SENSORS 2015

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Session: O4

Fiber Optic Position Sensors: Applications & Lessons Learned

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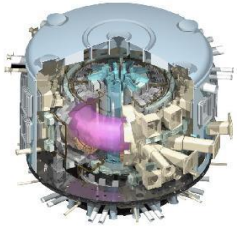
Motivation for using Fiber Optic Sensors

- Passive optical design
- Immune to EMI and RFI
- Immune to Lightning and Atmospheric Static
- Immune to High Magnetic Fields
- Transparent to Magnetic Fields (MRI, SQUID, Radar)
- No Ground Loops
- Outdistances copper – links up to 4000 meters and more.
- Inherently Safe (no sparks)
- Immune to Radiation
  - Special engineered versions have been supplied for radiation environments
  - Gamma, Neutron, Electron Beam and X-ray
- Wide Temperature Range : -60°C to +150°C
  - Micronor has realized application working at **cryogenic** temperature (-273°C)
  - Temperatures in excess of +250°C are possible

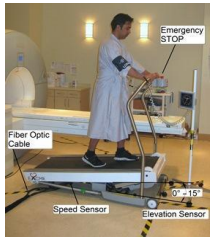
Fiber Optic Sensors & Applications


Grain Elevator


Nuclear-Projects


Power Generator


Oil Drilling



Medical (MRI)


Welding Equipment


Locks for Shipping


Food Processing Temperature


Rail Infrastructure

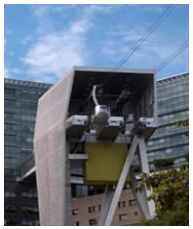

High-Voltage


Crane-Infrastructure


Military


Aerospace Research


Gas Generators

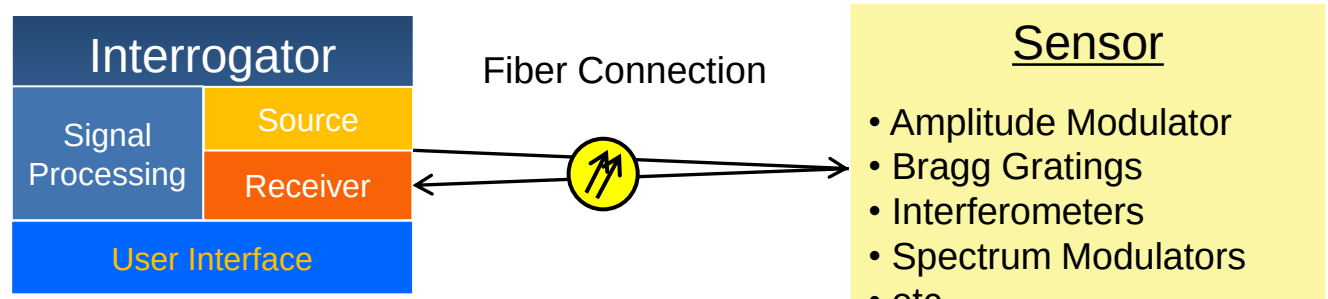

Cable Tram


Mining

Principle of Fiber Optic Sensors

"Remote sensing and measuring of a physical quantity using photonics for both sensing and transmission."

Since most Fiber Optic Sensors are not of transducer(1) type they require an interrogator.

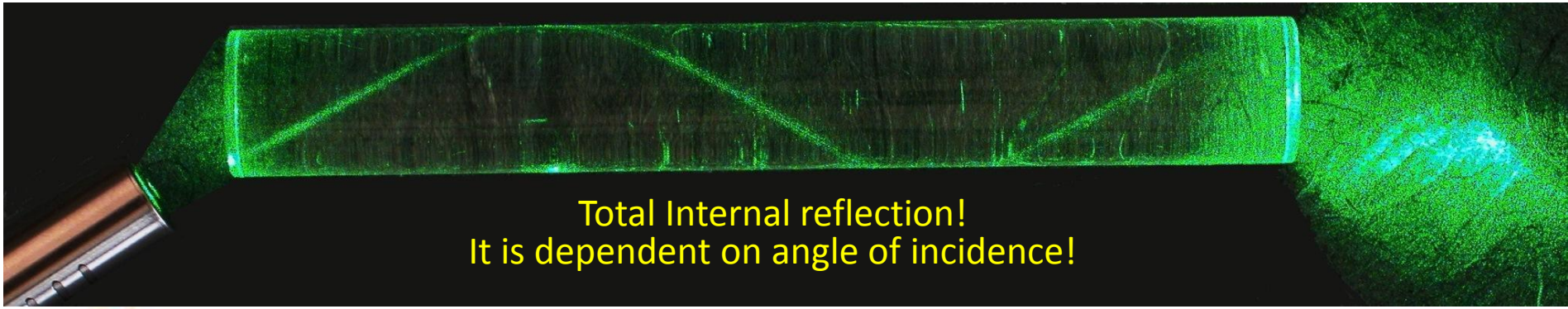


➡ Non Electric – No Interference

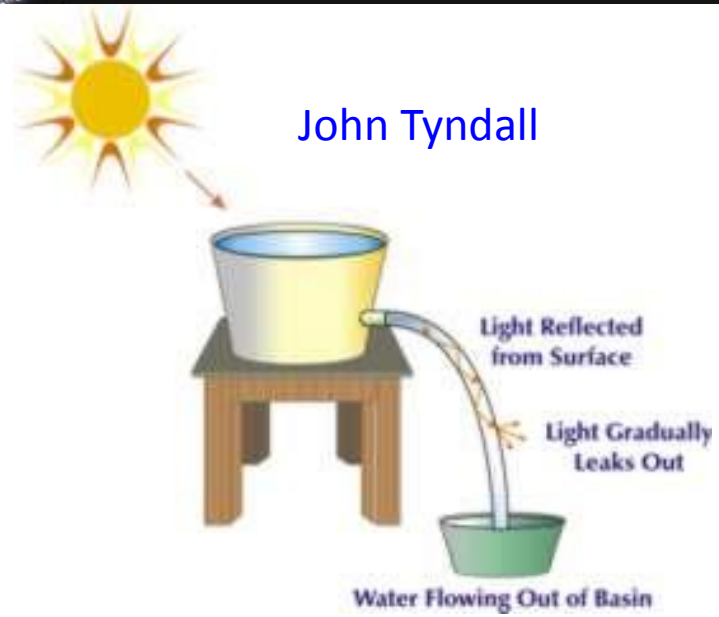
Review: Types of Fiber Optic Sensors

- Amplitude Modulators
  - External attenuation, MEMS based microphones, accelerometers.
  - Difficult to calibrate because light is not stable in optical fiber. Only good for relative and temporal measurements – such as a microphone.
- Interferometers
  - Changes spectral behavior of the light passing through the sensor.
  - Strain sensors, gyroscopes (Sagnac effect) , sonar, nanometer sensitivity and accuracy.
  - Are generally very sensitive and very accurate but use expensive and complicated interrogators.
- Speckle Disturbance
  - Security systems. Very sensitive but can only detect disturbances with minimal indication of magnitude of disturbance. Cannot be calibrated for absolute measurements.
- Time of Flight
  - Measures the time of flight within the optical fiber. Generally used within long-haul applications. Applications are strain measurement, security fences. Point of breakage.
- Electro Luminescence (Time Measurement)
  - Decay time of Photo Luminescence is a function of temperature. It is a time measurement and generally accurate and reliable. Used for temperature measurements.
- Spectral Modulation
  - The sensor modulates the spectrum of a broadband light source. Temperature measurement (InGaAs bandgap is a function of temperature). Position Measurement MICRONOR Inc. absolute encoder.
- Polarization Modulators (Faraday effect)
  - The electromagnetic field changes the polarization of light. The change is a function of the field strength. Used in current measurements for power plants.

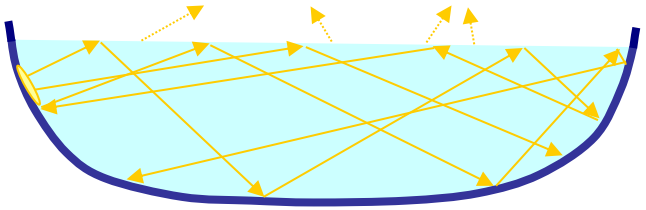
Fiber Optic Waveguide



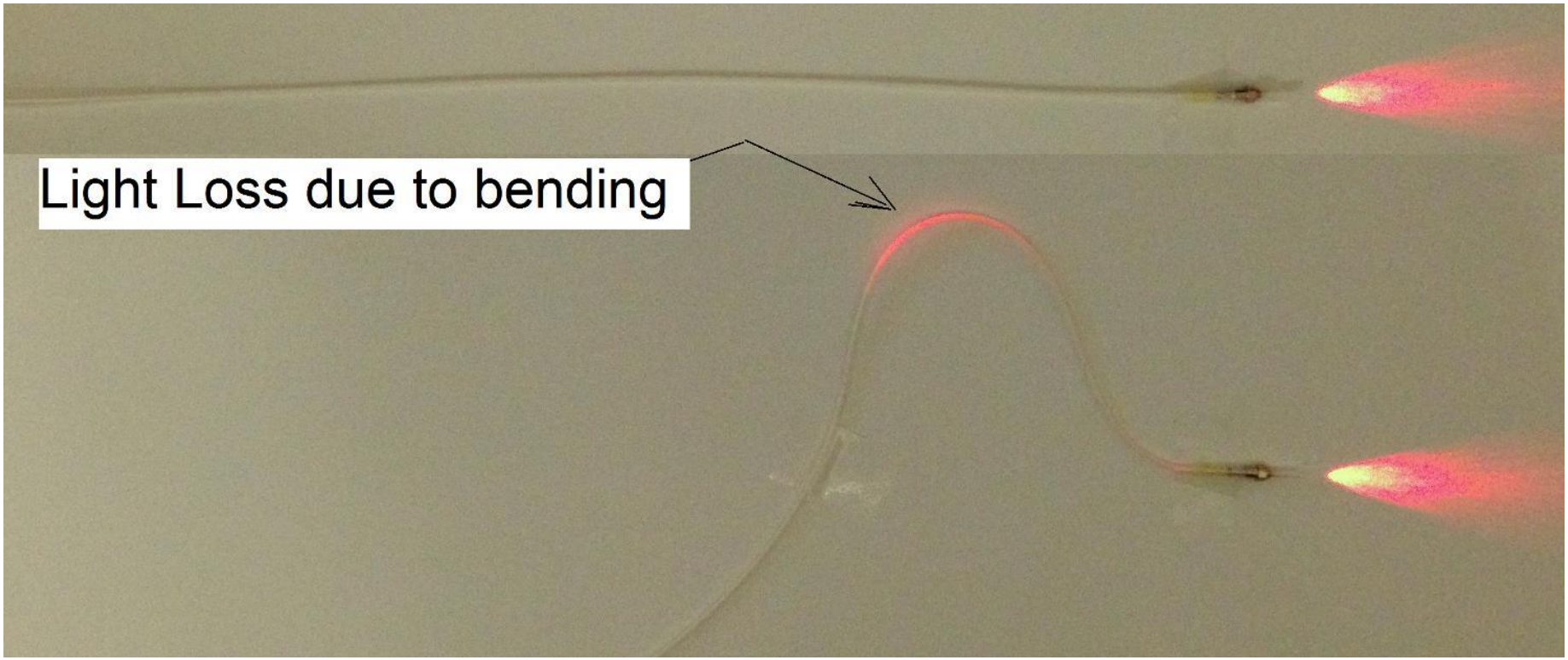
John Tyndall



Swimming Pool

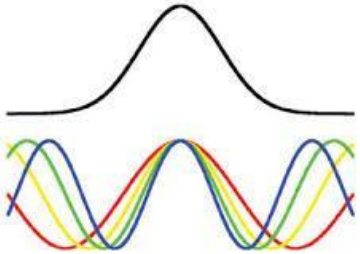


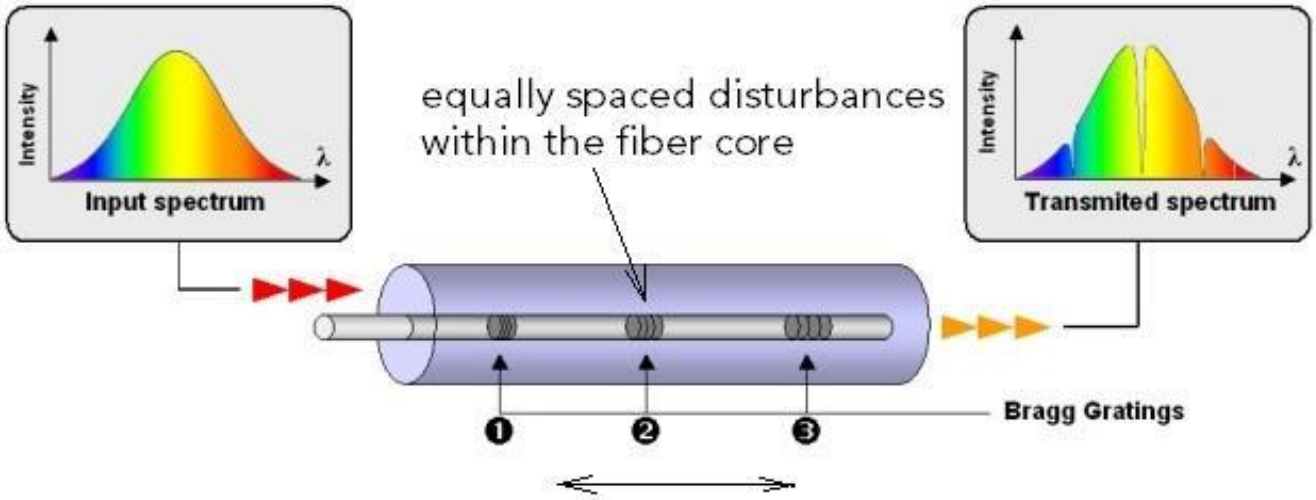
Amplitude in Fiber Optics is not stable



Wave Interference Sensors

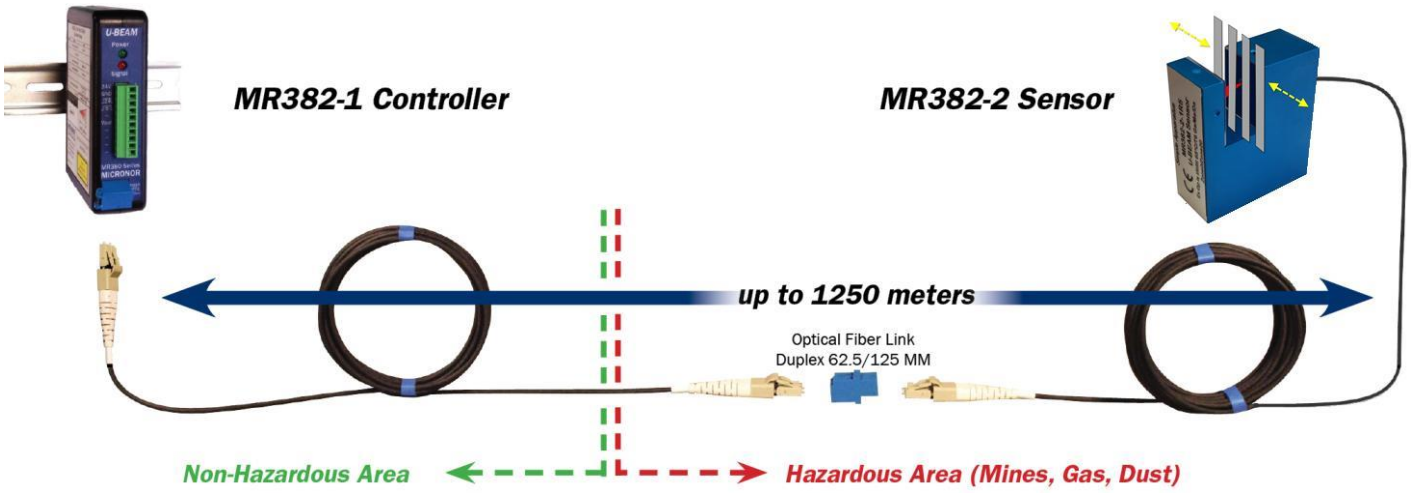
- Optical waveforms are allowed to interfere.
  - Achieve super high resolution in the nanometer range
  - Sometimes too sensitive.
  - Uses complex (expensive) optics





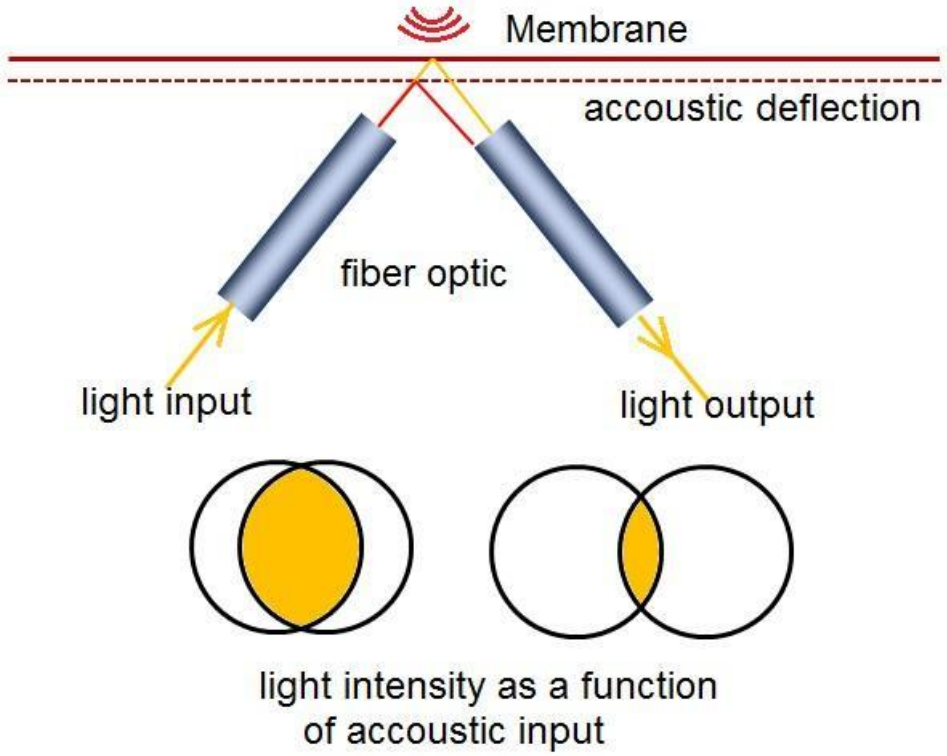
Example 1: Amplitude Modulator

- U-Beam Sensors
  -> light throughput (On-OFF)

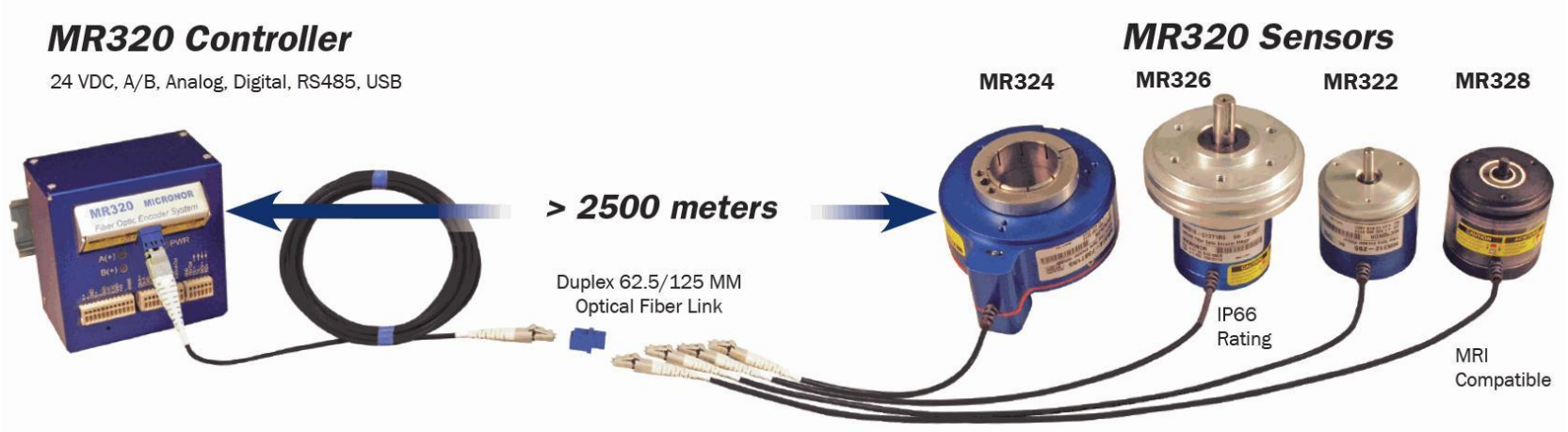


Example 2: Amplitude Modulator

- External attenuation, MEMS based microphones, accelerometers.
- Only useful when no absolute reference is required.
- MEMS based microphones and accelerometers



Rotary Incremental Sensor

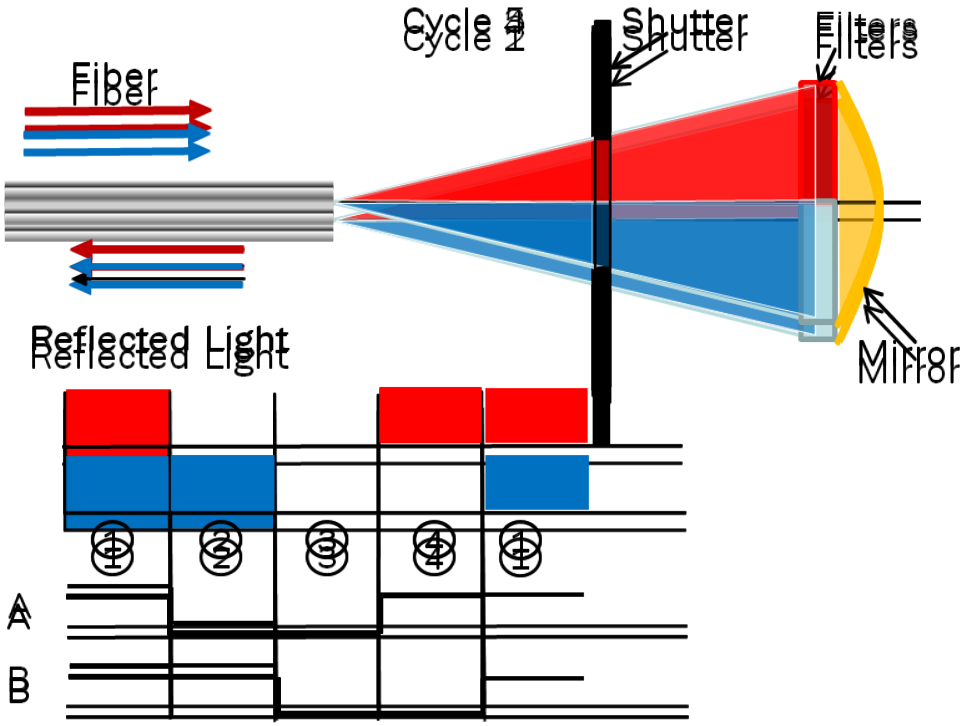


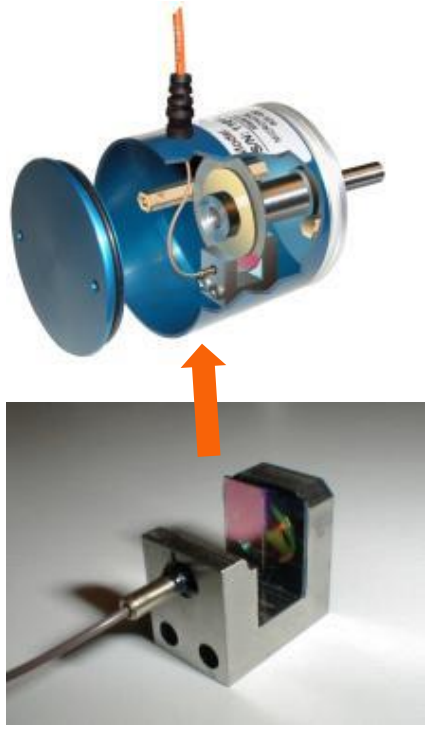
- Passive optical sensor design
- Resolution up to 1024 pulses per revolution (ppr)
- Immune to EMI, RFI, lightning and atmospheric discharge
- Outdistances copper – links to 2500 meters and more
- Intrinsically Safe
- Non-metallic MRI Safe model available
- Wide Temperature Range : -60°C to +150°C

US Patent 7,196,320

Rotary Incremental Sensor

Optical signals at two distinct separate wavelengths sense the direction of a moving graduated disk. The two phase shifted signals provide directional information.

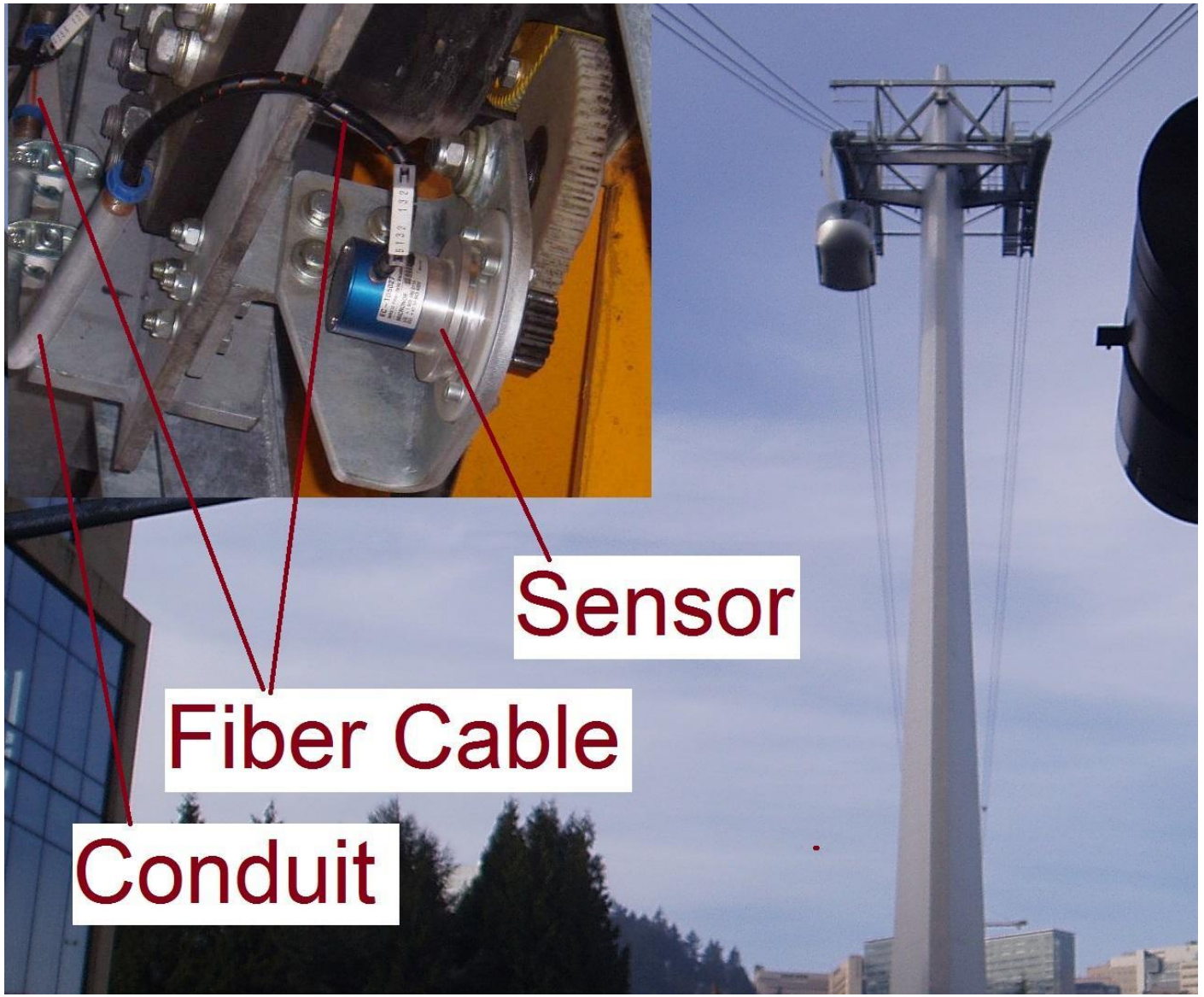




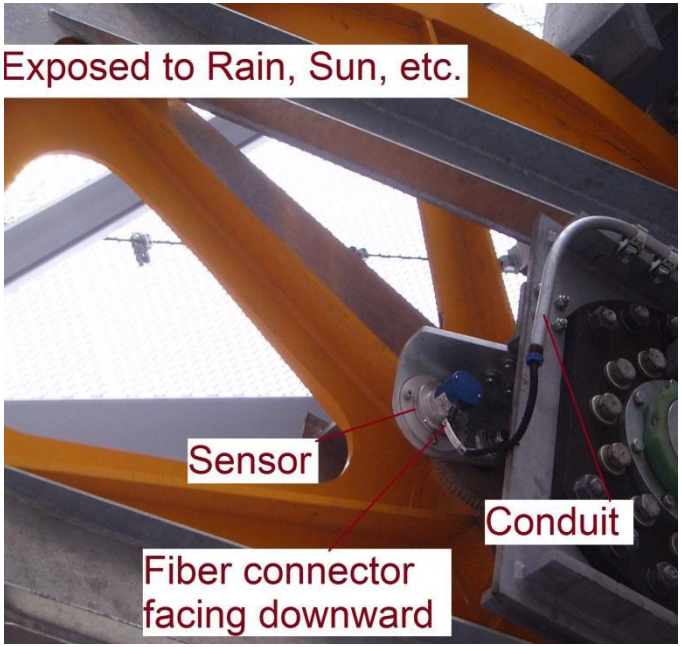
Rotary Incremental Sensor

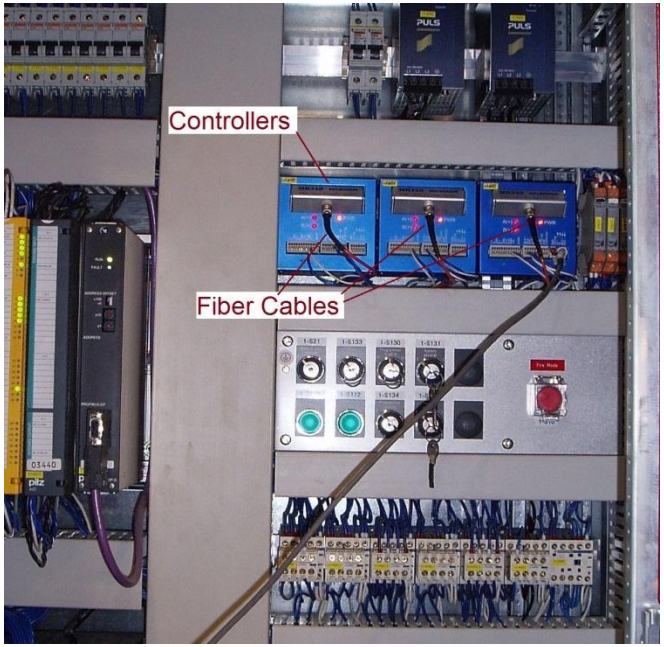
- Application – Cable Tram Movement Sensor
- Motivation:
  - Immunity from Lightening Strikes
  - Ground Loops
- Deployment challenges:
  - Outdoors, Wide Temperature Range IP Protection
  - Multiple Cable Segments
  - Installation Personnel has minimal Fiber Optic expertise

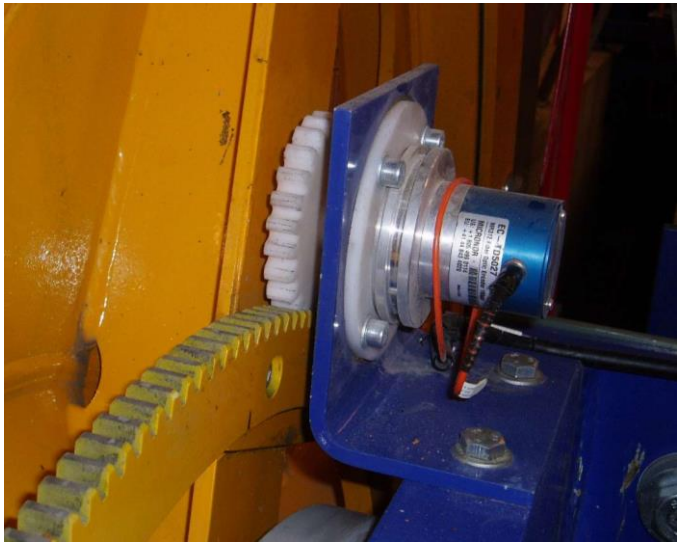
- Solution:
  - Sensor is robust designed. IP67 protection, -40°C to +85°C
  - Fiber Optic Connector is Water Sealed
  - Controller has self calibrating functions compensating for changes in fiber loss.


Sensor
Fiber Cable
Conduit

Fiber Optic Sensors & Applications



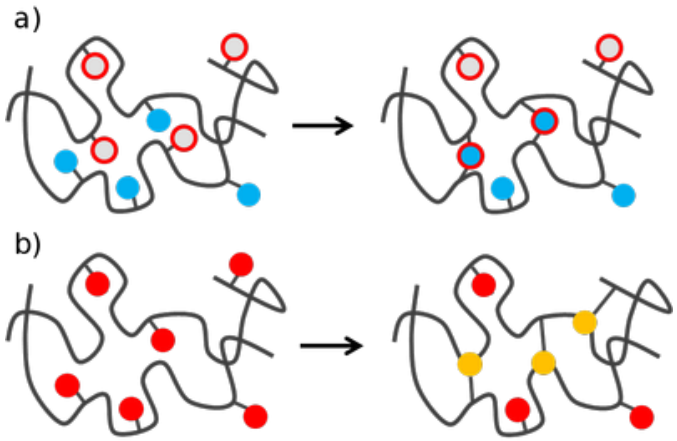




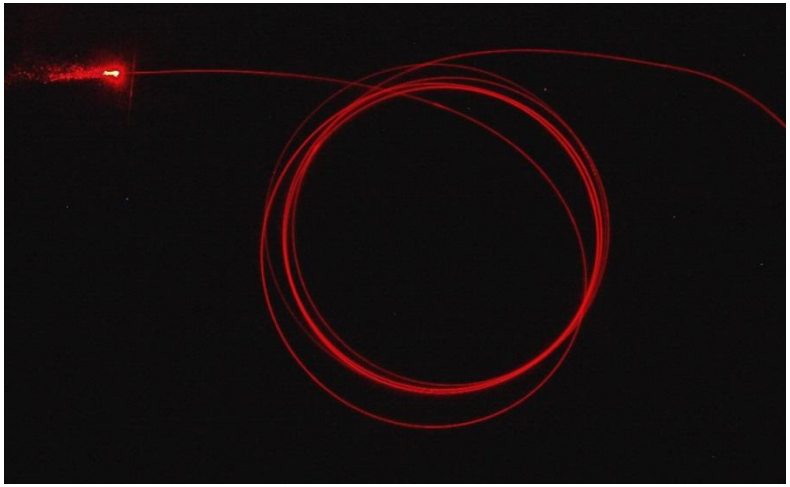
Rotary Incremental Sensor

- Application – High Energy Electron Beam
  - Polymer Cross Linking increases material strength
- Motivation:
  - Immunity to extreme high electron beam fields. Electronics does not survive.
- Deployment challenges:
  - No known knowledge on fiber optic performance
  - Within protected “Concrete Bunker”
  - Most Materials do not hold up
  - Very dusty environment
- Solution:
  - Conducted Actual Test by irradiating optical fibers
  - Used special Radiation resistant fibers and built custom cable.
  - Designed special cabling scheme.
  - Used robust dust sealed sensor encoder

Polymer Cross Linking



Radiation is a Harsh Environment !!!

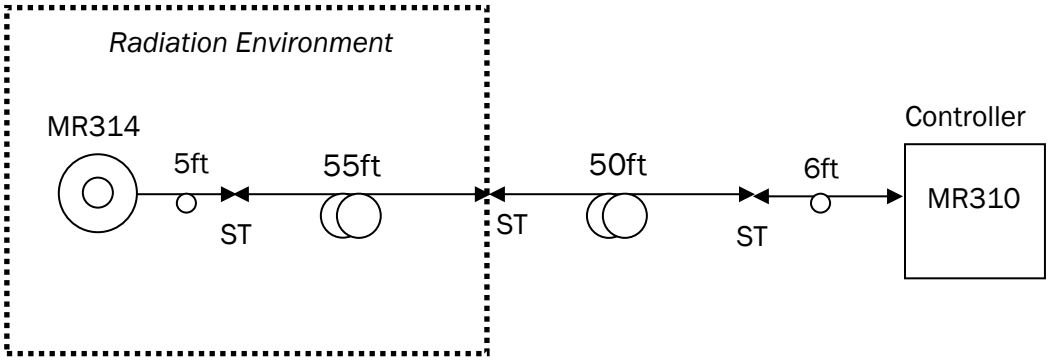


Solarization Resistant Fiber after 75MRAD exposure.

Fiber was replaced with a pure silica glass step index design.
Connectors were protected with lead.

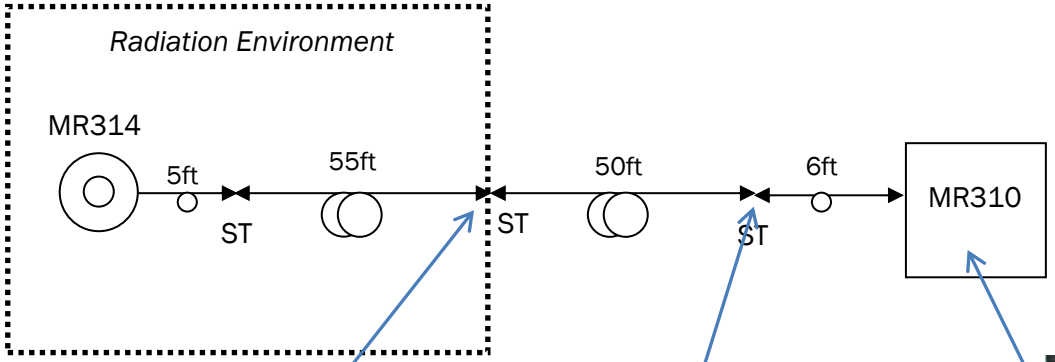
ST Fiber Connector after 1 year in operation

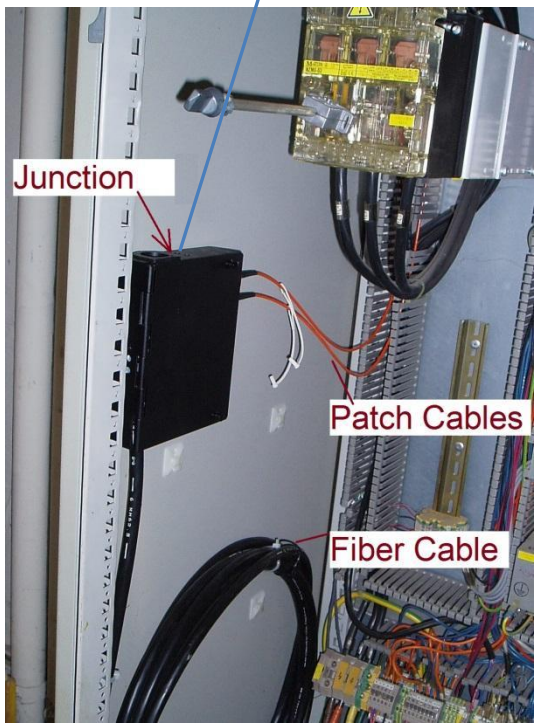
Planning the Fiber Link

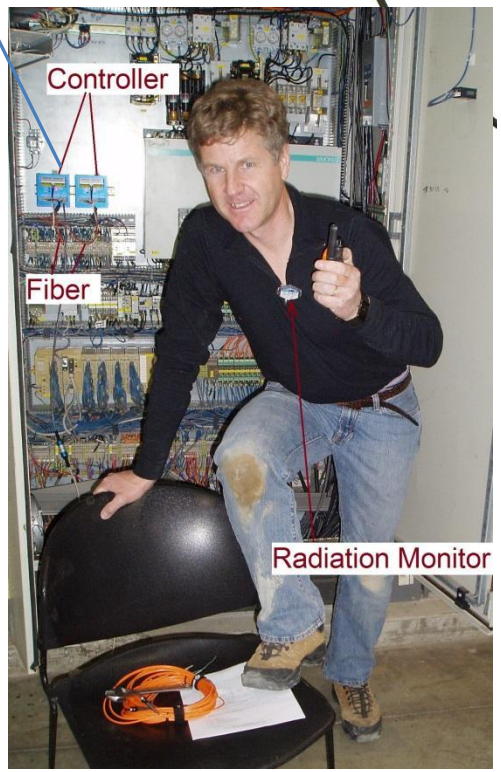


	Specified Losses in dB			
	Typ.	Max.	Typ. x2	Max. x2
Encoder (1x only)			4.5dB	5.5dB
Connector #1	0.25dB	0.5dB	0.5dB	1.0dB
Cable (55ft / 17m) Radiation resistant	1.0dB	1.5dB	2.0dB	3.0dB
Connector #2	0.25dB	0.5dB	0.5dB	1.0dB
Cable 50ft /16m 3.5dB/km	0.06dB	0.07dB	0.12dB	0.14dB
Connector #3	0.25dB	0.5dB	0.5dB	1.0dB
Total Losses			8.12dB	11.64dB
Controller Dynamic Range			13dB	13dB
System Margin			4.88dB	1.36dB

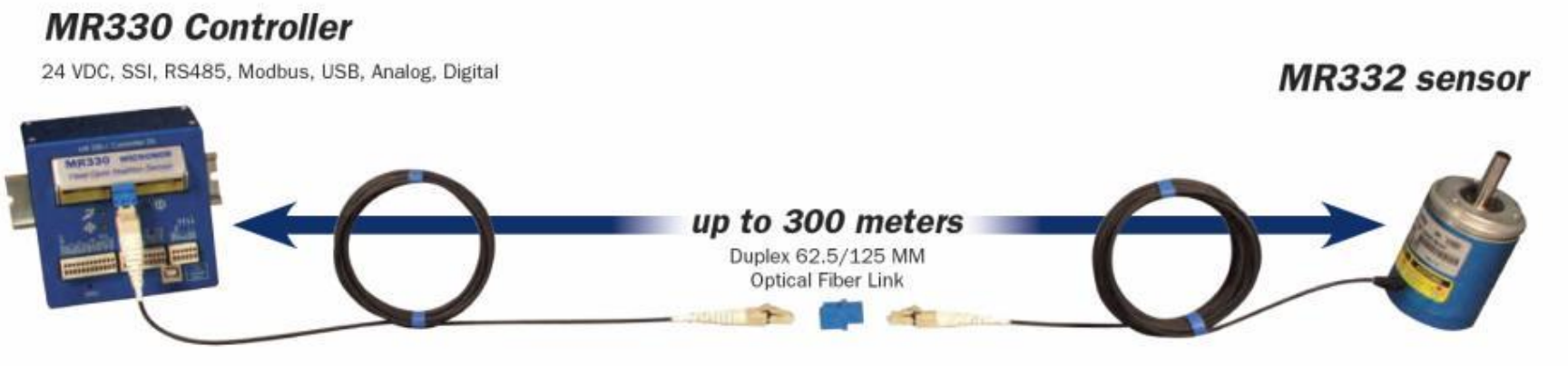
Fiber Optic Sensors & Applications







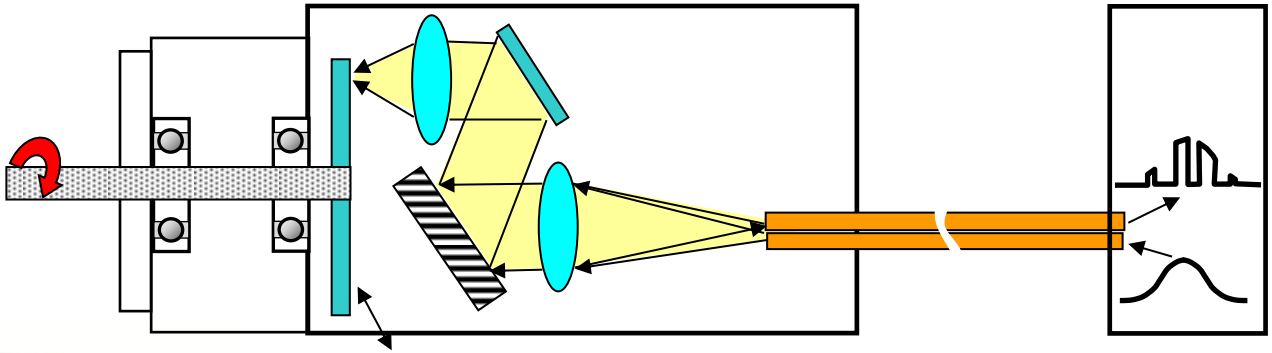
Absolute Position Sensor



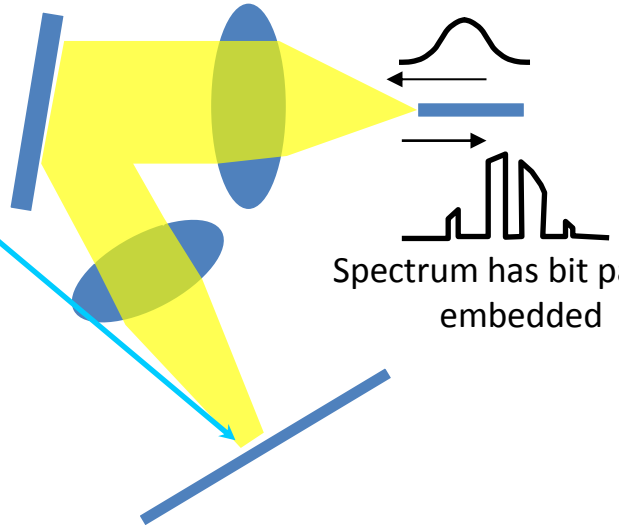
- Passive optical design
- Absolute angular position over 0-360° with 14-bit resolution (0.025°)
- Immune to EMI, RFI, lightning and atmospheric discharge
- Outdistances copper – links up to 300 meters
- Intrinsically Safe
- Non-metallic MRI Safe model available
- Wide Temperature Range: -60°C to +80°C

US Patent 8,461,514 B1

Principle: Spectral Modulation



Linear Spectral distribution
of light on the sensor disk

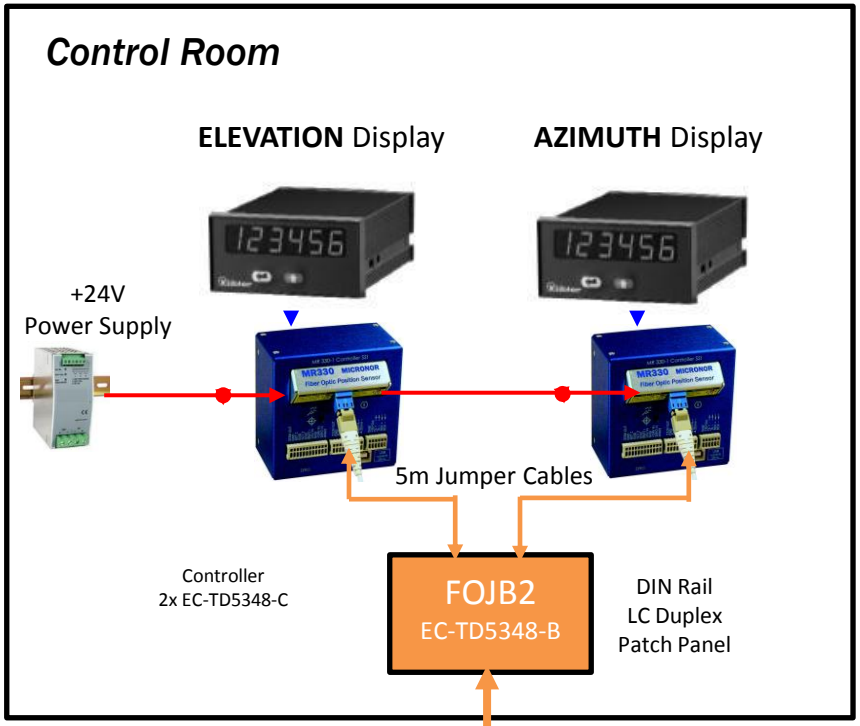


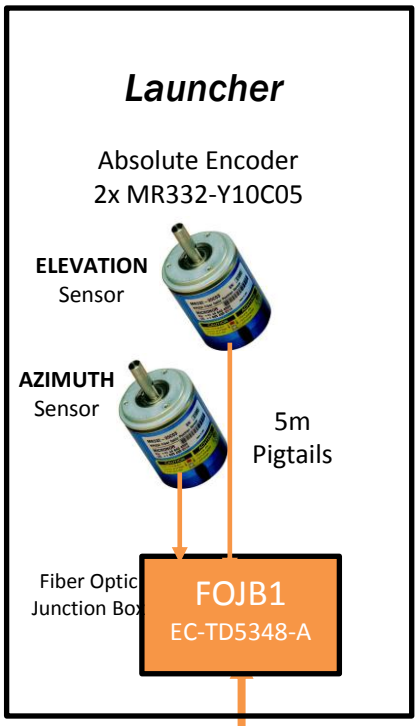
Spectrum has bit pattern
embedded

Rotary Absolute Sensor

- Application – Launcher Position Display System (NASA/Orbital Sciences)
  - accurately display both the Elevation and Azimuth of the launcher.
- Motivation:
  - Immunity to external interferences, avoid ground loops. Link length is 500 feet.
- Deployment challenges:
  - Outside exposed to environment
  - Mobile installation
- Solution:
  - Micronor MR330 Absolute Position sensor with 0.025° resolution.
  - Using SSI compatible Display units

Fiber Optic Sensors & Applications





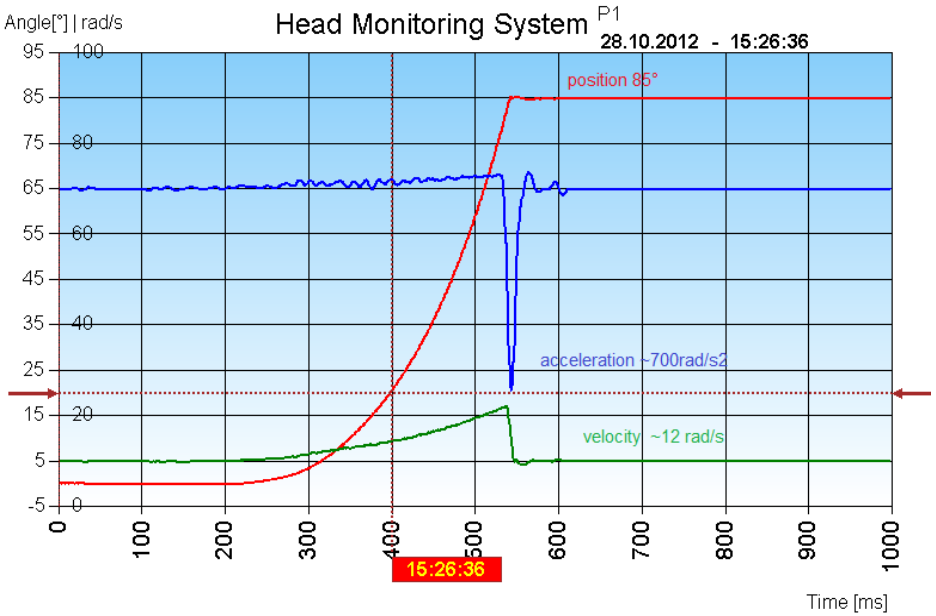
500 ft

Fiber Optic Jumper Cables
MMF OM1 62.5/124 Duplex Cable With
Standard Duplex LC Plug (Non-Environmental)

OCC Terminated Cable Assembly (est 500 ft)
OCC B-008CWLS5KMF9 MilTac FRP B.O. Cable
8C Cable allows for 2 LC Duplex Spares

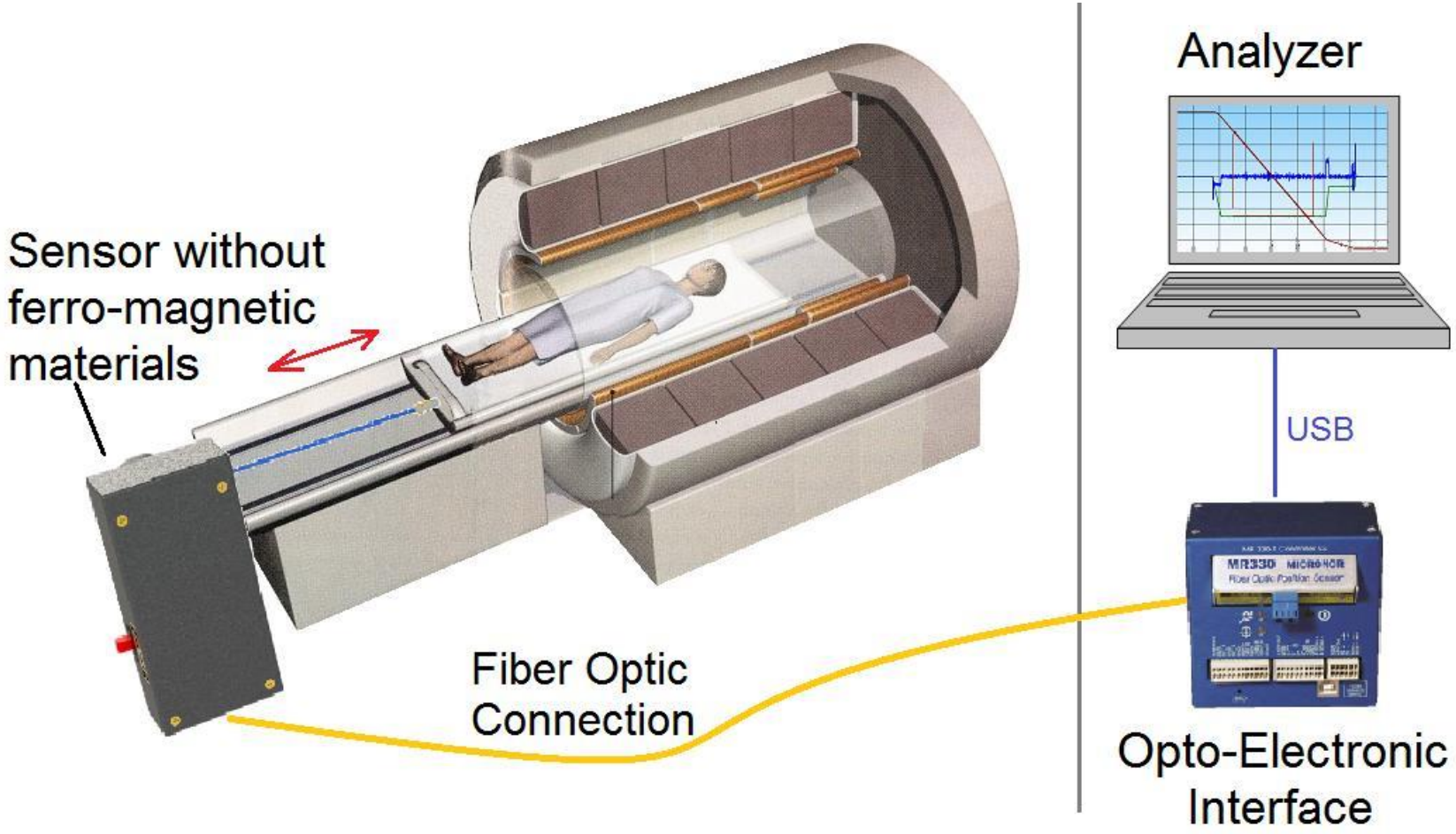
Cine Tagged Magnetic Resonance Imaging

Sensor Operates in a High Magnetic Field
Controller measures position every 850µs
Speed and acceleration is derived from the positional information.

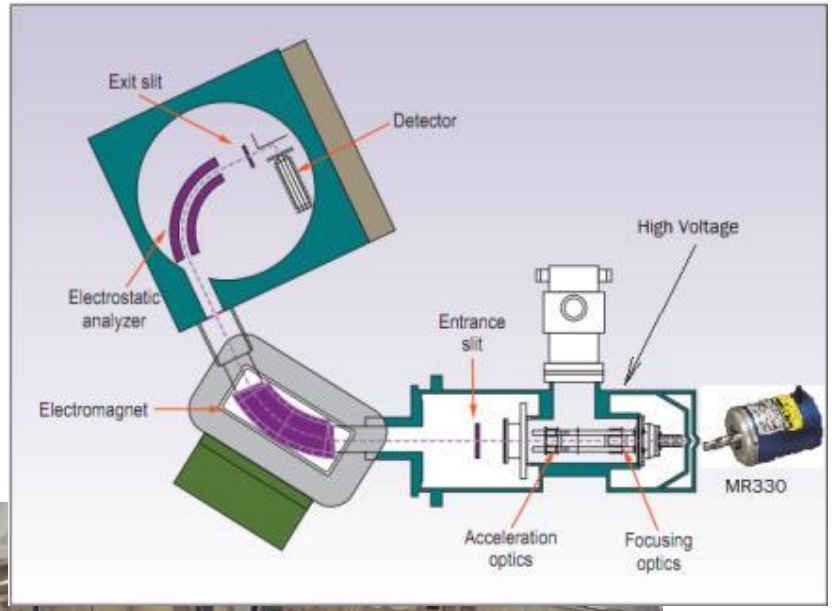


Micronor delivers complete system including the software.

System for Analyzing Movement of Patient Cradle



Mass Spectrometer



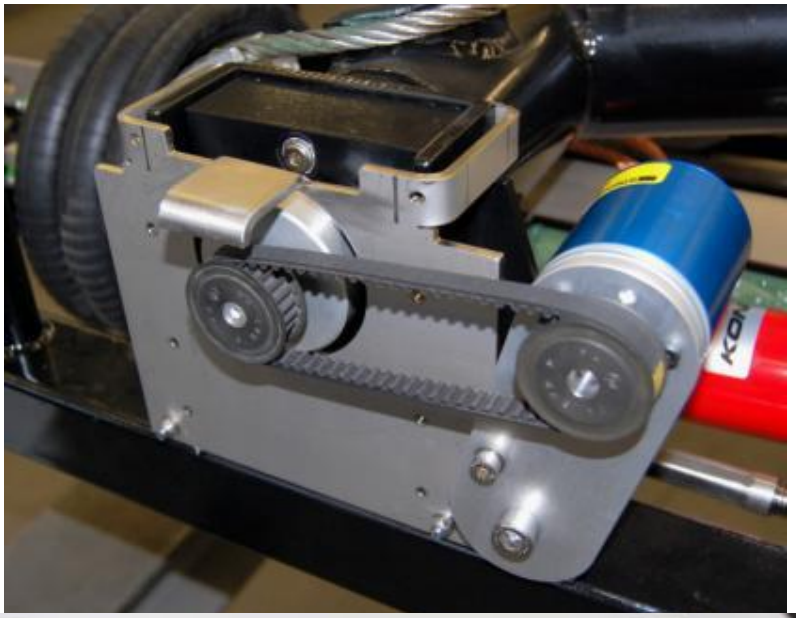
Position Sensor is used to adjust focus and direction of particle beam.

The sensor resides at ~30kV potential with the fiber bringing the position signal to normal ground voltage potential.

Fiber Optic Sensor eliminates complicated electrical isolation amplifiers.

Sensor Controller seamlessly integrates to system via Modbus interface

Pantograph Position Sensor



Marine Application
Dredge Depth Measurement

MR326 Encoder measures length of cable pay-out.
MR320 Controller adapted to Marine NMEA standard

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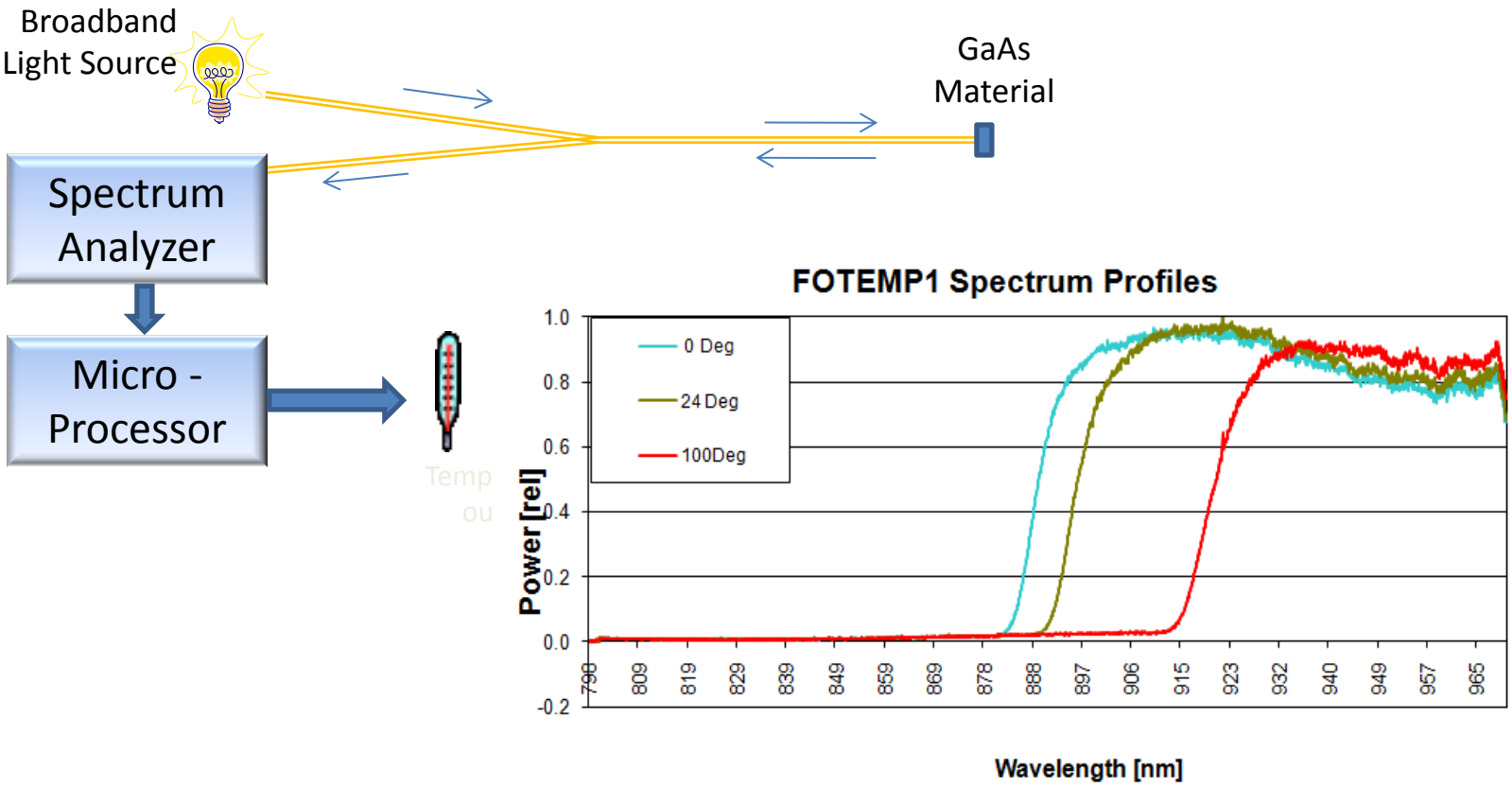
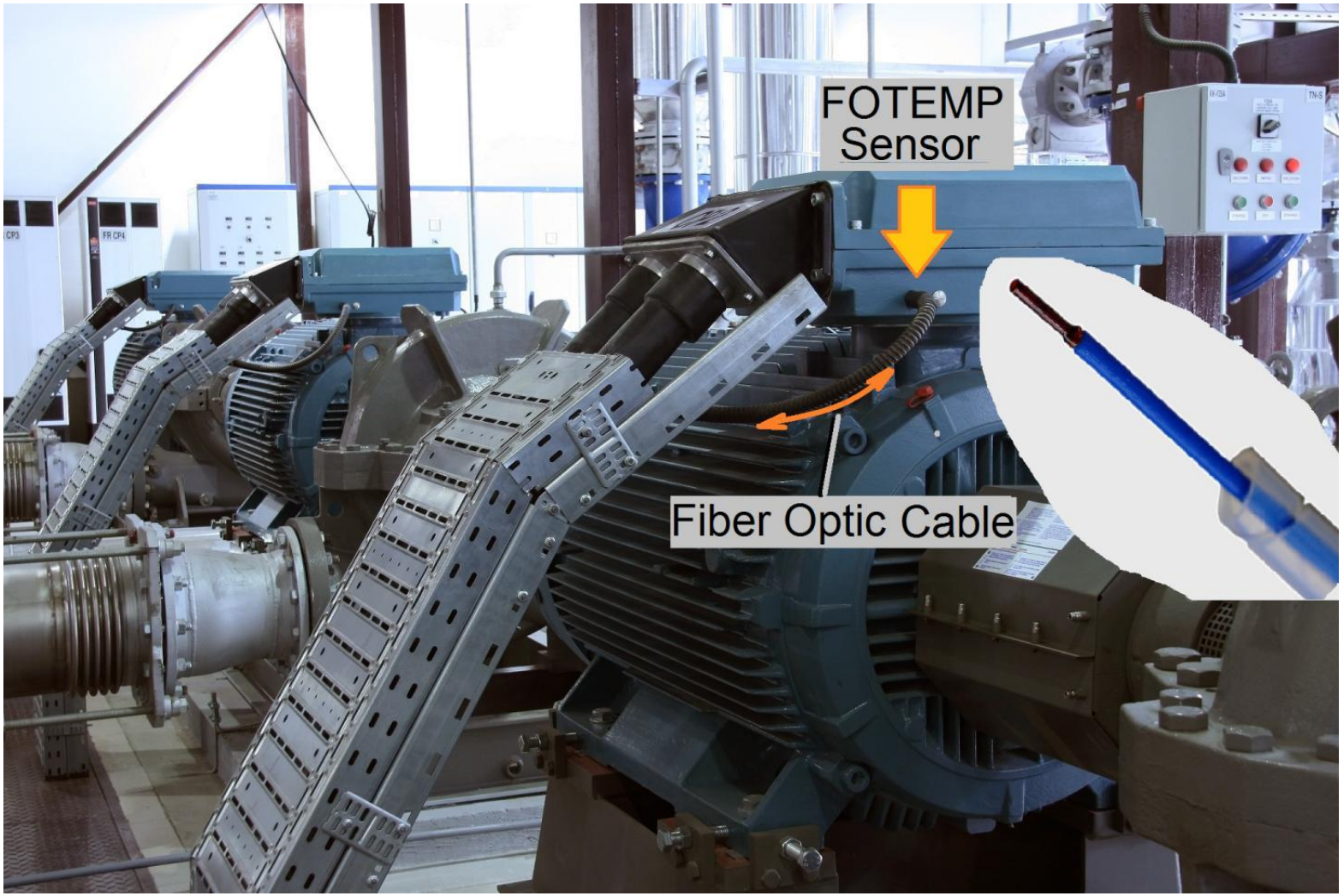
Spectral Modulation Temperature Sensor

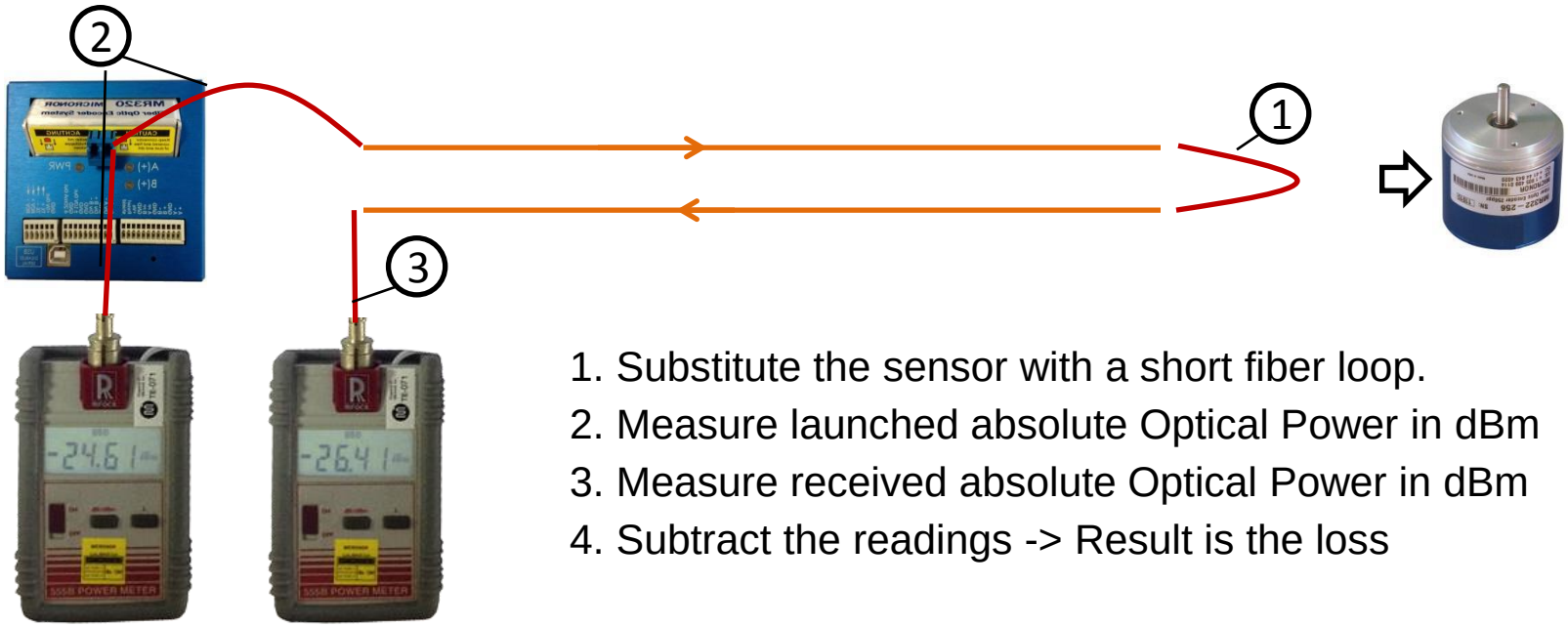


Temperature Sensor System

Motor Temperature Sensing



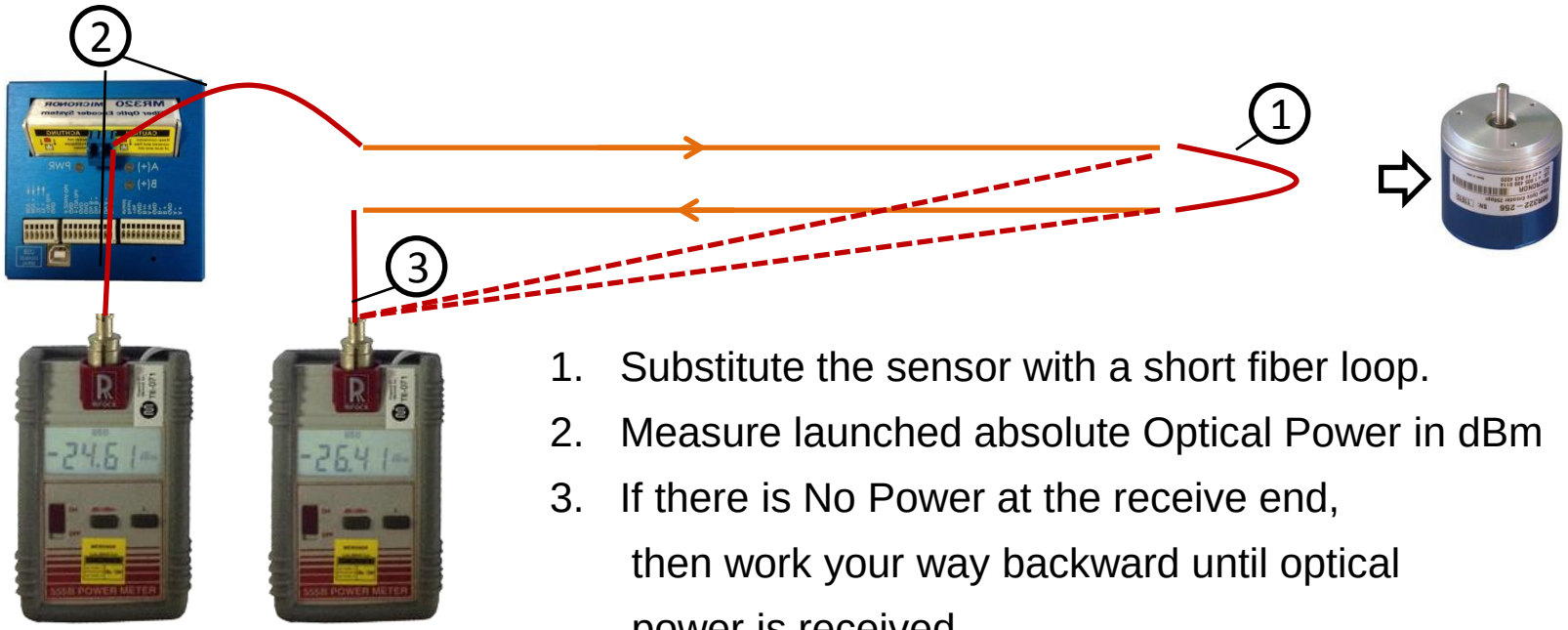
Measuring Loss of a Fiber Optic Link used for Sensors



1. Substitute the sensor with a short fiber loop.
2. Measure launched absolute Optical Power in dBm
3. Measure received absolute Optical Power in dBm
4. Subtract the readings -> Result is the loss

Launched Power:	-24.61dBm
Received Power:	-26.41dBm
Link Loss:	1.80dB

Trouble Shooting a Fiber Optic Link used for Sensors

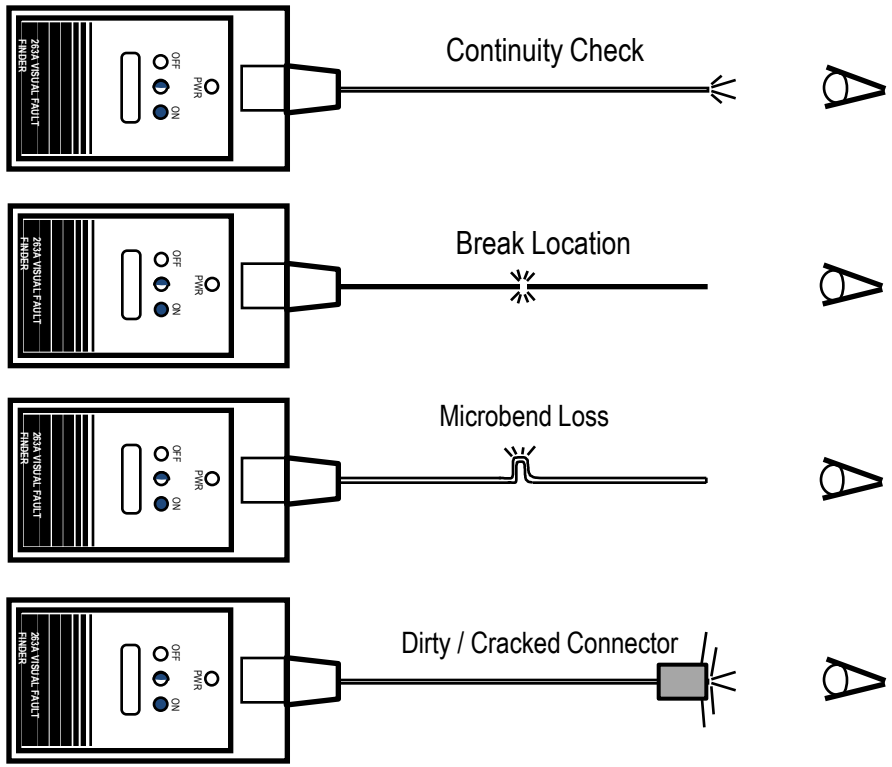


1. Substitute the sensor with a short fiber loop.
2. Measure launched absolute Optical Power in dBm
3. If there is No Power at the receive end, then work your way backward until optical power is received.
4. Determine which connector end is the problem.

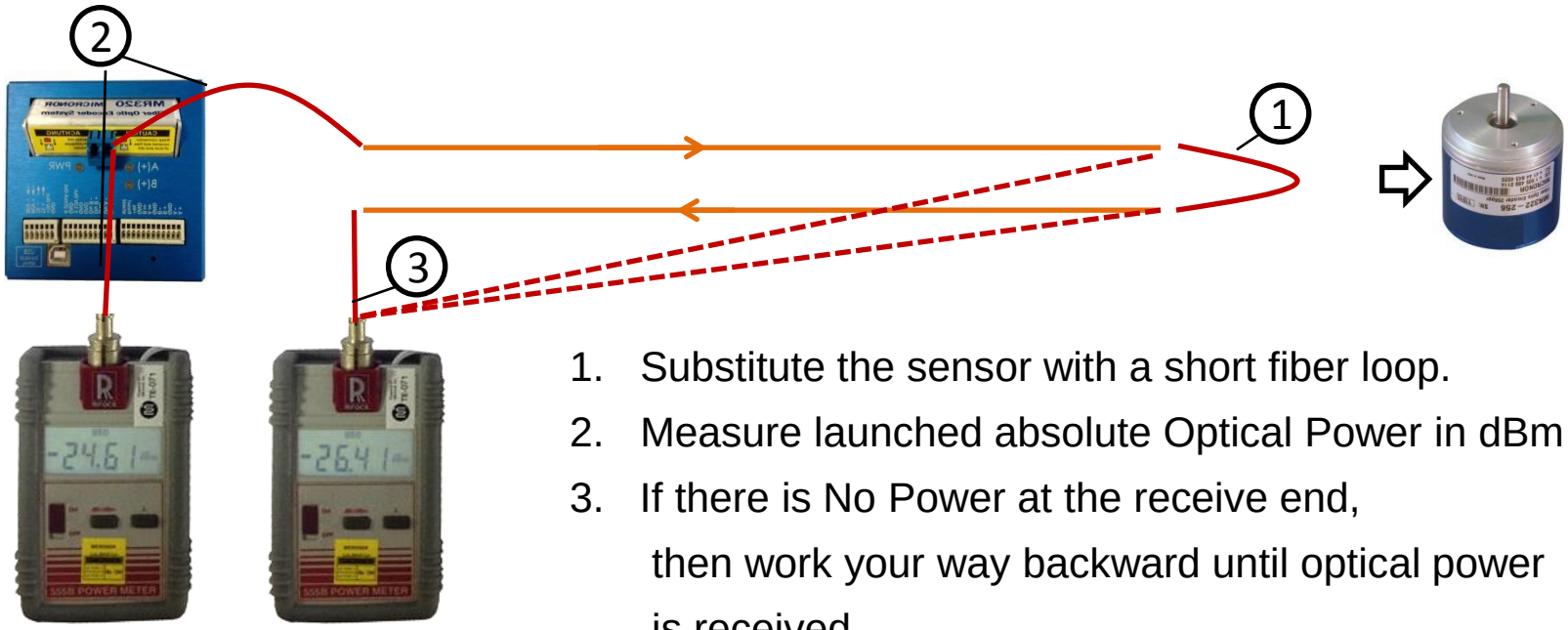
How To Visually Locate Faults

Simple to use! A Visual Fault Finder (VFF) launches visible red laser light into fiber.

May not work with armored multi-fiber cables due to jacket material and/or jacket thickness.



Trouble Shooting a Fiber Optic Link used for Sensors

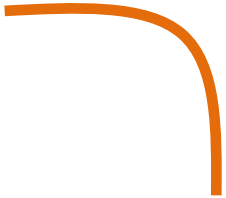


1. Substitute the sensor with a short fiber loop.
2. Measure launched absolute Optical Power in dBm
3. If there is No Power at the receive end,
   then work your way backward until optical power is received.
4. Determine which connector end is the problem.

Repairing Fiber Optic links

1. Generally it is easiest to replace defective Cables / Connectors.
2. Broken Connectors can be re-terminated in the field.
   - There is a learning curve - use trained personnel
   - Hire local specialized fiber services. They typically can come out within a day or so.
3. Broken cables. That very rarely happens!
   - Fusion Splicing -> requires equipment and trained personnel
   - Replacement is the best option.
4. Defective Sensors are usually NOT field repairable.

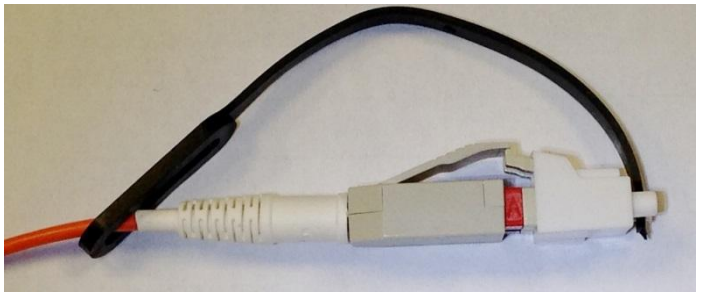
Doe's & Don'ts



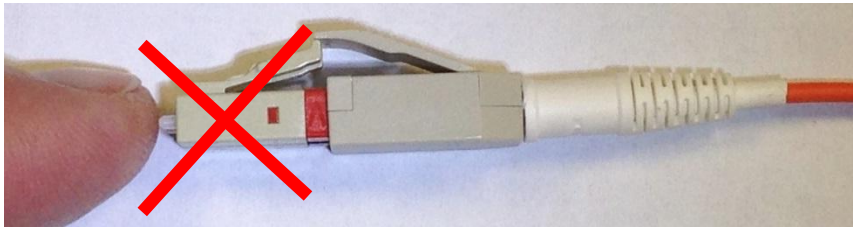
No kinks or sharp edges

Use Velcro straps
not cable ties

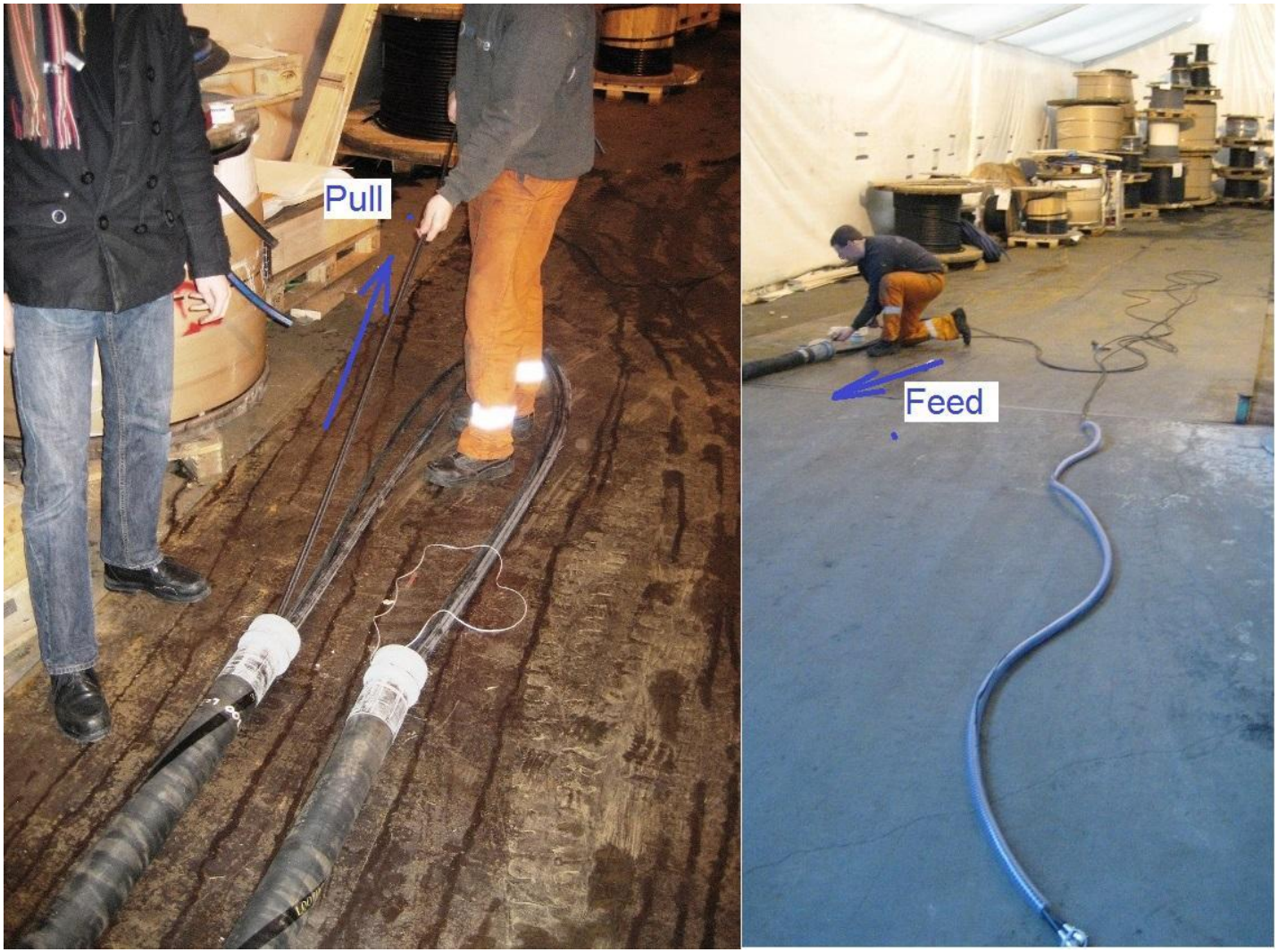
Keep Connectors covered



Do not touch Connector ends



Does & Don'ts



Conclusion

- Fiber Optic Sensors outperform electronic sensors in challenging environments
- Fiber Optic technology offers an intrinsic solution to EMI/RFI concerns
- No ground loops
- Immune to lightning
- Not affected by - and will not interfere with - high magnetic fields
- Resistant to radiation (X-rays etc)
- When deploying Fiber Optic Sensors – have F.O. competence in house.
- Choose F.O. Sensor supplier who can also support installation.
- Ask supplier for assistance!

Links for Fiber Optic Suppliers

- Fluke Test Equipment (High Quality Test Equipment)
  - http://www.flukenetworks.com/datacom-cabling?td=products#Fiber_Certification_and_Testing
- Fiber Optic Instrument sales (Complete Fiber Optic Warehouse)
  - http://www.fiberinstrumentsales.com/
- Coastal Connections (Cable Assemblies and Custom Terminations)
  - www.costalcon.com
- Timbercon (Custom Cabling)
  - http://www.timbercon.com/
- SENKO Fiber Optics (Connectors, Cable, Custom Cables)
  - http://www.senko.com/fiber/index.html