilt. The TLA occupies two slots in the common shelf and dissipates 43W under worst case conditions.

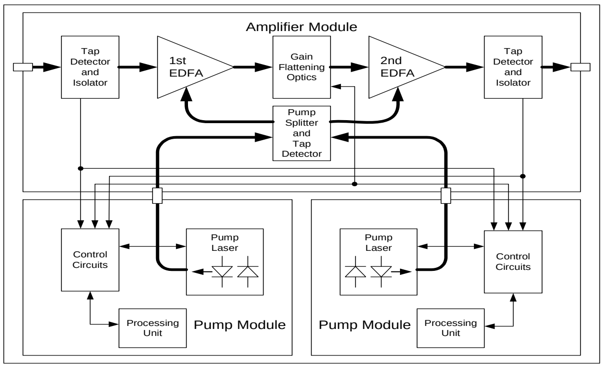

Figure 4: TLA Block Diagram

TLA reliability and availability are of primary concern to the end customer and must be extremely high, since the TLA is common to all channels on a fiber. The TLA incorporates two field-replaceable pump laser circuit modules to meet a service-affecting product requirement of 500 FITs. These pump modules operate redundantly with independent control loops to maintain constant amplifier output power or constant amplifier gain as provisioned. A pump module can be quickly replaced while the TLA remains in-service without unwanted output transient performance. The optical connections between individual pump laser modules (the removable active circuits) and the optical amplifier (the service-affecting passive components) are made with expanded-beam optical connectors [1]. These connectors have reduced optical power density at their fiber end-faces by approximately 90% compared to conventional single-mode PC or APC connectors. Reduced optical power density means improved reliability. These connections between pump laser modules and amplifier are contained behind an accessible faceplate door and are fail-safe interlocked to meet IEC 60825 safety standards.

5 INITIAL LOADING EQUIPMENT

Figure 5 is a simplified schematic of the Initial Loading Equipment (ILE). The function of the ILE is to uniformly load the unused optical spectrum of the wet plant with ASE noise having a power spectral density equivalent to full deployment loading with discrete modulated wavelengths. The ILE supports orderly but flexible placement of channels at their full deployment density during installation of first wavelengths. During the upgrade process, the noise power in a previously unused band is turned off to make room for the new channels.

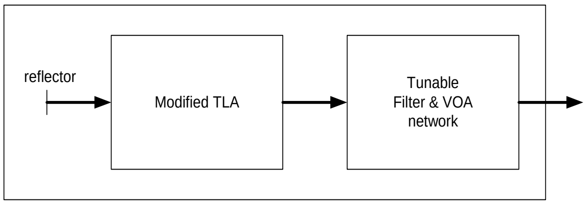

Figure 5: ILE Block Diagram

The ILE is partially constructed by modifying a broadband, gain-flattened TLA to be a broadband, gain-flattened, unpolarized noise source. The output of this noise source is cascaded by a network of optical filters and attenuators to create multiple tunable noise passbands. This ILE architecture has the advantage of the TLA architecture in providing redundancy of all critical active components, including the pump lasers and their independent control circuits. This level of reliability and availability is required, since failure of the ILE may result in impairments to all channel wavelengths. The ILE filter network is composed of highly-reliable optical filters and Variable Optical Attenuators (VOA's) that only require energizing currents at infrequent times when wavelengths are added. This architecture is superior in reliability to the alternate architecture of using unprotected discrete laser tones distributed across the entire spectrum.

6 LINE MONITORING EQUIPMENT

The Line Monitoring Equipment (LME) is the fourth primary circuit pack in the new SLTE family of products and the only one that is not service-affecting. LME function relies upon the placement of narrowband passive high-loss loopbacks inside each submarine repeater connecting outbound and inbound paired fibers. Figure 6 illustrates the preferred implementation of a dual-sidetone high-loss loopback using dual-wavelength fiber Bragg gratings and directional splitter/couplers. This implementation provides a preferential loopback loss for two sidetones at the edges of the repeater optical passband. Terminal-based loopback Line Monitoring offers the great advantage of enabling the undersea repeater to be as simple and reliable as possible without transponder circuits.

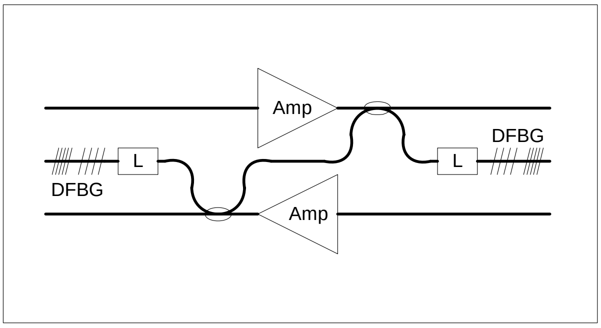

Figure 6: High Loss Loopback Schematic

The function of the LME is to detect, classify and quantify any impairment in the undersea plant, such as these specific degradations or failures:

- Repeater pump power loss
- Outbound Amplifier gain
- Inbound Amplifier gain
- Outbound fiber insertion loss
- Inbound fiber insertion loss
- High loss loopback insertion loss
- Fiber pair kink (insertion loss in both fibers at same location)

The LME operates by measuring round-trip gain or loss through each high loss loopback. The collection of loopback gain/loss peaks plotted against distance provides a unique signature for each impairment listed. The LME transmits a special repetitive test pattern at one of the two wavelengths of the repeater high-loss loopback. The collection of delayed echoes from all submarine loopbacks on the inbound fiber forms a white noise incident upon the receiver in the LME. See Figure 7 for the LME block diagram. The LME performs a linear cross-correlation in time between the reference test pattern and the received signal. The reference test pattern is one of a family of bit sequences whose auto-correlation is an ideal Dirac delta function [2]. Loopback gains are measured as the discrete peaks in the cross-correlation results. Spatial resolution in this new LME can be provisioned to 0.5km or 0.8km, independent of distance, and it is determined by the bit interval of the repetitive test pattern. It is necessary to maintain a database of historical loopback gains in the EMS for reference, since amplifier gain at the two sidetones is typically less than fiber span loss, and the net gain or loss through the wet plant varies with repeater span. Impairments are detected by comparing the scan of loopback gains against the historical baseline or by comparing the scan of repeater span gains against the equivalent historical baseline.

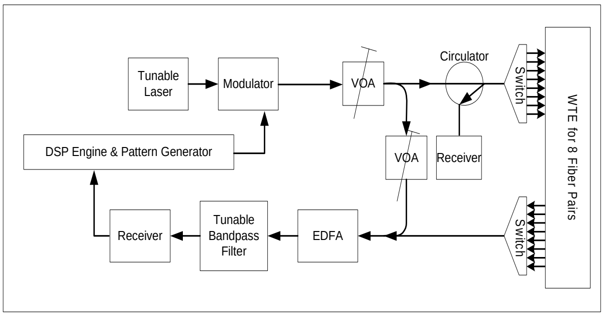

Figure 7: LME simplified block diagram

The same correlation principles that enable loopback gain measurement can extend LME capability to operate as an OTDR. When the LME wavelength is tuned away from either loopback sidetone, the returned signal is an aggregate collection of the delayed echoes of Rayleigh backscatter in the outbound fiber span between each repeater pair. Signal dynamic range is no longer dominated by the echoes from the high loss loopbacks. Spatial resolution remains at the provisionable 0.5km or 0.8km, independent of distance. Rayleigh scatter is typically 30dB lower than the signals returned from high loss loopbacks, so it is necessary to run this correlation out-of-service at higher launch powers. Out-of-service OTDR capability for this LME is useful for repeater spans to 90km with correlation times less than a commercial C-OTDR.

The new LME can support connection to 8 fiber-pairs and analyze each fiber pair automatically in sequence and in service. Typical correlation times for HLLB scans is 10-30 minutes. The circuit pack fills 3 adjacent slots in the Common Shelf and relies upon the Element Management System for database management and signature classification of loop gain scans.

7 SUMMARY

We have introduced a new cost-reduced generation of SLTE to efficiently accommodate a wide range of requirements. This family of SLTE products can support the highest performance in transponders as well as low cost and high density of implementation. By way of two differing examples, a single SLTE bay can support 4 wavelengths on each of two fiber pairs for a thin and short regional system, and a 4-bay design can support 64 wavelengths on multiple fiber pairs, including all necessary TLA's, ILE's, LME's and all WTE's.

8 REFERENCES

1. J. Gardner , B.Dean and B. Jander, "Reliability Considerations for Terminal Amplifiers", SubOptic 2007.
2. B. Jander, H. Zhang, R. Engira, W. Ruthrauff, J.Y. Jiang, A. Giordano, B. Bark, R. Kram, S. Sabet, B. Li, J. Liss, C. Breverman, "Novel Undersea Line Monitoring Technology Enables Improved Performance and OTDR Capability", SubOptic 2007