

Suppliers of Undersea Telecommunications Systems

A Technology & Market Assessment Report: Table of Contents

(including list of figures and tables beginning on page 18)



Legal Address: 221 River Street, 9th Floor, Hoboken, New Jersey 07030 USA **WWW.pioneerconsulting.com**



Table of Contents

CHAPTER 1: INTRODUCTION, OVERVIEW & METHODOLOGY

- **1.1 INTRODUCTION**
- **1.2 PURPOSE OF THIS REPORT**
- **1.3 REPORT SCOPE**
 - 1.3.1. Market Dynamics
 - 1.3.2. Submarine Fiber Optic Technology Primer
 - 1.3.3. Supplier Profiles
 - 1.3.4. System Integrators
 - 1.3.5. SLTE Suppliers
 - 1.3.6. Cable Suppliers
 - 1.3.7. Sub-System Suppliers
 - 1.3.8. Submarine Fiber Optic System Components
- **1.4 REPORT METHODOLOGY**
- **1.5 REPORT ORGANIZATION**
- 1.6 DISCLAIMER

CHAPTER 2: MARKET DYNAMICS FOR SUBMARINE CABLE SYSTEMS SUPPLY

- 2.1 MARKET FIGURES
- 2.2 MARKET TRENDS, GROWTH, DRIVERS AND CONSTRAINTS
 - 2.2.1. Bandwidth Market
 - 2.2.1.1. Bandwidth Market Characteristics
 - 2.2.1.2. Bandwidth Products
 - 2.2.1.3. Bandwidth Needs
 - 2.2.2. New Customers and New Requirements
 - 2.2.2.1. High Capacity
 - 2.2.2.2. Lower Cost per Transported Bit
 - 2.2.2.3. Reliability
 - 2.2.2.4. Lifetime
 - 2.2.2.5. Open Cable Systems
 - 2.2.2.6. End-to-End Connectivity
 - 2.2.2.7. Coarser Capacity Quantum
 - 2.2.2.8. Network Reconfigurability



- 2.2.3. New Ownership Model
 - 2.2.3.1. OTTs as New Subsea Cable System Project Initiators
 - 2.2.3.2. OTTs as Founding Customers
 - 2.2.3.3. OTT-Led/Supported Subsea Cable Systems
 - 2.2.3.4. Consortium-Led Projects
 - 2.2.3.5. Private Developers
- 2.2.4. Diversity and Redundancy
- 2.2.5. New Routes
 - 2.2.5.1. Low Latency
 - 2.2.5.2. South Atlantic Routes
 - 2.2.5.3. Arctic Routes
 - 2.2.5.4. Connecting Data Centers to Data Centers
 - 2.2.5.5. Connecting Underserved Areas
 - 2.2.5.6. Geopolitical Drivers
- 2.2.6. New Terminating Sites
 - 2.2.6.1. Open Cable Landing Stations
 - 2.2.6.2. Data Centers
- 2.3 GROWTH OF THE UPGRADE MARKET
 - 2.3.1. Changes to the Upgrade Paradigm
 - 2.3.2. Strategy of the "New Suppliers"
- 2.4 TECHNOLOGY TRENDS: WHAT'S NEW?
 - 2.4.1. Shannon Limit
 - 2.4.2. Coherent Technology
 - 2.4.3. New Fiber Designs
 - 2.4.4. New Protocol Standards
 - 2.4.5. Long Range Repeaterless Systems
 - 2.4.6. Repeater Mechanical Design
 - 2.4.7. Repeater Optical Design
 - 2.4.7.1. Wider Bandwidth Repeater
 - 2.4.7.2. High Fiber Count
 - 2.4.7.3. Pump Farming
 - 2.4.8. Terrestrial and Submarine System Convergence
 - 2.4.9. Upgrade Suppliers and Open Cable Systems
 - 2.4.10. Spatial Division Multiplexing (SDM)
 - 2.4.11. Open Cable



2.4.12. Cable

- 2.4.13. Branching Units and ROADM-based Branching Units
- 2.4.14. Cable Capacity Limitations
- 2.4.15. Photonic Integrated Circuits
- 2.4.16. Cable Network Architectures
- 2.4.17. Bandwidth Variable Transponders and Flex Ethernet
- 2.4.18. Digital Nonlinearity Compensation
- 2.5 SUBSEA CABLE SYSTEM SUPPLY MARKET ANALYSIS
 - 2.5.1. Market Per Segment
 - 2.5.2. Cable System Ownership Structure
 - 2.5.2.1. Consortia or Multi-Owned Cable Systems
 - 2.5.2.2. Private or Single-Owned Cable Systems
 - 2.5.2.3. Ownership Analysis
 - 2.5.3. Cable and Fiber Lengths Deployed per Year
 - 2.5.4. Total Supplier Revenue and Price pers Installed Cable Kilometer
 - 2.5.5. Evolution Price per Installed Kilometer per Route
 - 2.5.6. Annual Installed Cable Length per Region
 - 2.5.7. Breakdown by System Integrators
 - 2.5.7.1. Market Share by Cable System Count
 - 2.5.7.2. Market Share by Cable Kilometers
 - 2.5.7.3. Market Share by Revenue
 - 2.5.7.4. Number of Systems and Revenue per System Integrator and per Main Route
 - 2.5.7.5. Number of Systems and Revenue per System Integrator and per Main Region
 - 2.5.7.6. Revenue per System Integrator and per Main Region (Maps)

CHAPTER 3: SUBMARINE SYSTEM TECHNOLOGY

3.1 INTRODUCTION

- 3.2 SUBMARINE CABLE SYSTEM DESIGN
 - 3.2.1. Optical Fiber Design
 - 3.2.1.1. Optical Fiber Loss Mechanisms
 - 3.2.1.2. Continuous Improvement in Fiber Loss
 - 3.2.1.3. Optical Bandwidth
 - 3.2.1.4. Effective Area
 - 3.2.1.5. Chromatic Dispersion



- 3.2.1.6. Polarization Mode Dispersion (PMD)
- 3.2.1.7. Nonlinear Fiber Impairments
- 3.2.1.8. Mechanical Strength
- 3.2.1.9. Evolution
- 3.2.2. Optical Amplification
 - 3.2.2.1. Erbium Ion Energy Levels and Optical Amplification
 - 3.2.2.2. Amplified Spontaneous Emission (ASE)
 - 3.2.2.3. Optical Noise Build-Up
 - 3.2.2.4. Saturated Output Power Regime
 - 3.2.2.5. EDFA Gain Spectrum
 - 3.2.2.6. Repeater Gain Spectrum Management in a Cable System
- 3.2.3. Multi-Level Modulation Formats
 - 3.2.3.1. Symbol Vector and Constellation Diagram
 - 3.2.3.2. Symbol Alphabet Size
 - 3.2.3.3. Polarization Multiplexing
 - 3.2.3.4. Combination of Symbol Rates and Modulation Formats
- 3.2.4. Forward Error Correction (FEC)
- 3.2.5. Shannon Limit
 - 3.2.5.1. Spectral Efficiency
 - 3.2.5.2. Linear Shannon Limit Curve
 - 3.2.5.3. Nonlinear Shannon Limit Curve
 - 3.2.5.4. Linear Shannon Limit Curve in Coherent Optical Networks
 - 3.2.5.5. Options for Increasing Subsea Cable System Capacity
 - 3.2.5.6. Gap to the Shannon Limit
 - 3.2.5.7. Getting Closer to the Shannon Limit
 - 3.2.5.8. Constellation Shaping

3.3 CABLE

- 3.3.1. Fiber Containment
- 3.3.2. Cable Strength
- 3.3.3. Cable Conductor
- 3.3.4. Cable Armor
- 3.3.5. Jointing
- 3.3.6. Potential Evolutions
 - 3.3.6.1. Lower Grade Steel in Submarine Cables
 - 3.3.6.2. Less Power Conductor along the Length of an Undersea Cable



3.3.6.3. Deep Water Armored Cable

3.4 REPEATER

- 3.4.1. Mechanical
- 3.4.2. Electrical Powering of the Repeaters and Cable
- 3.4.3. Basic Optical Design
- 3.4.4. Supervision and Monitoring in Repeatered Wet Plant
 - 3.4.4.1. High-Level Comparison of Supervision and Monitoring Approaches
 - 3.4.4.2. Passive Monitoring of Repeaters and Fiber
 - 3.4.4.3. Command / Response Active Monitoring of the Wet Plant
- 3.4.5. Supervision and Monitoring in Repeaterless Wet Plant
- 3.4.6. Undersea Reliability

3.5 BRANCHING UNIT

- 3.5.1. Cable System Powering Reconfiguration
- 3.5.2. Optical Reconfiguration
 - 3.5.2.1. Fiber Routing
 - 3.5.2.2. Fixed OADM Branching
 - 3.5.2.3. Switchable OADM Branching Unit
 - 3.5.2.4. ROADM Branching Unit
 - 3.5.2.5. Branching Unit Control

3.6 SUBMARINE LINE TERMINAL EQUIPMENT (SLTE)

- 3.6.1. SLTE Definition and Functionality
- 3.6.2. SLTE by the Sea or Inland
- 3.6.3. SLTE Main Components
- 3.6.4. SLTE Planes and Inputs / Outputs
- 3.6.5. SLTE Mechanical Design
- 3.6.6. Chromatic Dispersion Compensation
- 3.6.7. Polarization Mode Dispersion (PMD) Compensation
- 3.6.8. Transponder
- 3.6.9. Spectral Efficiency Variable Transponders
- 3.6.10. Channel Coding or Coded Modulation
- 3.6.11. Implementation of Coherent Detection in Real ASICs
- 3.6.12. Loading Channel Equipment
- 3.7 OPEN CABLE SYSTEM INTERFACE
 - 3.7.1. Open Cable System Interface Configuration
 - 3.7.2. Spectrum Sharing



3.8 UNREPEATERED CABLE SYSTEMS

- 3.8.1. Extending the Unrepeatered Reach
 - 3.8.1.1. Lower Attenuation Fibers
 - 3.8.1.2. Higher Amplifier Output Power
 - 3.8.1.3. Coherent Detection
 - 3.8.1.4. Distributed Raman Optical Amplification
 - 3.8.1.5. Remote Optically-Pumped Amplifier (ROPA)
- 3.8.2. Repeaterless Submarine Line Terminal Equipment (SLTE)
- 3.8.3. Raman Pumping Technology
 - 3.8.3.1. Semiconductor-Based Raman Pump
 - 3.8.3.2. Third-Order Pump

3.9 COHERENT TRANSPONDER MODULATION FORMAT AND RECEIVER DESIGN

- 3.9.1. Introduction
 - 3.9.2. Evolution of Optical Bandwidth, Baud Rate and Spectral Efficiency
 - 3.9.3. Quadrature Phase Shift Keying (QPSK) Modulation Implementation
 - 3.9.4. Polarization Division Multiplexing
 - 3.9.5. Demodulation of nQAM Signals
 - 3.9.5.1. Single-Polarization I/Q Demodulator
 - 3.9.5.2. Dual-Polarization I/Q Demodulator
 - 3.9.6. Detection of nQAM signals
 - 3.9.7. Chromatic Dispersion Compensation
 - 3.9.8. Polarization Mode Dispersion Compensation
 - 3.9.9. Carrier Frequency and Phase Estimation / Recovery
 - 3.9.10. Modulating and Demodulating Higher Order nQAM
 - 3.9.11. Nyquist Shaping for Improved Spectral Efficiency
 - 3.9.12. Recent Developments
 - 3.9.12.1. Sub-Carriers
 - 3.9.12.2. Polarization Shifting
 - 3.9.12.3. FEC Gain Sharing

3.10 THE COHERENT ECOSYSTEM

- 3.10.1. Components within the Coherent Ecosystem
 - 3.10.1.1. Narrow-Linewidth, Tunable-Wavelength Laser Diodes (ITLA & ITLA)
 - 3.10.1.2. Linear Modulator Drivers (Distributed Microwave Amplifiers
 - 3.10.1.3. Linear Differential Photodiodes (Dual Anode-to-Cathode Photodiodes)
 - 3.10.1.4. Linear Photodiode (Transimpedance) Preamplifiers



- 3.10.1.5. Dual-Polarization Integrated Coherent Receivers (ICR and ICR
- 3.10.1.6. Dual-Polarization nQAM Modulators
- 3.10.1.7. DSP ASICs or DSP Engines
- 3.10.2. 100G Complete 5" x 7" Pigtailed Coherent Modules
- 3.10.3. Client TX/RX Transceiver Modules
- 3.10.4. OTN, SDH, Ethernet & SAN Framer / Wrapper / FEC ASICs & FEC
- 3.11 POWER FEED EQUIPMENT
- **3.12 OPERATIONS SOFTWARE**
 - 3.12.1. Software Layers
 - 3.12.2. Availability and Security
- **3.13 INTELLECTUAL PROPERTY**
 - 3.13.1. Value of Patented Technology
 - 3.13.2. Use of Patents: Litigation
 - 3.13.3. Other Intellectual Property
- 3.14 FIBER CAPACITY
 - 3.14.1. Laboratory Demonstrations
 - 3.14.2. Field Trial Demonstrations
- 3.15 REFERENCES

CHAPTER 4: SYSTEM INTEGRATORS

4.1 INTRODUCTION

- **4.2 ALCATEL SUBMARINE NETWORKS**
 - 4.2.1. General Company Information
 - 4.2.2. History
 - 4.2.3. Locations
 - 4.2.4. Capabilities
 - 4.2.5. Financial
 - 4.2.6. Recent Systems/Projects
 - 4.2.7. What is New?
 - 4.2.8. Terminal Equipment for Repeatered Systems
 - 4.2.8.1. Overview
 - 4.2.8.2. Network Applications
 - 4.2.9. Terminal Equipment for Repeaterless Systems
 - 4.2.10. Cable



- 4.2.10.1. URC2
- 4.2.10.2. URC4
- 4.2.10.3. OALC4 Copper and Aluminum Conductor
- 4.2.10.4. OALC5
- 4.2.10.5. OALC7
- 4.2.11. Repeater
 - 4.2.11.1. Mechanical Characteristics
 - 4.2.11.2. Electrical Characteristics
 - 4.2.11.3. Transmission Amplifiers
- 4.2.12. Branching Units
 - 4.2.12.1. Overview
 - 4.2.12.2. Switched Power Functionality
 - 4.2.12.3. Optical Functionality
 - 4.2.12.4. Mechanical Characteristics
- 4.2.13. WSS ROADM Unit
 - 4.2.13.1. Overview
 - 4.2.13.2. Reconfiguration Functionalities
- 4.2.14. Branching Unit and WSS ROADM Unit Supervisory System
- 4.2.15. Fault Characterization and Localization
- 4.2.16. Fiber and Wave Portals for Open Cable Systems
 - 4.2.16.1. Fiber Portal
 - 4.2.16.2. Wave Portal
- 4.2.17. Power Feed Equipment (PFE)
- 4.2.18. Submarine Network Management
 - 4.2.18.1. Overview
 - 4.2.18.2. Network Topologies
 - 4.2.18.3. Dry and Wet Line Monitoring
- 4.2.19. Cable Laying and Marine Services
- 4.2.20. Contact Information

4.3 HUAWEI MARINE NETWORKS

- 4.3.1. General Company Information
- 4.3.2. History
- 4.3.3. Capabilities
- 4.3.4. Financial
- 4.3.5. Supply Contracts Completed (Partial List)



- 4.3.6. Submarine Line Terminal Equipment (SLTE)
- 4.3.7. Submarine Line Monitor
- 4.3.8. Power Feed Equipment
- 4.3.9. Four Repeater Designs
- 4.3.10. Two Branching Unit Designs
- 4.3.11. Cable
- 4.3.12. Contact Information

4.4 NEC

- 4.4.1. General Company Information
- 4.4.2. History
- 4.4.3. Locations
- 4.4.4. Capabilities
- 4.4.5. Financial
- 4.4.6. Recent Systems/Projects
- 4.4.7. The Complete Cable System
- 4.4.8. Terminals for Repeatered Systems
- 4.4.9. Open Cable Interface
- 4.4.10. Coherent Technology and DSP ASICs
- 4.4.11. Terminal for Repeaterless Systems
- 4.4.12. Cable Background
- 4.4.13. Cable
 - 4.4.13.1. SC300 Cable
 - 4.4.13.2. SC500 Cable
- 4.4.14. Repeater
 - 4.4.14.1. Mechanical Design
 - 4.4.14.2. Pumping Scheme
 - 4.4.14.3. Optical Design
 - 4.4.14.4. Electrical Design
- 4.4.15. Fault Characterization and Localization
- 4.4.16. Branching Unit
- 4.4.17. Power Feed Equipment
- 4.4.18. Network Management
 - 4.4.18.1. Fault Management
 - 4.4.18.2. Performance Management
 - 4.4.18.3. Configuration Management



4.4.18.4. Power Feeding Management

4.4.18.5. Fiber Path/Optical Path Management

- 4.4.19. Contact Information
- 4.5 SUBCOM
 - 4.5.1. General Company Information
 - 4.5.2. History
 - 4.5.3. Financial
 - 4.5.4. Capabilities
 - 4.5.5. Recent Systems/Projects
 - 4.5.6. Locations
 - 4.5.7. SubCom Evolution to Open Cables Business Model
 - 4.5.8. Open Cable Interface
 - 4.5.8.1. Dry ROADM
 - 4.5.8.2. Initial Loading Equipment (ILE)
 - 4.5.8.3. Line Monitoring Equipment (LME)
 - 4.5.8.4. Line Monitoring System (LMS) Operation
 - 4.5.8.5. Command Response Equipment (CRE)
 - 4.5.9. Repeaterless Raman/ROPA Terminal Pump
 - 4.5.10. Cable
 - 4.5.10.1. SL17 Lightweight Cable Design
 - 4.5.10.2. SL17 and SL21 Cable Families
 - 4.5.10.3. SL12 Cable Family
 - 4.5.10.4. SL17-A1 Variant
 - 4.5.11. Repeaters
 - 4.5.11.1. What Was New in 2017?
 - 4.5.11.2. What is New in 2020?
 - 4.5.11.3. SubCom's Repeater Design
 - 4.5.12. Branching Unit
 - 4.5.12.1. General Description
 - 4.5.12.2. Optical Functions
 - 4.5.12.3. Electrical Functions
 - 4.5.12.4. Branching Unit Control and Management
 - 4.5.12.5. Optical and Electrical Fault Location
 - 4.5.12.6. Mechanical Characteristics
 - 4.5.13. Reconfigurable Optical Add/Drop Multiplexer Wavelength Management Unit



4.5.13.1. General Description

4.5.13.2. Optical Add/Drop Function

- 4.5.14. Power Feed Equipment
- 4.5.15. Element Management System
- 4.5.16. Marine Capabilities
 - 4.5.16.1. Reliance Class Cable ships
 - 4.5.16.2. Cable Plows and ROVs
 - 4.5.16.3. Oil and Gas Industry
 - 4.5.16.4. Surveys and Mapping Cable Routes
 - 4.5.16.5. Permitting and Regulatory Compliance
 - 4.5.16.6. Maintenance Administration Services: Operation and Maintenance
 - 4.5.16.7. Technical Support
 - 4.5.16.8. Global Depots
 - 4.5.16.9. Jointing Services
 - 4.5.16.10. Outside Plant Repairs
 - 4.5.16.11. Automatic Identification System (AIS) Monitoring and Notification
 - 4.5.16.12. Geographic Information System (GIS)
- 4.5.17. Contact Information

4.6 MINOR SYSTEM INTEGRATORS

- 4.6.1. FiberHome Marine
 - 4.6.1.1. General Company Information
 - 4.6.1.2. History
 - 4.6.1.3. Capabilities
 - 4.6.1.4. Terminal for Submarine Cable
 - 4.6.1.5. Repeater and Branching unit
 - 4.6.1.6. Cable
 - 4.6.1.7. Line Monitoring Equipment (LME)
 - 4.6.1.8. Contact information
- 4.6.2. IPG Photonics
 - 4.6.2.1. General Company Information
 - 4.6.2.2. History
 - 4.6.2.3. Undersea Repeater
 - 4.6.2.4. Contact Information

4.6.3. Xtera

4.6.3.1. General Company Information



4.6.3.2. History
4.6.3.3. Location
4.6.3.4. Recent Supply Contracts
4.6.3.5. Capability
4.6.3.6. Terminal Equipment
4.6.3.7. Repeaters
4.6.3.8. Branching Unit
4.6.3.9. Network Management
4.6.3.10. Contact Information

CHAPTER 5: SLTE INTEGRATION SUPPLIERS

5.1 INTRODUCTION

5.2 CIENA

- 5.2.1. General Company Information
 - 5.2.1.1. History
 - 5.2.1.2. Financial
 - 5.2.1.3. Supply Contracts
- 5.2.2. WaveLogic[™] Coherent Optical Processors
 - 5.2.2.1. WaveLogic 3
 - 5.2.2.2. WaveLogic Ai
 - 5.2.2.3. WaveLogic 5 Extreme (WL5e)
 - 5.2.2.4. WaveLogic Client Interface Features
- 5.2.3. 6500 SLTE
 - 5.2.3.1. 6500 SLTE Shelf
 - 5.2.3.2. Waveserver Ai Platform
 - 5.2.3.3. Waveserver 5 Platform
- 5.2.4. Network Management
 - 5.2.4.1. Blue Planet MCP (Manage, Control, Plan)
 - 5.2.4.2. GeoMesh Offering
- 5.2.5. Contact Information

5.3 CISCO

- 5.3.1. General Company Information
 - 5.3.1.1. History
 - 5.3.1.2. Financial



5.3.1.3. Capabilities

5.3.1.4. Recent Projects

- 5.3.2. Acacia Communications Coherent Modules
- 5.3.3. Cisco's SLTE Solution
 - 5.3.3.1. NCS 1004 Coherent Equipment
 - 5.3.3.2. NCS 2006 Common Equipment

5.3.4. Network Management

5.3.5. Contact Information

5.4 INFINERA

- 5.4.1. General Company Information
 - 5.4.1.1. History
 - 5.4.1.2. Financials
 - 5.4.1.3. Initial PIC Technology Positioning
 - 5.4.1.4. Supply Contracts
- 5.4.2. Coherent Optical Engine
 - 5.4.2.1. 500G PIC
 - 5.4.2.2. ICE4
 - 5.4.2.3. ICE6
- 5.4.3. Terminal Equipment
 - 5.4.3.1. DTN
 - 5.4.3.2. DTN-X
- 5.4.4. Contact Information

5.5 NOKIA

- 5.5.1. General Company Information
 - 5.5.1.1. History
 - 5.5.1.2. Financial
 - 5.5.1.3. Capabilities
 - 5.5.1.4. Recent Projects
- 5.5.2. Photonic Service Engine
 - 5.5.2.1. PSE-2s
 - 5.5.2.2. PSE-3s
- 5.5.3. Contact Information



CHAPTER 6: CABLE SUPPLIERS

6.1 INTRODUCTION

- 6.2 HENGTONG MARINE CABLE SYSTEMS (HTDG)
 - 6.2.1.1. History
 - 6.2.1.2. Financial
 - 6.2.1.3. Recent Projects
 - 6.2.1.4. Capabilities
 - 6.2.2. Submarine Optical Fiber Cable Products: Unrepeatered
 - 6.2.2.1. HOUC-1 Series (Fiber Count: 1-24)
 - 6.2.2.2. HOUC-2 Series (Fiber Count: 1-96)
 - 6.2.2.3. HOUC-3 Series (Fiber Count: 1-96)
 - 6.2.3. Submarine Optical Fiber Cable Products: Repeatered

6.2.3.1. HORC-1 Series (Fiber Count: 1-16)

- 6.2.4. Submarine Optical Fiber Cable Products: Joint Enclosures
 - 6.2.4.1. HORCJ-1 Series
 - 6.2.4.2. HOUCJ-1 Series
- 6.2.5. Submarine Optical Fiber Cable Products: Branching Unit
- 6.2.6. Offshore capability
- 6.2.7. Contact Information

6.3 HEXATRONIC CABLES AND INTERCONNECT SYSTEMS

- 6.3.1. General Company Information
 - 6.3.1.1. History
 - 6.3.1.2. Financial
 - 6.3.1.3. Recent Supply Contracts
- 6.3.2. Hexatronic Submarine Systems Global References
- 6.3.3. Cable Overview
- 6.3.4. Submarine Cable Design
- 6.3.5. Ribbon Cables
 - 6.3.5.1. Single Armored Ribbon Submarine Cables
 - 6.3.5.2. Double Armored Ribbon Submarine Cables
 - 6.3.5.3. Rock Armored Ribbon Submarine Cables
 - 6.3.5.4. Submarine Joints for Ribbon Cables
- 6.3.6. Loose Tube Cables
 - 6.3.6.1. Single Armored Loose Tube Submarine Cables
 - 6.3.6.2. Double Armored Loose Tube Submarine Cables



- 6.3.6.3. Electroding Single Armored
- 6.3.6.4. Electroding Double Armored
- 6.3.6.5. Submarine Joints for Loose Tube Cables
- 6.3.7. Cable Parts for Integration
- 6.3.8. Contact Information

6.4 NEXANS

- 6.4.1. General Company Information
 - 6.4.1.1. History
 - 6.4.1.2. Capabilities
 - 6.4.1.3. Financial
 - 6.4.1.4. Recent Supply Contracts
- 6.4.2. Cable
 - 6.4.2.1. Repeaterless Cable (URC-1)
 - 6.4.2.2. Repeatered Cable: ROC-1 (Legacy)
 - 6.4.2.3. Repeatered Cable: ROC-2
- 6.4.3. Joints
- 6.4.4. Branching Unit
- 6.4.5. Remote Amplifier Box
- 6.4.6. Offshore Capability
- 6.4.7. Contact Information

6.5 PRYSMIAN GROUP

- 6.5.1. General Company Information
 - 6.5.1.1. History
 - 6.5.1.2. Recent Supply Contracts
 - 6.5.1.3. Financial
 - 6.5.1.4. Location
- 6.5.2. Draka Cable (Legacy)
- 6.5.3. NSW Capabilities
 - 6.5.3.1. Repeaterless MINISUB Cable
 - 6.5.3.2. Repeatered MINISUB Cable
- 6.5.4. Offshore capability
- 6.5.5. Contact Information

6.6 ZTT

- 6.6.1. General Company Information
 - 6.6.1.1. History



- 6.6.1.2. Location
- 6.6.1.3. Financial
- 6.6.1.4. Recent Systems/Contracts
- 6.6.1.5. Submarine Capabilities
- 6.6.2. SOFC-Q10 Repeaterless Cable
- 6.6.3. ZTT: SOFC-S17 Cable for Repeatered Systems
- 6.6.4. Other cables
- 6.6.5. Miscellaneous Cables
- 6.6.6. Contact Information

CHAPTER 7: SUBMARINE SUB-SYSTEM SUPPLIERS

- 7.1 INTRODUCTION
- 7.2 ANRITSU
 - 7.2.1. C-OTDR
 - 7.2.2. Contact Information

7.3 IPG PHOTONICS

- 7.3.1. General Company Information
- 7.3.2. Products
- 7.3.3. Contact Information

7.4 MPB COMMUNICATIONS

- 7.4.1. General Company Information
 - 7.4.1.1. History
 - 7.4.1.2. Financial
- 7.4.2. Summary

7.4.2.1. Raman Amplifiers

7.4.3. Contact Information

7.5 SPELLMAN HIGH VOLTAGE CORPORATION

- 7.5.1. General Company Information
- 7.5.2. Spellman Low-Voltage PFE
- 7.5.3. Spellman Gen4 HV PFE
 - 7.5.3.1. Specifications
- 7.5.4. Spellman Shipborne PFE
- 7.5.5. Contact Information

7.6 TINSLEY INSTRUMENTATION LTD



7.6.1. General Company Information

7.6.2. Tinsley Products

7.6.2.1. Tinsley Cable Termination Unit

7.6.2.2. Tinsley Electroding Signal Generator

7.6.2.3. Tinsley Electroding Detectors

7.6.2.4. Long Haul Submarine Cable Test Set

7.6.2.5. Short Haul Submarine Cable Test Set

7.6.3. Contact Information

7.7 OPEN CABLE SYSTEMS CAPACITY TEST SET

CHAPTER 8: COMPONENT SUPPLIERS FOR UNDERSEA SYSTEMS

8.1 INTRODUCTION

8.2 THE IMPORTANCE OF INDUSTRY STANDARDS FOR COMPONENT AVAILABILITY

8.3 FIBER

- 8.3.1. Introduction
- 8.3.2. Corning
- 8.3.3. OFS
- 8.3.4. Sumitomo Electric

8.4 PUMP LASERS

- 8.4.1. Introduction
- 8.4.2. Lumentum (Formerly JDSU)

8.4.3. II-VI Corporation (Formerly Oclaro)

8.5 GAIN FLATTENING FILTER

- 8.5.1. ITF Technologies
- 8.5.2. iXblue Photonics
- 8.5.3. Kohoku
- 8.5.4. Lumentum
- 8.5.5. Sumitomo
- **8.6 SUBMARINE QUALIFIED ROADMS**

CHAPTER 9: CONCLUSIONS

9.1 BANDWIDTH DEMAND GROWTH DRIVING TECHNOLOGICAL TRENDS

9.2 CABLE SYSTEM SUPPLIERS

9.2.1. Key Market Figures



- 9.2.2. Cable System Suppliers' Relative Positioning
- 9.2.3. ASN
- 9.2.4. HMN
- 9.2.5. NEC
- 9.2.6. SubCom
- 9.2.7. Cable Suppliers
- 9.3 SLTE SUPPLIERS
- 9.4 COMPONENT SUPPLIERS FOR UNDERSEA SYSTEMS

List of Figures

Figure 2-1: Inter-region total used bandwidth – 2024 forecast

- Figure 2-2: OTT Data centers and subsea cable systems
- Figure 2-3: Evolution of C band repeater bandwidth from 1993 to 2020
- Figure 2-4: Repeater pumping schemes

Figure 2-5: Revenue per market segment (2015-2019)

Figure 2-6: Number of cable systems per customer ownership type from 2015-2019

- Figure 2-7: Cable length installed per customer ownership structure from 2015-2019
- Figure 2-8: Total supplier revenue per customer ownership structure from 2015-2019
- Figure 2-9: Impact of customer ownership structure on the supply market
- Figure 2-10: Cable and fiber lengths deployed, and fiber/cable length ratio per RFS year
- Figure 2-11: Total supplier revenue and average price per installed cable kilometer (per RFS year)

Figure 2-12: Price per installed kilometer per RFS year (All cable system segments: branch, long-haul, regional, and unrepeatered)

Figure 2-13: Price per installed kilometer per RFS year (Repeatered cable systems: regional and long haul)

- Figure 2-14: Price per installed kilometer per RFS year (Long-haul repeatered cable systems only)
- Figure 2-15: Definition of the main routes for subsea cable deployments
- Figure 2-16: Evolution of price per installed kilometer per route (cable systems named)
- Figure 2-17: Price per installed kilometer per RFS year (cable routes differentiated)
- Figure 2-18: Definition of the main regions for subsea cable deployments
- Figure 2-19: Installed cable length per region over the 2015-2019 period
- Figure 2-20: Annual installed cable length per region over the 2015-2019
- Figure 2-21: Annual installed cable length per region over the 2015-2019 period (map)
- Figure 2-22: System integrator market shares (number of cable systems from 2015-2019)
- Figure 2-23: System integrator market shares in cable kilometers from 2015-2019



- Figure 2-24: System integrator market shares in revenue from 2015-2019
- Figure 2-25: System integrator market shares in cable kilometers and revenue from 2015-2019
- Figure 2-26: Number of systems per system integrator and per route (2015-2019)
- Figure 2-27: Revenue per system integrator and per route (2015-2019)
- Figure 2-28: Number of systems (top) and revenue (bottom) per system integrator and per route (2015-2019)
- Figure 2-29: Number of systems per system integrator and per region (2015-2019)
- Figure 2-30: Revenue per system integrator and per region (2015-2019)
- Figure 2-31: Number of systems (top) and revenue (bottom) per system integrator and per region (2015-2019)
- Figure 2-32: ASN's 2015-2019 revenue per region (\$2,672m total)
- Figure 2-33: HMN's 2015-2019 revenue per region (\$1,111m total)
- Figure 2-34: NEC's 2015-2019 revenue per region (\$2,078m total)
- Figure 2-35: SubCom's 2015-2019 revenue per region (\$1,921m total)
- Figure 3-1: Example of a point-to-point cable system (MAREA)
- Figure 3-2: Example of a festoon cable system (Jakarta Surabaya Cable System JAYABAYA)
- Figure 3-3: Example of a trunk and branch architecture (AAE-1 cable system
- Figure 3-4: Example of a ring architecture (TAT-14)
- Figure 3-5: Branched submarine cable network
- Figure 3-6: Typical single-mode fiber design
- Figure 3-7: Optical fiber loss mechanisms
- Figure 3-8: Continuous improvement in fiber loss
- Figure 3-9: Material, waveguide, and total dispersion in single-mode optical
- Figure 3-10: Fiber chromatic dispersion and pulse broadening
- Figure 3-11: Principal states of polarization (PSPs) and differential group delay (DGD) caused by fiber PMD
- Figure 3-12: Schematic diagram of an erbium-doped fiber amplifier (EDFA)
- Figure 3-13: Energy levels of erbium ions in silica
- Figure 3-14: Requirements for achieving high population inversion in a 3-level system
- Figure 3-15: Typical erbium-doped fiber design
- Figure 3-16: Pump power and population inversion
- Figure 3-17: Spontaneous and stimulated emission in erbium doped fiber
- Figure 3-18: Broadening of the energy levels in erbium-doped fiber
- Figure 3-19: Amplified spontaneous emission (ASE) in erbium-doped fiber
- Figure 3-20: Amplified spontaneous emission spectrum from an erbium-doped fiber amplifier
- Figure 3-21: ASE power spectral density at erbium-doped fiber and amplifier output
- Figure 3-22: Optical noise build-up along a string of optical repeaters
- Figure 3-23: Cable system ASE power spectral density vs repeater spacing and fiber attenuation



Figure 3-24: Amplifier noise build up and signal power decrease

Figure 3-25: OSNR vs distance in a repeater cascade

Figure 3-26: Amplifier gain and noise figure vs input power in saturated output power regime

Figure 3-27: Amplifier output power vs input power in saturation regime

Figure 3-28: Gain / output power recovery in case of high span loss degradation

Figure 3-29: Evolution of OSNR and signal power in the event of cable repairs

Figure 3-30: ASE and flattened gain spectra

Figure 3-31: Schematic diagram of an erbium-doped fiber amplifier with gain flattening filer (GFF) and optical isolators

Figure 3-32: Input and output spectra in a cascade of repeaters with flattened gain spectrum (with 42 unmodulated wavelengths)

Figure 3-33: Input and output spectra in a cascade of repeaters with flattened gain spectrum (with 56 modulated wavelengths)

Figure 3-34: Per channel power at repeater output with no "dummy" light / loading channel

Figure 3-35: Impact of channel distribution across repeater bandwidth on gain flatness

Figure 3-36: Repeater loading techniques

Figure 3-37: Raman effect inside silica fiber

Figure 3-38: Intra-band Raman amplification and gain tilt

Figure 3-39: Gain equalization for repeater-span combination

Figure 3-40: Amplifier gain excursion and tilt definitions

Figure 3-41: Gain tilt equalizer (GTE) and gain shape equalizer (GSE) in a cable system

Figure 3-42: Representation of signal electrical field

Figure 3-43: Vector / symbol phase modulation

Figure 3-44: Binary phase shift keying (BPSK) modulation

Figure 3-45: On off keying (OOK, aka intensity modulation direct detection - IMDD) modulation

Figure 3-46: Associating 2 bits per symbol out of a 4-symbol alphabet

Figure 3-47: Possible phase coding for a 4-symbol alphabet

Figure 3-48: Constellation diagrams for different symbol alphabet sizes

Figure 3-49: Optical waveform and constellation diagram for 16QAM modulation format

Figure 3-50: Impact from polarization multiplexing upon number of bits per symbol

Figure 3-51: Symbol and data rates for PM-QPSK and PM-16QAM modulation formats

Figure 3-52: Output BER vs input BER and OSNR for two FEC implementations

Figure 3-53: Soft-decision forward error correction (FEC)

Figure 3-54: Net coding gain vs FEC overhead

Figure 3-55: Linear Shannon limit curve for one propagation channel



Figure 3-56: Examples of nonlinear Shannon limit curves

Figure 3-57: Linear Shannon limit curve considering two states of optical polarization

Figure 3-58: Radar chart showing five multiplexing

Figure 3-59: Radar charts showing historical technology / performance of submarine cable systems

Figure 3-60: Spectral efficiency achievable with various modulation formats

Figure 3-61: 16QAM and 64QAM modulation formats with no constellation

Figure 3-62: 64QAM modulation format with no constellation shaping

Figure 3-63: 64QAM modulation format with probabilistic constellation shaping

Figure 3-64: Use of adjustable distribution matcher to produce probabilistically shaped 64QAM constellations

Figure 3-65: 64APSK modulation format with probabilistic geometric

Figure 3-66: 16-symbol modulation format using 16QAMand 16APSK constellations

Figure 3-67: 64APSK modulation format with probabilistic geometric shaping

Figure 3-68: HS-56APSK constellation (hybrid shaping with geometric and probabilistic shaping

Figure 3-69: Slotted core and tight buffer fiber containment structures

Figure 3-70: Metallic loose tube fiber containment

Figure 3-71: Cable strength structures

Figure 3-72: Relative cable cost vs. linear dead current resistance for copper and aluminum conductors

Figure 3-73: Five varieties of submarine cable with various levels of protection

Figure 3-74: Example of double-armored cable

Figure 3-75: Universal joint component diagrams

Figure 3-76: Repeater housing for up to 8 fiber pairs of optical

Figure 3-77: SubCom's repeater housing and component for up to 16 fiber pair applications

Figure 3-78: Repeater voltage regulation with a Zener diode

Figure 3-79: Optical amplification of a single power-modulated wavelength

Figure 3-80: Optical amplification of a multiplex of wavelengths

Figure 3-81: A basic C+L band EFA optical amplifier

Figure 3-82: A basic EDFA optical amplifier design

Figure 3-83: Pump sharing for one amplifier pair (left) and two amplifier pairs (right)

Figure 3-84: Example of repeater block diagram (with passive monitoring

Figure 3-85: Passive repeater supervision architecture showing broadband loopback (for LME signal) and C-OTDR paths

Figure 3-86: Passive HLLB architecture showing narrowband loopback and broadband C-OTDR paths 3

Figure 3-87: HLLB output-to-output (left) and output-to-input coupling (right) schemes

Figure 3-88: HLLB output-to-input coupling scheme with probe waves on either side of repeater spectrum

Figure 3-89: Three examples of branching unit mechanical design



Figure 3-90: Power feeding path re-configuration in the case of trunk

Figure 3-91: Full fiber drop branching unit with no optical switching

Figure 3-92: Full fiber drop branching unit with optical switching

Figure 3-93: Branching unit with fixed wavelength selective devices

Figure 3-94: Wavelength re-use with branching unit with fixed wavelength selective devices

Figure 3-95: Branching unit with fixed wavelength selective devices and optical switching

Figure 3-96: Switchable OADM branching unit with fixed wavelength selective devices and optical switching

Figure 3-97: Two-body branching unit arrangement

Figure 3-98: Practical implementation of switchable OADM unit

Figure 3-99: WSS-based ROADM unit design with redundant WSS arrangement

Figure 3-100: Alternative WSS-based ROADM unit design with redundant WSS arrangement

Figure 3-101: Current branching unit and WSS-based wavelength management unit arrangement

Figure 3-102: Repeater bandwidth and supervision / monitoring wavelengths

Figure 3-103: Main subsea cable system components in traditional design

Figure 3-104: In-station (top) and inland (bottom) SLTE location

Figure 3-105: SLTE synoptic and main components

Figure 3-106: Representation of control (green lines), power (red lines) and date planes (black lines) within SLTE and SLTE inputs / outputs

Figure 3-107: Typical SLTE shelf organization

Figure 3-108: Example of net data rates and spectral efficiencies achievable with 33 Gbaud symbol rate

Figure 3-109: Example of net data rates and channel spacings achievable with PM-QPSK modulation format

Figure 3-110: Reconfigurable submarine networks – Baseline

Figure 3-111: Reconfigurable submarine networks – More capacity needs in site C

Figure 3-112: Reconfigurable submarine networks – Dynamic / adaptive behavior

Figure 3-113: Achievable spectral efficiency with PM-16QAM modulation format

Figure 3-114: Achievable spectral efficiency with nQAM modulation formats vs Shannon limit

Figure 3-115: Achievable spectral efficiency using selectable nQAM modulation format

Figure 3-116: PM-16QAM modulation format and associated Euclidean space constellation

Figure 3-117: Probabilistically shaped 64QAM constellations

Figure 3-118: Typical DSP real estate distribution

Figure 3-119: Generic architecture of an open cable system interface

Figure 3-120: Spectrum sharing for fractional dark fiber pair product

Figure 3-121: Silica molecules at different energy levels in silica fiber

Figure 3-122: Excited silica molecule relaxation processes

Figure 3-123: Raman amplification process through a pumped silica fiber



Figure 3-124: Raman spectrum inside silica fiber

Figure 3-125: Composite Raman gain spectrum with three pump wavelengths

Figure 3-126: Distributed Raman amplification within an unrepeatered cable system

Figure 3-127: Distributed Raman amplification within a 334 km unrepeatered cable system with 150 wavelength multiplexed channels

- Figure 3-128: Receive remote optically-pumped amplifier (ROPA) design
- Figure 3-129: Distributed Raman amplification and receive ROPA in a 410 km unrepeatered span
- Figure 3-130: Distributed Raman amplification and receive ROPA in a 557 km unrepeatered span
- Figure 3-131: Dedicated fibers for pump transport
- Figure 3-132: Unrepeatered reach for different cable system design options
- Figure 3-133: Example of backward Raman pump module architecture
- Figure 3-134: Dual clad 1,060 nm laser
- Figure 3-135: Cascaded Raman wavelength shifters
- Figure 3-136: Photograph of Nufern's dual clad fiber with octagonal core
- Figure 3-137: Possible implementation of third-order Raman pump source
- Figure 3-138: Schematic of a QAM (or I/Q) modulator with output QPSK signal
- Figure 3-139: Operation of a QAM (or I/Q) modulator delivering QPSK signal
- Figure 3-140: Schematic of a QAM (or I/Q) modulator with output 16QAM
- Figure 3-141: Schematic of a QAM (or I/Q) modulator with output PM-QPSK signal
- Figure 3-142: A single-polarization I/Q demodulator
- Figure 3-143: A dual-polarization I/Q demodulator-receiver
- Figure 3-144: Coherent 100 Gbit/s PM-QPSK transmitter and receiver
- Figure 3-145: Dual-polarization I/Q demodulator-receiver and digital signal processor
- Figure 3-146: Polarization demultiplexer and equalizer for PM-QPSK signal
- Figure 3-147: Typical implantation of hxx FIR filter
- Figure 3-148: Example of constellation diagrams for nQAM modulation format (single polarization)
- Figure 3-149: Schematic of an I/Q modulator with output 16QAM signal
- Figure 3-150: nQAM constellation evolution/flow in a digital coherent optical receiver
- Figure 3-151: 16QAM constellation within the DSP
- Figure 3-152: Frequency and impulse response of Nyquist raised-cosine filter with various roll-off factors
- Figure 3-153: QPSK eye diagram after Nyquist raised-cosine filtering with two different roll-off factors
- Figure 3-154: Spectra of single- and sub-carrier implementation of a 1 Tbit/s signal (no overhead considered)
- Figure 3-155: Carrier total width reduction using inner sub-carrier coherent clock recovery
- Figure 3-156: Half symbol time polarization shifting
- Figure 3-157: FEC coding gain sharing across the carriers



Figure 3-158: Generic coherent transmitter and receiver (100G PM-QPSK example)

Figure 3-159: Optical front-end for PM-nQAM coherent receiver

Figure 3-160: Modulator configuration for PM-nQAM transmitter (shown here with PM-QPSK modulation format)

- Figure 3-161: OIF MSA 100G client transceiver modules
- Figure 3-162: Cable system power feeding in case of path failure
- Figure 3-163: The TMN five-layer organization of network functionality
- Figure 4-1: Schematic of dry repeater
- Figure 4-2: Schematic of optical multiplex section protection (OMSP)
- Figure 4-3: Schematic of Y Node
- Figure 4-4: Cross section of ASN's URC2 single armor
- Figure 4-5: ASN's URC2 cable family
- Figure 4-6: ASN's OALC4 cable samples with different armoring levels
- Figure 4-7: ASN's R5 repeater external
- Figure 4-8: ASN's R5 repeater sea case
- Figure 4-9: Four electrical configurations for power switched branching unit (BU)
- Figure 4-10: Transition between electrical configurations for power switched branching unit
- Figure 4-11: Examples of branching unit optical fiber routing for eight fiber pair systems
- Figure 4-12: Optical by-pass switch functionality
- Figure 4-13: Housing unit external view
- Figure 4-14: ASN's branching unit sea case
- Figure 4-15: WSS ROADM unit and branching unit in a tow-body arrangement
- Figure 4-16: ROADM unit configurations
- Figure 4-17: Optical accesses available for active supervisory
- Figure 4-18: Main Fiber Portal blocks (case when the SLTE is close to the landing site
- Figure 4-19: Fiber Portal arrangement and location when the SLTE is distant from the landing site
- Figure 4-20: Main Wave Portal blocks
- Figure 4-21: ASN's PFE functional architecture
- Figure 4-22: PFE rack front view Non-redundant and duplicated (1+1) 3 kW PFEs.
- Figure 4-23: PFE rack front view Duplicated (1+1) 6 kW
- Figure 4-24: PFE rack front view Duplicated (1+1) 9 kW with dummy test load
- Figure 4-25: PFE rack front view Duplicated (1+1) 12-18 kW with dummy test load
- Figure 4-26: SN10 network management system screen showing a network topology
- Figure 4-27: Example of SN 10 management system screen for end to end path management
- Figure 4-28: Example of SN 10 management system screen for end to end fiber pair



Figure 4-29: Example of SN 10 management system screen for alarm management

Figure 4-30: Example of SN 10 management system screen for performance management

Figure 4-31: HMN's projects worldwide as of end 2019 (including upgrades and new builds – repeatered and unrepeatered)

Figure 4-32: Views of various OptiX ONS 8800 shelf configurations

Figure 4-33: Views of various OptiX ONS 9800 shelf and rack configurations

Figure 4-34: HMN's low-voltage

Figure 4-35: HMN's high-voltage PFE

Figure 4-36: HMN's 2 fiber pair repeater (RPT 1660 R1)

Figure 4-37: HMN's 8 fiber pair repeater (RPT 1660 R3)

Figure 4-38: HMN's pump sharing scheme in HMN previous generation repeaters

Figure 4-39: HMN's pump sharing scheme in RPT 1660 R4 repeater

Figure 4-40: Mechanical designs of HMN's 2/8/16 fiber pair

Figure 4-41: Evolution from output-to-input (Releases 1, 2 and 3 – left) to output-to-output (Release 4 – right) coupling

Figure 4-42: HMN's pump current source and surge current suppression circuit for four-pumping-four

Figure 4-43: HMN's BU1650 V100R001 for unrepeatered cable systems

Figure 4-44: HMN's BU1650 V100R002 for repeatered cable systems

Figure 4-45: HMN's BU1650 V100R002 mechanical design

Figure 4-46: Close-up view of the branch case and bend limiters of HMN's branching

Figure 4-47: HMN's V100R002 branching unit power switch states

Figure 4-48: HMN's V100R002 branching unit power switching legal state transitions

Figure 4-49: NEC's T740SW Terminal Equipment with 40 and 100 Gbit/s transponders

Figure 4-50: NEC's Open Cable Interface (OCI)

Figure 4-51: FLEX20 WSS filter bandwidth granularity (3.125 GHz)

Figure 4-52: Photograph of the present Kita-Kyushu factory

Figure 4-53: OCC's SC300 LW cable cross section

Figure 4-54: OCC's SC300 cable family (20.4 mm outside diameter for the LW variant)

Figure 4-55: OCC's SC500 LW cable

Figure 4-56: Structure of OCC's SC500 LW cable

Figure 4-57: Excerpt of OCC's SC500 cable family (17 mm outside diameter for the LW variant)

Figure 4-58: NEC's R640SW repeater

Figure 4-59: NEC's R640SW repeater pumping schemes

Figure 4-60: Schematic of NEC's R640SW repeater showing signal, pump, optical passive supervision and C-OTDR paths



Figure 4-61: High-level electrical schematic for powering the pump lasers in NEC's R640SW 4 fiber-pair repeater

- Figure 4-62: Measuring loop gain to monitor repeater section
- Figure 4-63: Measuring Rayleigh backscattered light to precisely locate faults in each fiber segment
- Figure 4-64: NEC's M640SW remote fiber test equipment (RFTE)
- Figure 4-65: OTDR result on a portion of a 4,100 km system
- Figure 4-66: NEC's B640 branching unit
- Figure 4-67: Example of branching unit power switching
- Figure 4-68: Schematic of NEC's branching unit and WSS-based wavelength management unit
- Figure 4-69: Reconfigurable optical transmission and drop coefficients of the PSBU-WMU combination
- Figure 4-70: The NPF series power feed equipment by NEC
- Figure 4-71: NEC's PFE block diagram for double-end feeding
- Figure 4-72: NEC's PFE block diagram for single-end feeding
- Figure 4-73: Example of NEC's PFE layout for 16 kV at 0.9 A duplicated PFE system
- Figure 4-74: Overall configuration of submarine cable system with NEC's WebNSV management system
- **Figure 4-75:** NEC's WebNSV network management (UMS), element management, web-based client (craft terminal), and data communication network (DCN) interconnections
- Figure 4-76: Example of map view, site view and performance monitoring view from NEC's WebNSV EMS
- Figure 4-77: Example of power path and configuration
- Figure 4-78: Example of fiber path view
- Figure 4-79: Example of optical path view
- Figure 4-80: Standard SubCom's open cable interface configuration
- Figure 4-81: SubCom's Ocean Gateway open cable interface configuration
- Figure 4-82: SubCom's dry ROADM circuit pack
- Figure 4-83: SubCom's line monitoring equipment (LME) circuit pack
- Figure 4-84: SubCom's command response equipment (CRE) circuit pack
- Figure 4-85: Part of SubCom's SL17 cable family
- Figure 4-86: Comparison of SL17-A1 with SL21 and SL17 variants
- Figure 4-87: SubCom's co-pumped, C-band, "2-pumping-2" amp-pair
- Figure 4-88: Fully-equipped SubCom's 8 fiber pair repeater housing
- Figure 4-89: Pump farming for four fiber pair amp-quad chassis
- Figure 4-90: 16 fiber pair repeater in SubCom's Type 300 repeater housing
- Figure 4-91: SubCom's repeater housing
- Figure 4-92: SubCom's repeater loading aboard a cable ship
- Figure 4-93: View of SubCom's branching unit
- Figure 4-94: Schematic of fiber connection between trunk and branch



- Figure 4-95: Functional block diagram of the power switched branching unit (PSBU)
- Figure 4-96: SubCom's branching unit on shipping pallet
- Figure 4-97: Optical arrangement inside SubCom's WSS-based ROADM wavelength management unit
- Figure 4-98: SubCom's high voltage power feed equipment
- Figure 4-99: FiberHome's submerged equipment family
- Figure 4-100: FiberHome's submarine cable family
- Figure 4-101: Padtec's repeater
- Figure 4-102: Padtec's 2018 repeater design (not deployed as of today)
- Figure 4-103: Xtera's Nu-Wave Optima™
- Figure 4-104: Xtera's hybrid Raman-EDFA repeater amplifier
- Figure 4-105: Optical variants of Xtera's repeater for low-noise / long span (1) and wide band (2) configuration
- Figure 4-106: Adjustable gain tilt in Xtera's repeater
- Figure 4-107: Outside view of Xtera's repeater
- Figure 4-108: Outside view of Xtera's branching unit
- Figure 5-1: Timeline of Ciena's WaveLogic coherent optical processors (optical spectrum and key characteristics)
- Figure 5-2: Frequency division multiplexing with WaveLogic 5 Extreme
- Figure 5-3: Ciena's coherent modulator and integrated coherent receiver for WaveLogic 5 Extreme technology
- Figure 5-4: Transmit board of Ciena's WaveLogic 5 Extreme transponder
- Figure 5-5: Ciena's 6500-S14 14-slot shelf
- Figure 5-6: Ciena's Waveserver Ai platform
- Figure 5-7: Ciena's Waveserver 5 platform
- Figure 5-8: Blue Planet software suite
- **Figure 5-9:** Loading channel equipment and optical channel monitoring subsystems to control repeater spectral load
- Figure 5-10: Cisco's financial results for fiscal year 2019 (ended July 27, 2019)
- Figure 5-11: Acacia's digital signal processor roadmap
- **Figure 5-12:** Controlling baud-rate and bits / symbol for line rates from 50 to 600 Gbit/s to meet reach and capacity needs
- Figure 5-13: Pictures of Cisco's NCS 1004 supporting coherent line cards
- Figure 5-14: Mechanical drawings of Cisco's NCS 1004 supporting coherent line cards
- Figure 5-15: Cisco's SLTE line system NCS 2006 shelf
- Figure 5-16: Infinera's 500G
- Figure 5-17: Nyquist subcarriers
- Figure 5-18: Non uniform sub-carrier loading
- Figure 5-19: Infinera's DTN optical transmission equipment



- **Figure 5-20:** Infinera's DTN-X variant portfolio
- Figure 5-21: Nokia's optical networking product family
- Figure 5-22: Principle of distribution matcher for probabilistic constellation shaping
- Figure 5-23: Impact of variable probabilistic constellation shaping on modulation format
- Figure 6-1: Hengtong's global project experience
- Figure 6-2: Megacable Project
- Figure 6-3: IGW project
- Figure 6-4: FOA project
- Figure 6-5: PEACE project
- Figure 6-6: Comoros project
- Figure 6-7: Kumul Cable System
- Figure 6-8: Hengtong's HOUC-1LW cable
- Figure 6-9: Hengtong's HOUC-1LWP cable
- Figure 6-10: Hengtong's HOUC-1SAL cable
- Figure 6-11: Hengtong's HOUC-1SA cable
- Figure 6-12: Hengtong's HOUC-1DA cable
- Figure 6-13: Hengtong's HOUC-2SA cable
- Figure 6-14: Hengtong's HOUC-2DA cable
- Figure 6-15: Hengtong's HOUC-3DA cable
- Figure 6-16: Hengtong's HORC-1LW
- Figure 6-17: Hengtong's HORC-1LWP
- Figure 6-18: Hengtong's HORC-1SAL
- Figure 6-19: Hengtong's HORC-1SA
- Figure 6-20: Hengtong's HORC-1DA
- Figure 6-21: Hengtong's HORCJ1: internal insulation and external view of joint closure
- Figure 6-22: Hengtong's HOUCJ-1 Joint Closure
- Figure 6-23: Hengtong's HOCBU-
- Figure 6-24: Hengtong's offshore product showcase
- Figure 6-25: Hexatronic's Factory in Hudiksvall, SE
- Figure 6-26: Cable loading at Hudiksvall quay
- Figure 6-27: Hexatronic's worldwide projects
- Figure 6-28: Submarine cable being loaded on to a cable ship
- Figure 6-29: Hexatronic's load out pier and manufacturing plant in Hudiksvall, Sweden
- Figure 6-30: Diagram of Hexatronic's submarine cable design
- Figure 6-31: Hexatronic's single armored product line



- Figure 6-32: Hexatronic's double armored product line
- Figure 6-33: Hexatronic's rock armored product
- Figure 6-34: Submarine joint for ribbon cable
- Figure 6-35: Hexatronic's single armored loose tube submarine cable
- Figure 6-36: Hexatronic's Double Armored product line
- Figure 6-37: Hexatronic's Electroding Single Armored design
- Figure 6-38: Hexatronic's Electroding Double Armored design
- Figure 6-39: Hexatronic's submarine joints for loose tube cables
- Figure 6-40: Hexatronic's hybrid cable
- Figure 6-41: CLV Nexans Aurora
- Figure 6-42: Nexans' URC-1 cable family
- Figure 6-43: Nexans' ROC-1 cable
- Figure 6-44: Nexans' ROC-2 repeatered cable
- Figure 6-45: Outline of Nexans' branching unit
- Figure 6-46: Nexans' branching unit
- Figure 6-47: Prysmian's History
- Figure 6-48: Draka NK Cable's underwater cable
- Figure 6-49: NSW's 3-port BU
- Figure 6-50: NSW's cable family
- Figure 6-51: NSW's LW cable design
- Figure 6-52: NSW's SA cable design
- Figure 6-53: NSW's DA cable design
- Figure 6-54: ZTT's SOFC-Q10-LW
- Figure 6-55: ZTT's SOFC-Q10-LWP
- Figure 6-56: ZTT's SOFC-Q10-SA1 (left) and SOFC-Q10-SA2 (right)
- Figure 6-57: ZTT's SOFC-Q10-DA1 (left) and SOFC-Q10-DA2 (right)
- Figure 6-58: ZTT's SOFC-Q10-RA
- Figure 6-59: ZTT's SOFC-S17-SA Cable Cross-Section
- Figure 6-60: ZTT's SOFC-ADK-/4~48SM single armored
- Figure 6-61: ZTT's SOFC-ASK/4~96SM
- Figure 6-62: ZTT's SOFC-BSK/4~96SM+8x1.6
- Figure 6-63: ZTT's SOFC-CSK/48~288M
- Figure 6-64: ZTT's SOFC-LWDK/4~24SM
- Figure 6-65: ZTT's SOFC-LWSK/4~24SM
- Figure 7-1: Anritsu's C-OTDR, Model MW90010A



Figure 7-2: MPB's repeaterless block diagram

Figure 7-3: Spellman's LV-PFE, 5KV, 1.0A continuous service

Figure 7-4: Spellman's Gen4 HV PFE

Figure 7-5: Spellman's Shipborne PFE

Figure 7-6: Spellman's shipborne PFE systems management terminal and display

Figure 7-7: Tinsley's Cable Termination Unit Model 5941

Figure 7-8: Tinsley's Cable Termination Unit Model 5915

Figure 7-9: Tinsley's Electroding Detector Model 5916

Figure 7-10: Tinsley's Electroding Detector Models 5917 and 5918

Figure 7-11: Tinsley's 5903 Long Haul Submarine Cable Test Set

Figure 7-12: Tinsley 5910 portable short haul submarine cable test set

Figure 7-13: Block diagram for one side (one half) of the Open Cable Systems Capacity Test

Figure 8-1: The genealogy of acquisitions by component suppliers which are important to wet plant and SLTE markets

Figure 8-2: Typical fiber attenuation distribution (low-loss, large effective area fibers)

Figure 8-3: Block-less dispersion map used in transmission experiment

Figure 8-4: II-VI Corporation 980 nm pump laser

Figure 8-5: Insertion loss vs optical wavelength for ITF Technologies' gain flattening filters

Figure 8-6: ITF Technologies' fiber Bragg grating gain flattening filter

Figure 8-7: Insertion loss vs optical wavelength for iXblue Photonics' gain flattening filters

Figure 8-8: Hybrid YM-101 optical isolator / gain flattening filter from Kohoku

Figure 8-9: Lumentum's thin film gain flattening filter

Figure 8-10: Principle of a wavelength selective switch (WSS) based on liquid crystal on silicon (LCoS) technology

Figure 8-11: Examples of WWS modules for terrestrial applications

Figure 8-12: Example of WSS-based wavelength management unit with built-in WSS redundancy

Figure 8-13: Example of fixed filter-based wavelength management unit

List of Tables

 Table 1-1: Main system/equipment suppliers described in this report

Table 2-1: List of OTT-led/supported subsea cable systems (July 2020)

Table 3-1: Examples of symbol rate x modulation scheme combinations

Table 3-2: FIT table for a four fiber pair repeater (with 2 redundant pumps per fiber pair

Table 3-3: FIT table for a two fiber pair repeater with pump farming (4 pumps shared by 2 fiber pair

 Table 3-4: Submerged equipment reliability and equivalent ship repair probability for transpacific system

Table 3-5: Minimum inter-symbol Euclidean distance vs modulation format



- **Table 3-6:** Evolution of coherent transponder design, technology, and performance
- Table 3-7: Tolerance to chromatic dispersion, PMD and noise vs bit rate in IMDD/OOK system
- Table 3-8: Comparison of required gross symbol rates for sub- and single-carrier implementations
- **Table 4-1:** ASN's supply history since 2009
- Table 4-2: ASN's current work
- Table 4-3: Summary of ASN's cable offering
- Table 4-4: Armor options for ASN's URC2 Cable
- Table 4-5: System deployments of ASN's URC2 cable
- Table 4-6: Armor options for ASN's URC4 cable
- Table 4-7: Armor options for ASN's OALC4 cable
- Table 4-8: Armor options and corresponding characteristics for ASN's OALC5 cable
- Table 4-9: Armor options for ASN's OALC7 cable
- Table 4-10: Main ASN's R5 repeater optical characteristics
- Table 4-11: Main ASN's R5 repeater mechanical characteristics
- Table 4-12: Typical ASN's R5 repeater electrical characteristics
- Table 4-13: ASN's PFE electrical characteristics
- Table 4-14: HMN's supply history since 2009
- Table 4-15: HMN current work
- Table 4-16: NEC's supply history since 2009
- Table 4-17: NEC current work
- **Table 4-18:** NEC's link budgets for repeaterless cable systems
- Table 4-19: NEC repeaterless systems completed or ongoing
- Table 4-20: OCC's SC300 cable characteristics
- Table 4-21: OCC's SC500 cable characteristics
- Table 4-22: NEC's branching unit types
- Table 4-23: SubCom's supply history since 2009
- Table 4-24: SubCom's current orders
- Table 4-25: SubCom's open cable interface configuration
- Table 4-26: Summary of SubCom's cable offering
- Table 4-27: Summary of SubCom's cable specifications
- Table 4-28: Performance for SubCom's SL17 repeatered cable
- Table 4-29: Performance for SubCom's SL21 repeatered cable
- Table 4-30: Armoring options for SubCom's repeaterless SL12 cable
- Table 4-31: Xtera's supply history since 2009 (excluding capacity upgrades)
- Table 4-32: Xtera's upgrade projects (2009-present)



Table 4-33: Xtera's current order Table 5-1: Evolution of CMOS technology Table 5-2: Supported modulation formats
 Table 5-3: Infinera's ICE4 optical engine characteristics
 Table 6-1: Technical Parameters for Hengtong Marine's HOUC-3 Series Table 6-2: Technical parameters for Hengtong Marine's HORC Series Table 6-3: Technical Parameters for Hengtong Marine's HORCJ-1 Table 6-4: Technical parameters for Hengtong Marine's HOUCJ-1 Table 6-5: Technical parameters for Hengtong Marine's HOCBU-1 Table 6-6: Hexatronic's recent contracts Table 6-7: Ribbon submarine cables: general Table 6-8: Hexatronic's ribbon submarine cable: detailed data Table 6-9: Hexatronic's ribbon submarine cable joint standard product information Table 6-10: Hexatronic's loose-tube: General Data Table 6-11: Hexatronic's loose tube cable detailed product information Table 6-12: Hexatronic's hybrid cable: optical cable data Table 6-13: Nexans' recent contracts Table 6-14: Armor options for Nexans' URC-1 cable Table 6-15: Prysmian's recent projects Table 6-16: Summary of Prysmian's (Draka) cable offering Table 6-17: Summary of NSW's MINISUB cable offering Table 6-18: ZTT's Financial results (in millions of US\$) Table 6-19: Recent ZTT's cable Table 6-20: Summary of ZTT's repeaterless cable Table 6-21: Summary of ZTT's repeatered cable Table 7-1: Specifications for the Anritsu MW90010A Table 7-2: Configurations for the Spellman's Shipboard Table 8-1: Previous generations of Corning's submarine fibers for long-Table 8-2: Latest Corning's optical fibers Table 8-3: Summary of legacy OFS' submarine fibers Table 8-4: OFS' Optics fiber for repeatered systems Table 8-5: Comparison of TeraWave Fibers Table 8-6: Summary of Sumitomo's submarine fibers

If interested in learning more about "Suppliers of Undersea Telecommunications Systems" or if you would like to purchase this report, please reach out via: info@pioneerconsulting.com.