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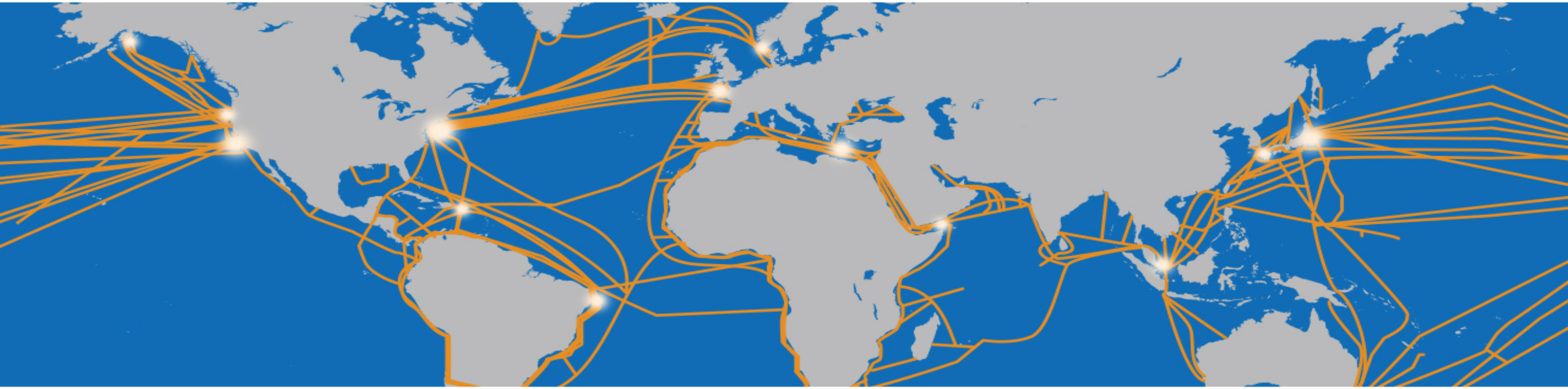
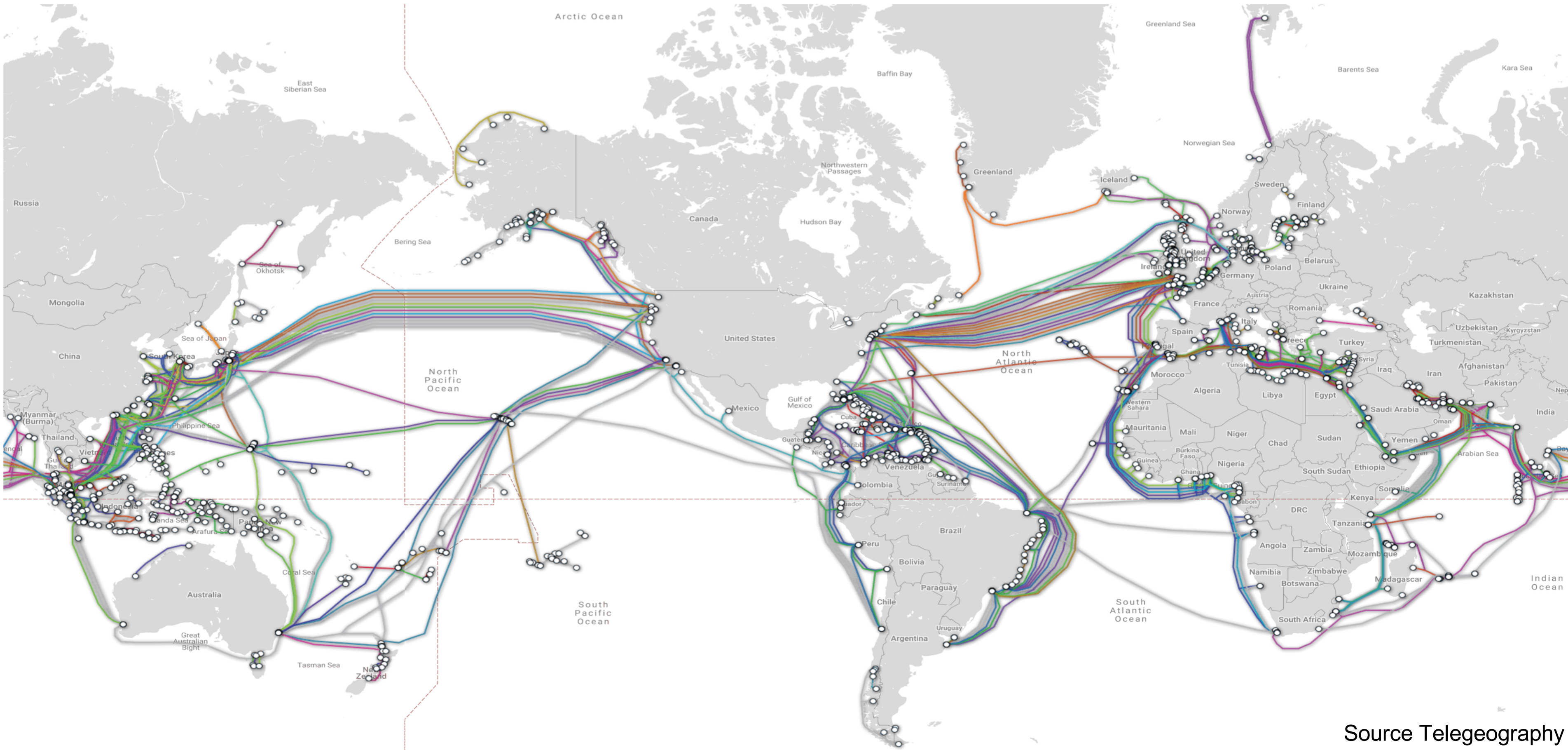


SMART Cable Systems: Integration of Sensors into Telecommunications Repeaters

Stephen Lentz and Bruce Howe

IEEE/MTS Oceans Kobe
29 May 2019

The World’s Submarine Cables



Source Telegeography
https://www.submarinecablemap.com
Accessed on 4-May-2018

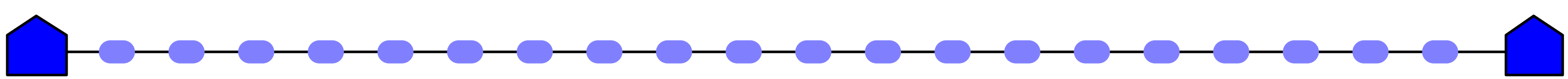
Scientific Monitoring and Reliable Telecommunications: SMART Cables

- Joint Task Force is sponsored by ITU, WMO, and IOC with the objective of integrating scientific sensors into trans-ocean submarine telecommunications cables
- To increase the reliability of global tsunami warning network
- To obtain sustained climate data from the deep oceans

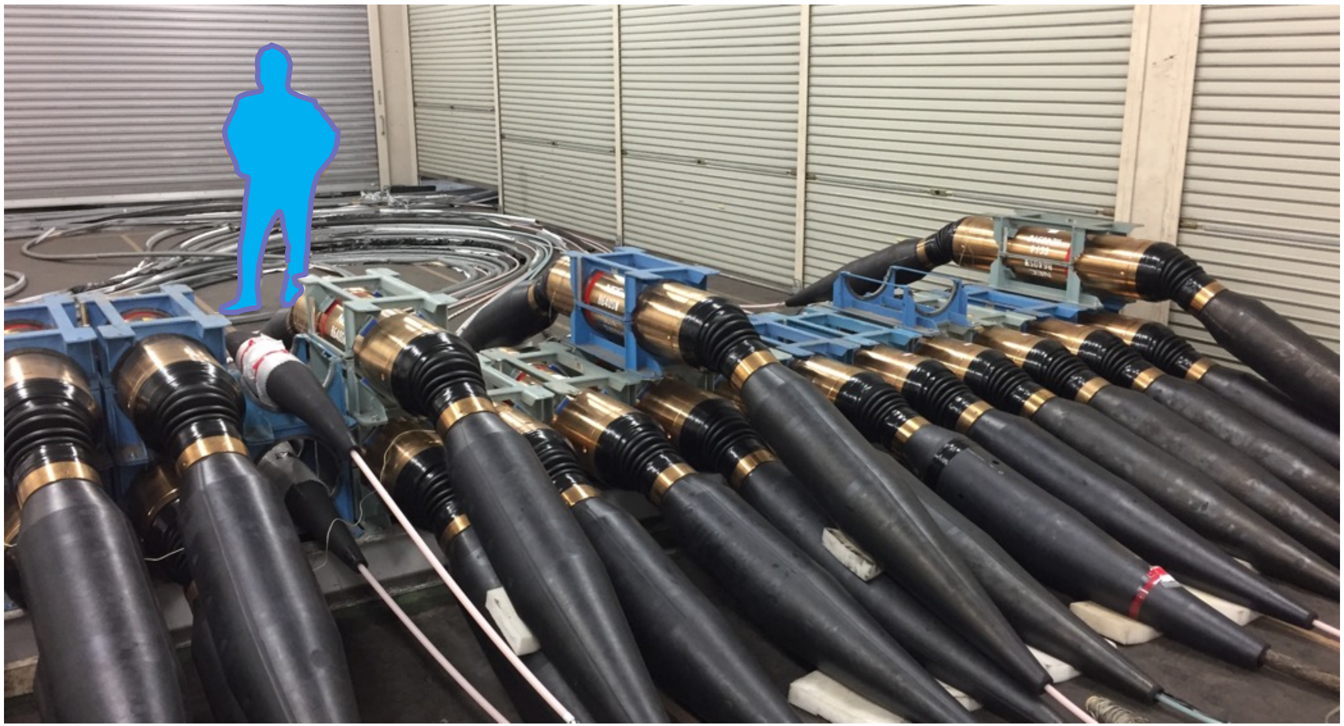
https://www.itu.int/en/ITU-T/climatechange/task-force-sc/Pages/default.aspx

SMART Cable Technical Objectives

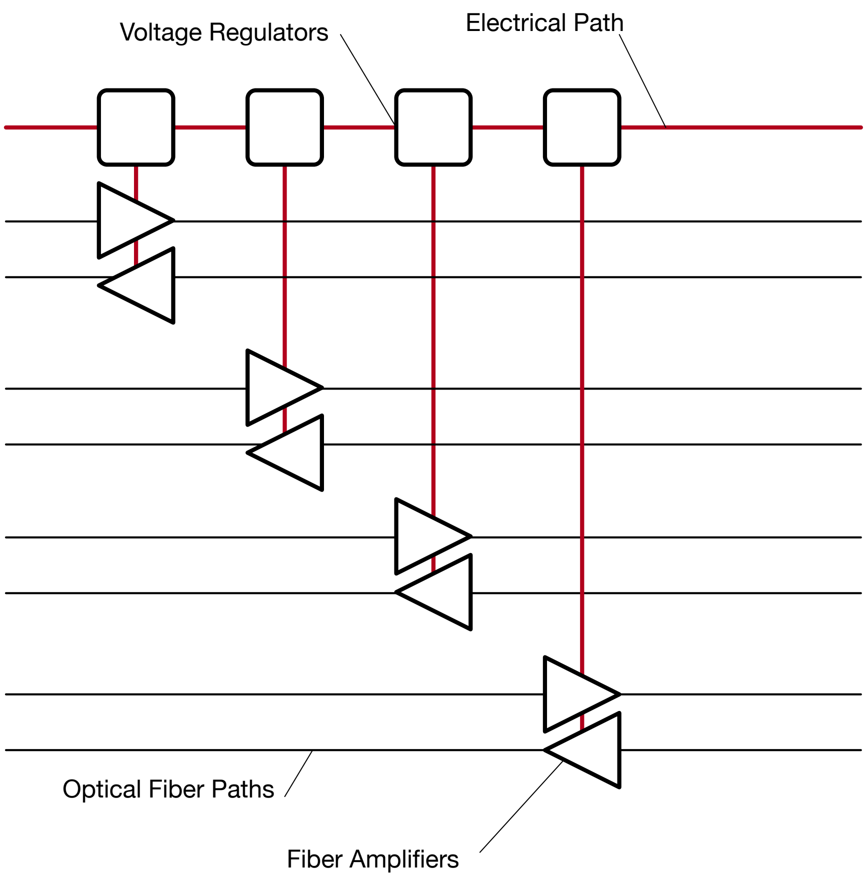
- Integrate Temperature, Pressure, and 3-axis Acceleration sensors into a commercial telecommunications repeater with negligible impact on the performance and reliability of the repeaters' telecommunications functions.
- Collect sensor data in real time and disseminate it to operational and research agencies (early warning, oceanographic, meteorological, geophysical).
- Sensor nodes 75 – 150 km apart, with cable spanning thousands of kilometers



Repeater Stack during Factory Testing



Simplified Repeater Block Diagram

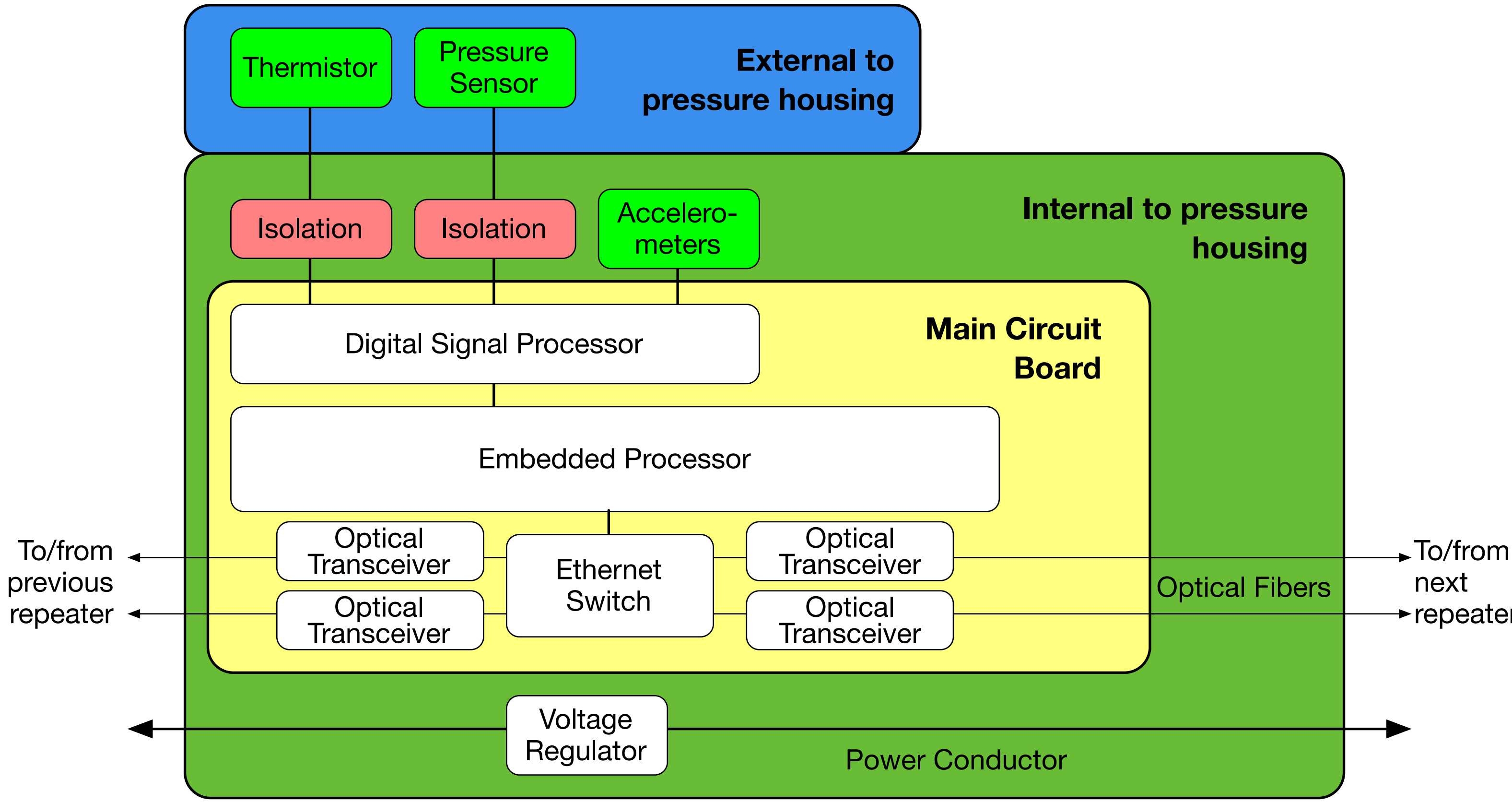


- Single Conductor Electrical Path
- Constant Current
- Voltage Regulators

- 1 to 8 Fiber Pairs
- Erbium Doped Fiber Amplifiers
- Bandwidth from 1.6 to 6.5 THz
- Data capacity over 20 Tb/s per fiber

- Not shown are optical loop back paths for testing and surge arrestors for electrical protection

Sensor Functions Block Diagram



Technical Challenges

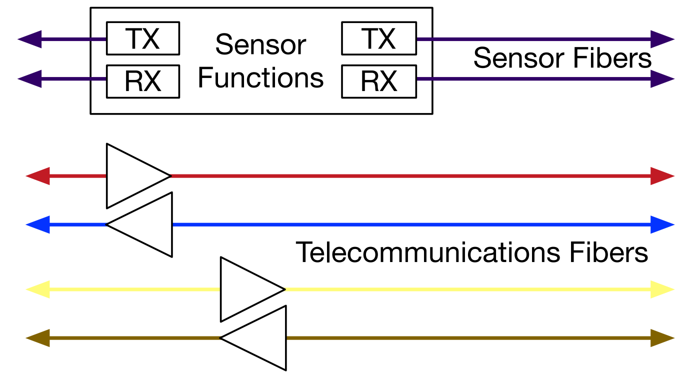
1) Provision of a data communications channel
2) Power consumption limits
3) Mechanical compatibility and limited volume within pressure housing
4) Mounting of sensors external to repeater housing
5) Delivery of power to external sensors
6) Reliability and failsafe design

Bandwidth Requirements

Data Source	Samples per Second	Bits per Sample	Data Rate
Accelerometer X	200	24	4,800 b/s
Accelerometer Y	200	24	4,800 b/s
Accelerometer Z	200	24	4,800 b/s
Pressure	10	24	240 b/s
Temperature	1	24	24 b/s
Total raw data rate			**15 kb/s**
Overhead	20	288	5.5 kb/s
Total data rate per repeater			20.5 kb/s
Maximum number of repeaters = 175			
System Wide Data Rate			**3.5 Mb/s**

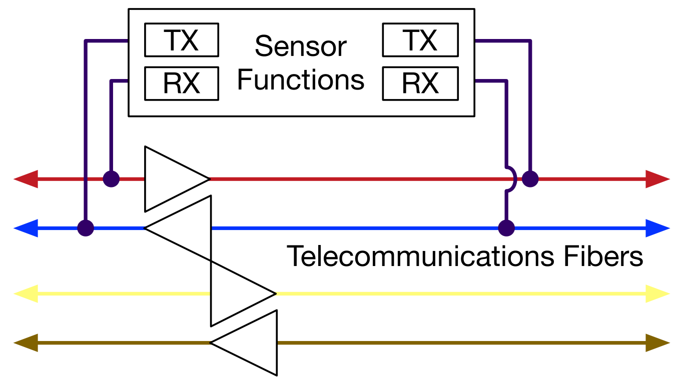
Data Transmission Option 1: Dedicated Fibers

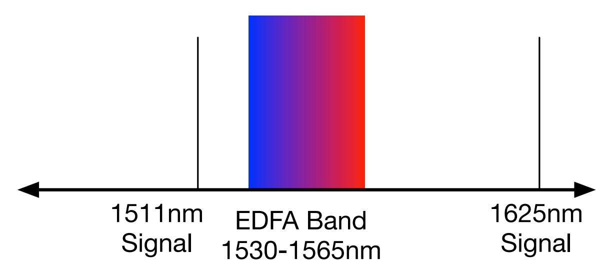
- Sensor data is transmitted via a dedicated pair of fibers
- Fast (100 Mb/s) Ethernet
- Data links are from repeater to repeater
- Transmission reach up to 140km
- Signals are regenerated at each repeater
- Transceiver redundancy requires CWDM, bidirectional transmission, or second fiber pair
- No impact on telecom fibers



Data Transmission Option 2: Out of Band Signal

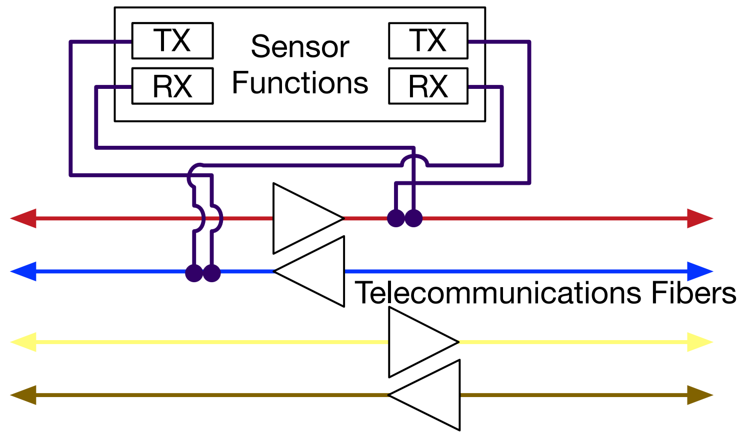
- Sensor data is transmitted on the telecommunications fibers at a wavelength outside the operating band of the EDFA such as 1511nm or 1625nm
- These signals are coupled onto the telecom fibers
- Fast (100 Mb/s) Ethernet
- Design of the sensor subsystem is essentially the same as Option 1

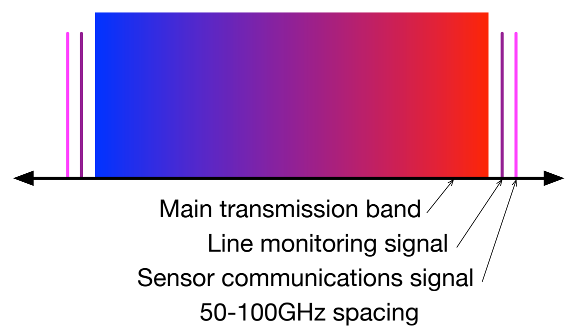




Data Transmission Option 3: Edge Band Signal

- Data is transmitted to/from sensors on the telecommunications fibers at the edge of the amplified transmission band.
- Wavelength close to, but not the same as, line monitoring signal.
- A poll and response mechanism needed so that only one repeater at a time is actively transmitting
- Forward Error Correction will also need implemented as part of the communications protocol
- Failure of sensor subsystem in one repeater should have no impact on other repeaters





Data Transmission Summary

- Option 1, Ethernet on dedicated fibers
- Options 2, Out-of-Band Ethernet on telecom fibers
- Options 3, Edge Band Signal on telecom fibers
- Other options have been considered but do not provide sufficient bandwidth.

Power Consumption Limits

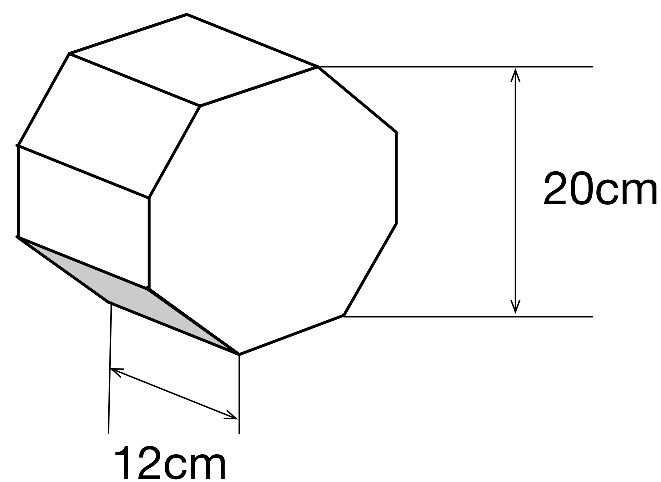
Device	Power consumption
Accelerometer X	25 mW
Accelerometer Y	25 mW
Accelerometer Z	25 mW
Pressure Sensor	7 mW
Thermistor	1 mW
DSP	750 mW
Embedded Processor	300 mW
Ethernet Switch	500 mW
Transceiver	900 mW
Transceiver	900 mW
Transceiver, in standby	0 mW
Transceiver, in standby	0 mW
Total	3,433 mW

- Sensors should be powered from the same voltage regulator as the fiber amplifiers
- Existing power supplies have proven reliability
- Available power is less than 5 W
- EDFA pump lasers are becoming more efficient, so this is a moving target for future systems

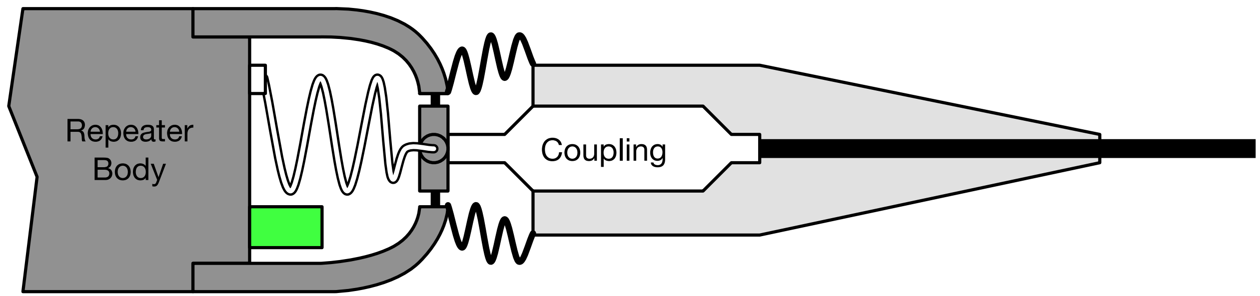
Mechanical Compatibility Issues

- Some repeater designs used stacked circuit boards, others are arranged radially
- 3,000 to 4,000 cm3 volume
- Heat sink to outside case
- Fiber routing
- Shock and vibration
- How to test during manufacturing and assembly
- Corona discharge
- Component selection
- Other proprietary design issues

Circuit board mechanical design will be manufacturer specific issue: it may be necessary to have multiple circuit board layouts in order to suit individual repeater designs

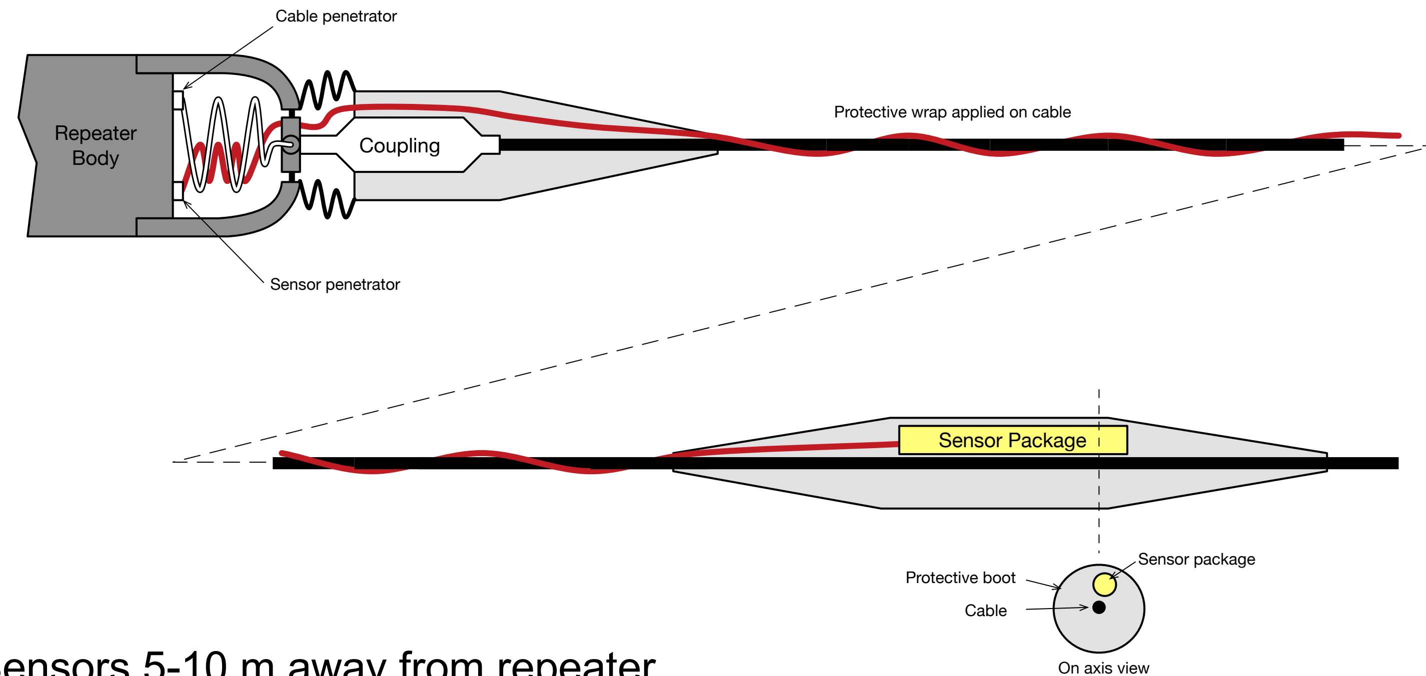


Sensor Mounting Option 1: End of Repeater



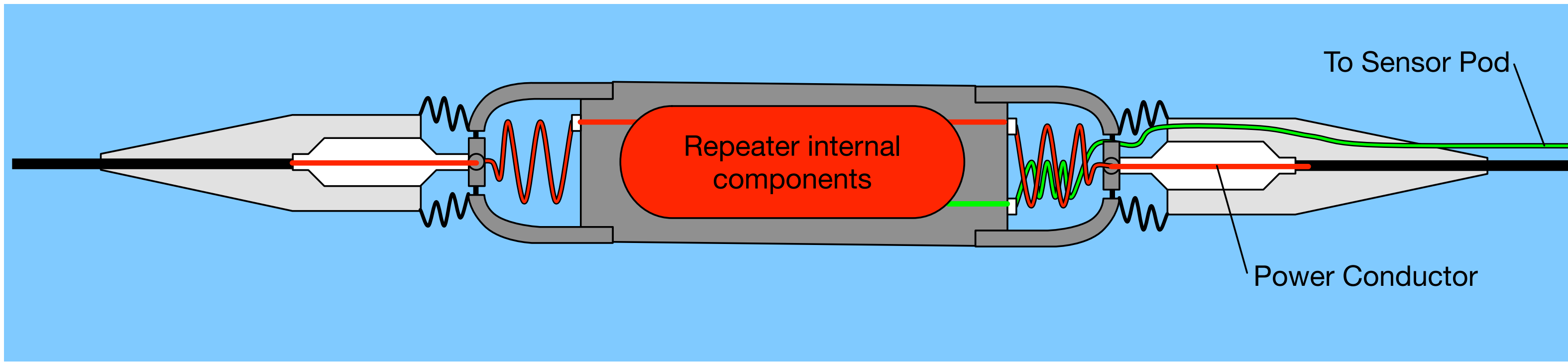
- Mechanically secure
- May require extension or modification of repeater end cone
- Impact of repeater heat loss on temperature measurements needs to be modelled
- Penetrator design needs to ensure failure of sensor housing does not impact repeater

Sensor Mounting Option 2: Pod on cable



- Sensors 5-10 m away from repeater
- Boot arrangement similar to new electrode designs used for Branching Units

Power Delivery Outside the Pressure Housing



- Cable center conductor carries constant current power feed (red lines). Voltage may be up to 10kV with respect to surrounding seawater
- Repeater is subjected to up to 70kV test during manufacture
- Internal components are directly connected to the power feed conductor (red area)
- Sensors connected to repeater (green line) must either withstand this voltage potential or be isolated from system supply voltage

Electrical Isolation Option 1: DC-DC Converter

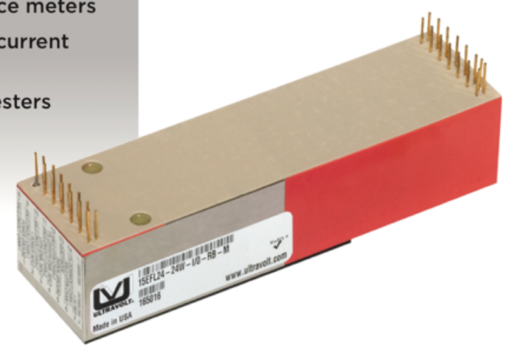
- Commercial product with 15kV isolation
- 3.3 to 5V, 12W, includes opto-isolators for data transmission

Features

- Precision analog control
- Linearity of ±0.05% and accuracy of ±0.2%
- 10ppm temperature coefficient
- Isolated up to 15 kV or 30 kV
- Isolation resistance of 150 GΩ (15 kV) or 2 GΩ (30 kV)
- 4 regulated floating LV power outputs
- Isolated digital and analog I/O to and from floating hot deck

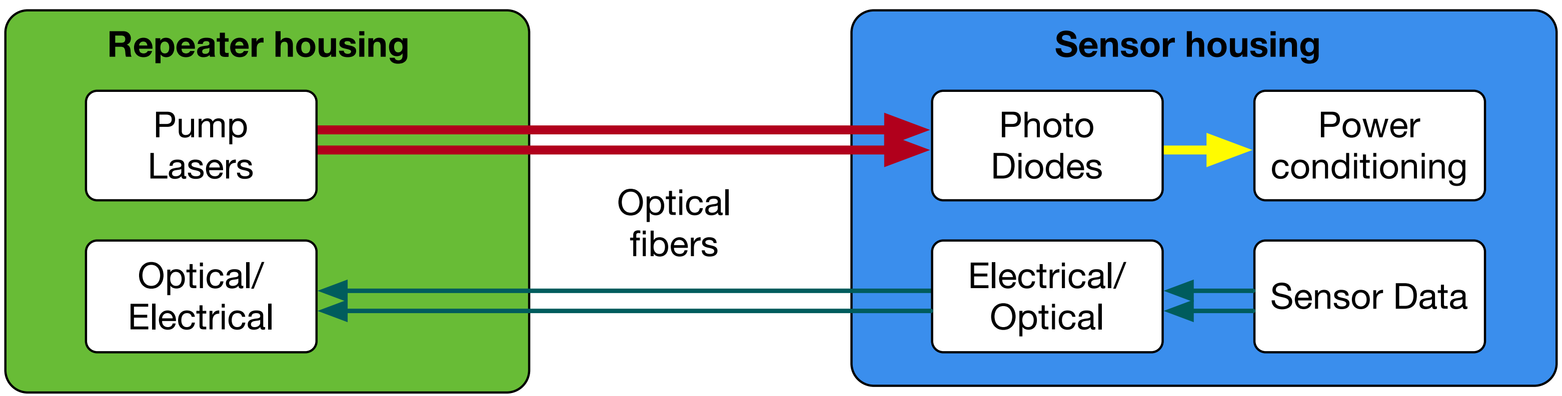
Typical Applications

- Floating/stacked ion or e-beam biases
- Floating filament bias
- Floating pulsers and gated grids
- Floating capacitance meters
- Floating high side current monitors
- Floating leakage testers



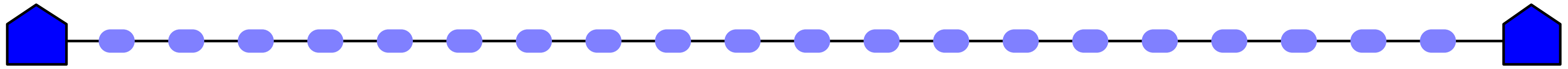
Electrical Isolation Options 2: Optical Fiber

- Pump laser output ~300mW (25 dBm)
- Photodiode 15% efficiency gives 45mW
- Separate fibers for power and signals
- Can easily meet voltage isolation requirements
- Can possibly use existing penetrator designs

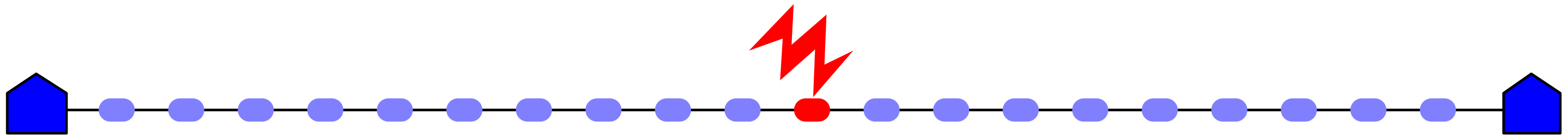


Impact of a Failure

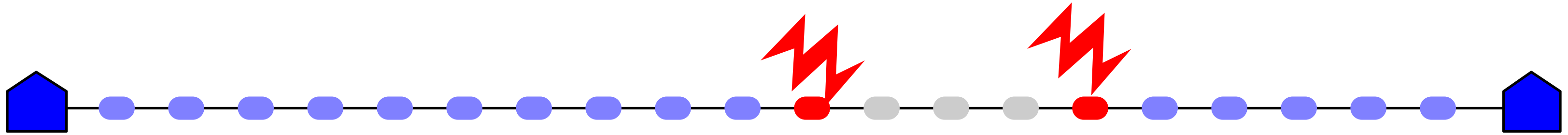
A normal, working system



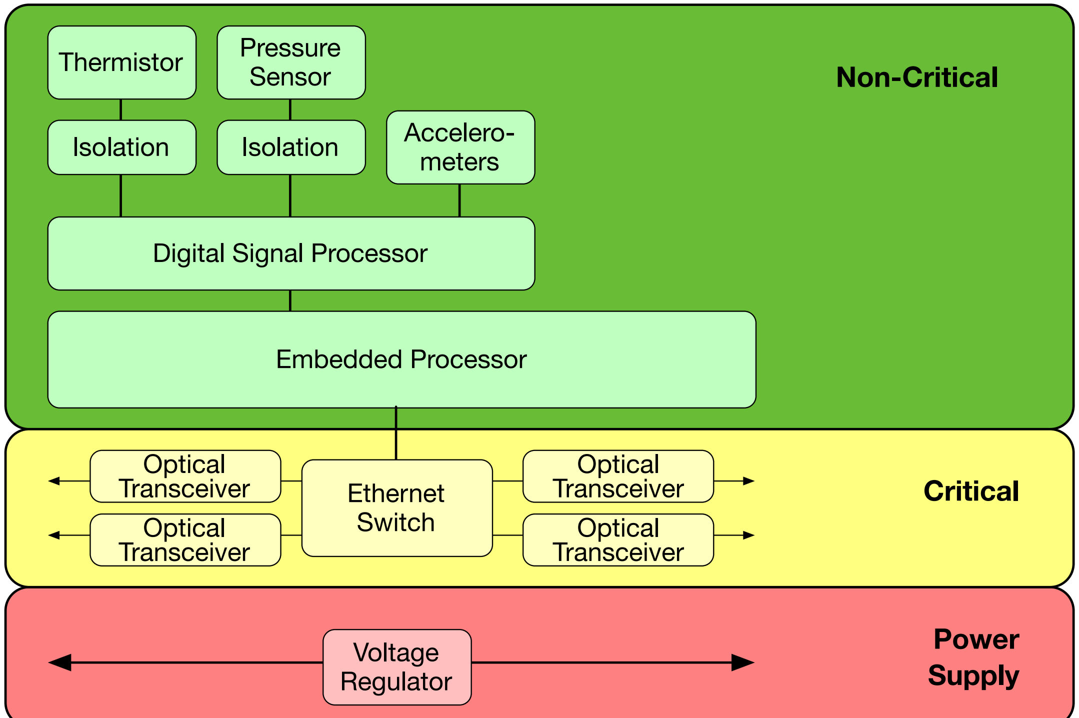
One Failure: All other units can connect to shore



Second Failure: Multiple working units may be isolated



Reliability Requirements



- Non-critical component failure results in loss of data from one location
- Critical component failure could impact data from other locations
- Power supply failure impacts telecom transmission

Reliability Calculations

Failures in Time (Failures in one billion hours)	FITS
Failure rate	r = FITS / 1E9 hours
Operating time	t = hours
Cumulative failure probability of one unit	P = 1 – exp(-r*t)
Probability N units in series operate without failure	S0 = (1-P)^N
Probability of exactly one failure in N units (binomial distribution with x = 1)	S1 = N • P • (1-P)^(N-1)
Success = Probability of no more than one failure	S = S0 + S1
If units are redundant	P1 = P^2

- Reliability goal is ten years of operation, assuming new cables will be installed over that time
- Assuming 50 repeaters in series, critical components must have <50 FITS to ensure 95% probability of no more than one failure in ten years
- With duplication, critical components can have 400 FITS and still reach 95% chance of success

Summary of Challenges

1	Data Communications Channel	Multiple options available
2	Power Consumption Limits	Achievable with careful component selection
3	Mechanical Compatibility	Relies on each manufacturer
4	Exterior Mounting	Two options available
5	Power to External Sensors	Two possible methods
6	Reliability	Depends on component availability

Summary and Conclusions

- Design issues relating to sensor integration have been identified
- Initial set of solutions is proposed
- Further refinement requires industry collaboration
- Reliability is an area requiring further study

https://www.itu.int/en/ITU-T/climatechange/task-force-sc/Pages/default.aspx