Fiber Optic Sensors are replacing their Electrical Counterparts in Critical Applications

Presented by **Dennis Horwitz**, President

Sensors Converge
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Today's Industrial Trends drive needs for Sensors of All Types

Trend	What/Why/Where	Issue
Electrification	Reduce use of fossil fuels, lower carbon footprint, combat climate change	Creates EMI/RFI Problems
Closed Loop Processing	Automation, robotics, process & equipment health feedback for increased efficiency and lower costs	Need for variety of sensors for better process monitoring, better yields, and predictive maintenance
Medical Devices	Surgical & biopsy robots, treatment delivery, MRI, patient rehabilitation	Need variety of sensors, low cost, small size, enhance health & longevity
Harsh Environments	Transformers, generators, oil & gas, pipelines, wind turbines, underwater, nuclear	Need very robust sensors – resistant to harsh environment factors
Hazardous Locations	Food industry, chemical, mines, food & process industries	Need for intrinsically safe or inherently safe sensors
Vehicle Health	Automotive, aerospace, rail transport	For increased safety and reliability
Structural Health	Buildings, dams, highways, railroad tracks, pipelines, transmission lines	For increased safety and reliability, eliminate waste caused by leakage

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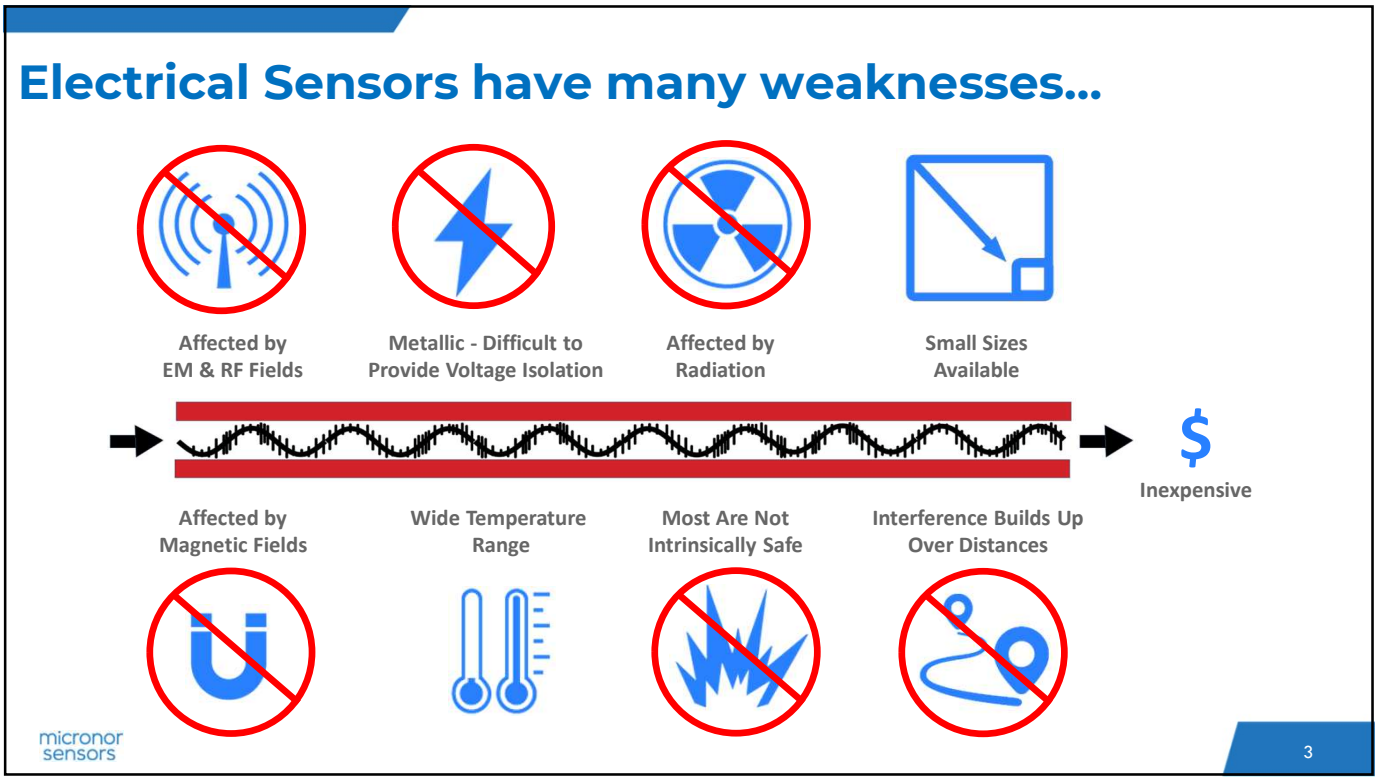
Electrical Sensors have many weaknesses...
Affected by EM & RF Fields
Metallic - Difficult to Provide Voltage Isolation
Affected by Radiation
Small Sizes Available
$
Inexpensive
Affected by Magnetic Fields
Wide Temperature Range
Most Are Not Intrinsically Safe
Interference Builds Up Over Distances
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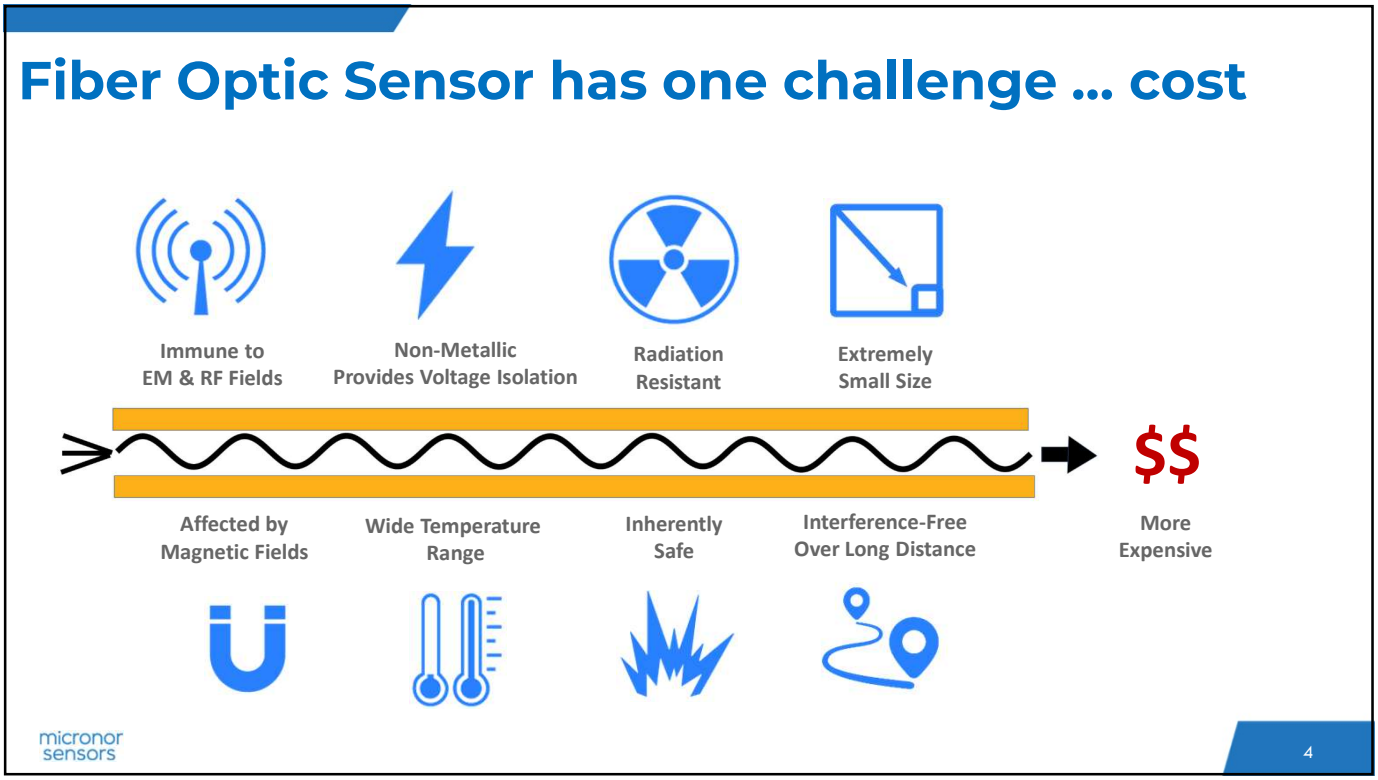
Fiber Optic Sensor has one challenge ... cost
Immune to EM & RF Fields
Non-Metallic Provides Voltage Isolation
Radiation Resistant
Extremely Small Size
$$
More Expensive
Affected by Magnetic Fields
Wide Temperature Range
Inherently Safe
Interference-Free Over Long Distance
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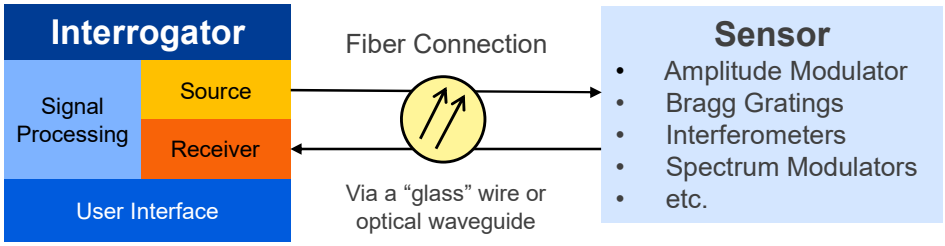
What is a Fiber Optic Sensor?

"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



➡ **All Optical - Non-electric – No Interference**

Definition: Transducer – a device that converts one form of energy into another.

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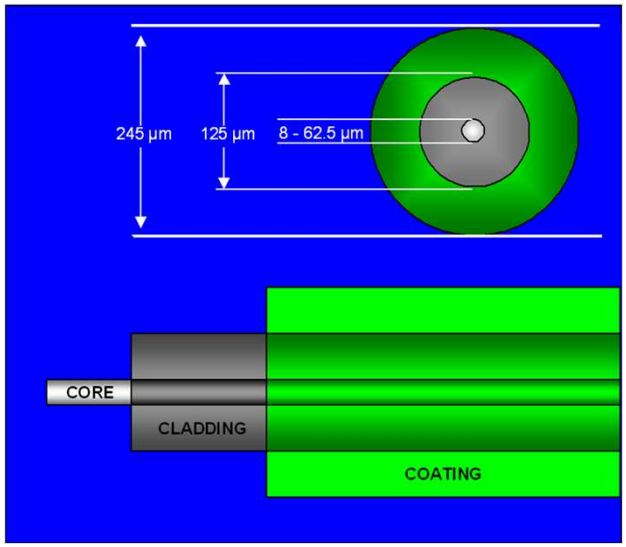
What is Fiber Optics?



Core
- Carries the light signals
- Silica and a dopant, special pure silica core fiber
- POF uses polymer core
- 9µm for telecom SM, 5.6 µm for FiSens SM800 FBGs
- 50 or 62.5µm for multimode, 1mm for POF

Cladding
- Keeps light in the core
- Pure silicon or polymer

Coating
- Protects the bare fiber
- Acrylate (polymer) or Polyimide (for high temp)

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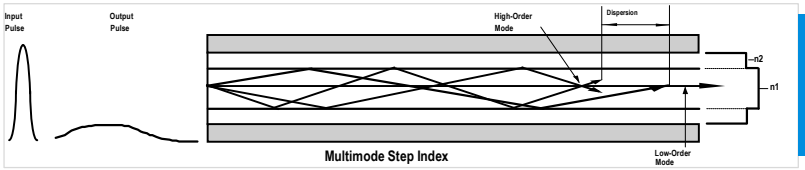
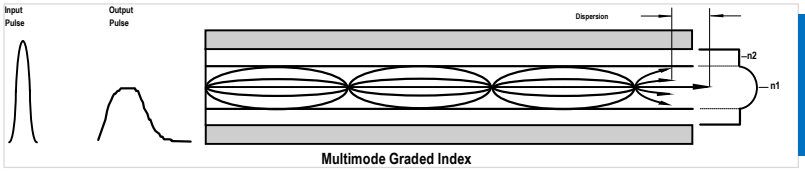
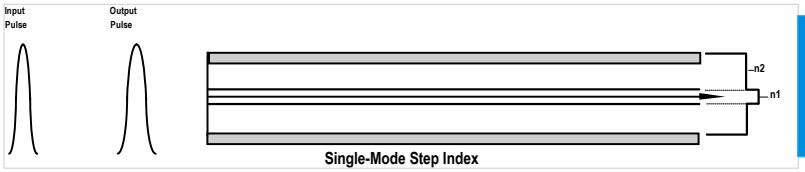
Single Mode versus Multimode: Many Types and Sizes of Optical Fiber



Multimode Step Index Fiber
- Short distance links, <100 m
- 10-100 Mb/s, Single λ
- POF, Large Core SI Fiber, Imaging Bundles



Multimode Graded Index Fiber
- Short-Medium distance links, 10m - 2000m
- 100 Mbs - 10Gb/s, Single λ
- 50/125 (OM2/OM3) or 62.5/125 (OM1)



Single Mode Fiber
- Long distance links, 1-100km,1310-1550nm
- 10//100/1000 Gb/s, Single λ or WDM)
- 9/125 (OS1/OS2), Specialty SMF for other λ

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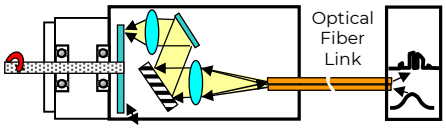
Fiber Optic Absolute Encoders

Absolute Encoder/Position Sensor

US Patent 8,461,514 B1

THEORY:
Code disk contains a single track, non-repeating code. Internally 14-bit Position is derived from 10-bit value plus 4-bits phasing.



MR330 series
OM1 62/5/125 MMF
Optical Concept:
Spectral Domain

MR430 series
M-POF MMF
Optical Concept:
Visual Domain

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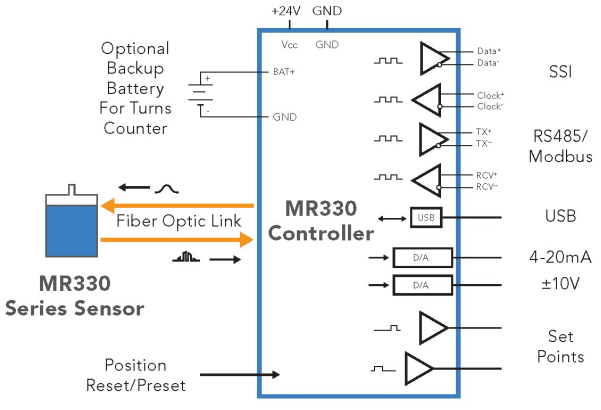

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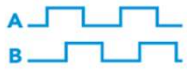
Fiber Optic Incremental Encoders

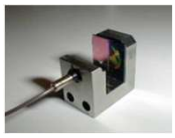


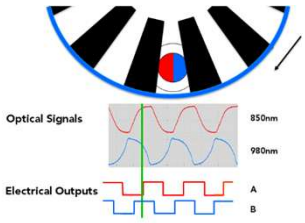
Incremental Encoder

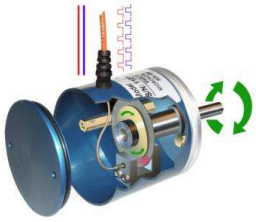
US Patent 7,196,320

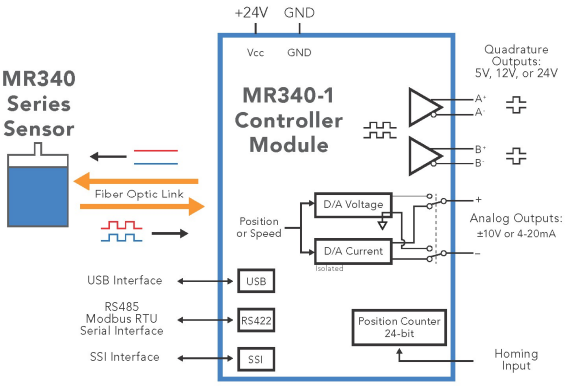
THEORY:
Wavelength Division Multiplexing (WDM) used to emulate the A/B Quadrature Pulses as separate wavelengths - 850nm and 980nm.

MR340
MMF-62.5/125 Series









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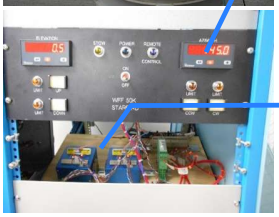
Case Study #1: NASA Launcher Upgrades

Application: Elev and Azimuth Feedback

FO Attributes



Micronor MR332 FO Absolute Encoder

Programmable SSI Readouts

Micronor MR330 Controllers

NASA/ORBITAL SCIENCES

- Global network of Cold War-era Launchers repurposed & upgraded for use with modern Sounding Rockets
- Azimuth and Elevation Position Feedback
- Operator safely situated outside the blast zone (300m)

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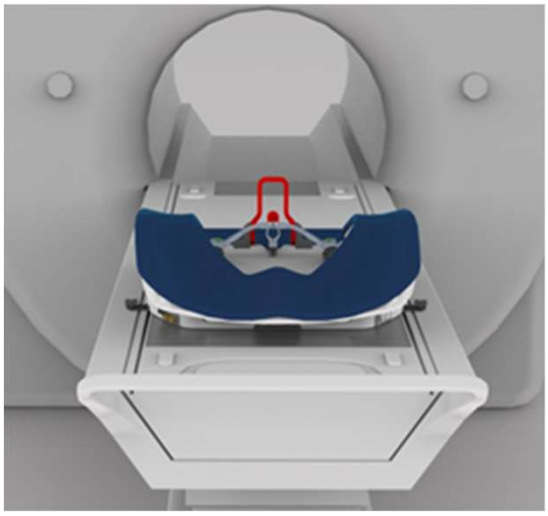
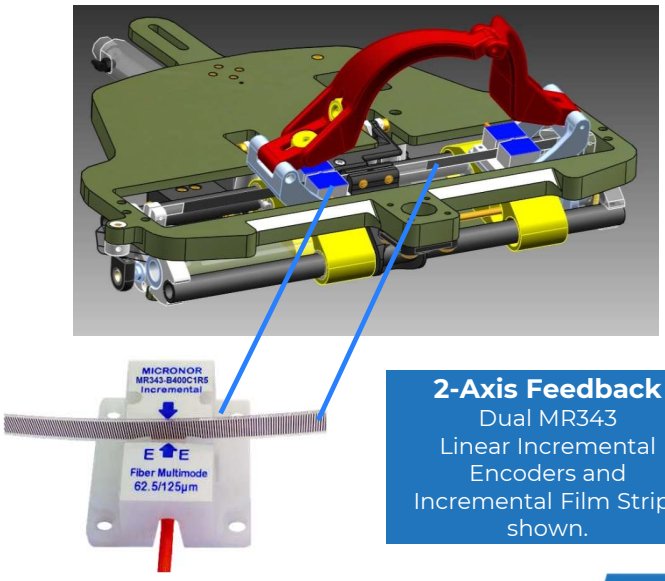
Case Study #2: MRI Guided Biopsy Robot

Application: MRI-Safe Linear Encoder for Position Feedback

FO Attributes



Photos and renderings courtesy of Polymer Robotics / Umano Medical



2-Axis Feedback
Dual MR343 Linear Incremental Encoders and Incremental Film Strips shown.

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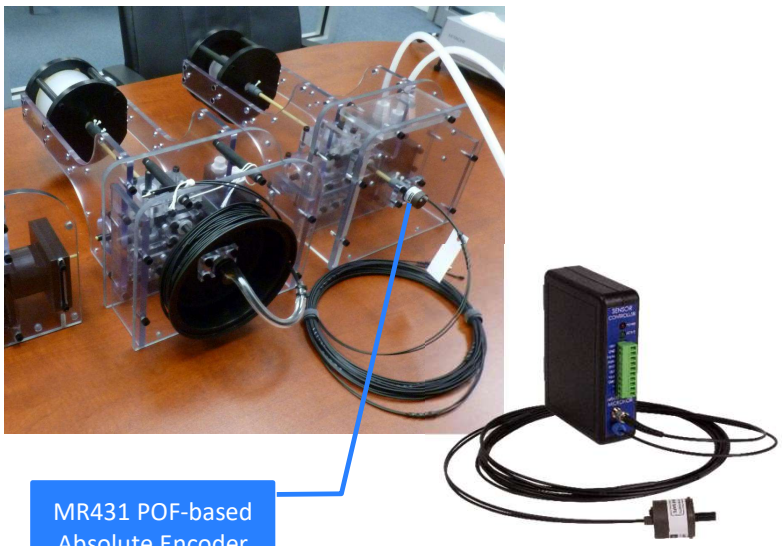
Case Study #2b: MRI Dynamic Brain Phantom

Application: MRI Operator Training & Calibration

FO Attributes

The ALA SCIENTIFIC MRI Dynamic Brain Phantom is designed to address training and quality assurance protocols for MRI machines by providing rapid control feedback from within the MRI bore, while remaining invisible to MRI scans.



MR431 POF-based Absolute Encoder

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Case Study #3: ITER Fusion for Energy Project

Application: High Resolution FO Encoders for IVVS

FO Attributes

APPLICATION
The mission of Fusion for Energy (F4E) is to make fusion possible on Earth. ITER ("The Way") will be the first fusion device to generate more heat than is used to start the reaction. The process involves raising the temperature to 150 million °C to generate super-hot plasma, producing 500 MW of heat for about 7 minutes.

CHALLENGE
When the fusion device is turned off, the In-Vessel Viewing System (IVVS) needs to examine plasma-facing components in the vacuum vessel. This requires an extremely precise inspection system.

SOLUTION
Six probes are used at different points within the machine. Each uses a laser beam and rotating turret to scan the surface, producing a 3D map of the machine. Extremely high-resolution FO Encoders were developed by Micronor AG for IVVS.

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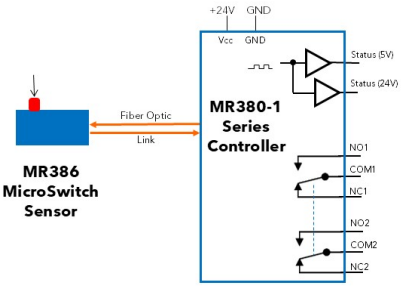
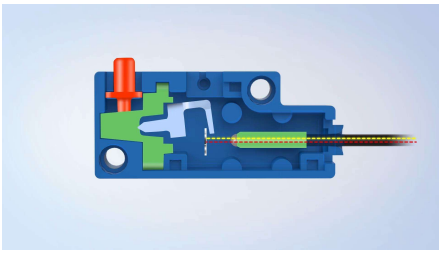
MR386 Series Fiber Optic Microswitch

Operates on basic principle of photo interruption
(light on / light off)

MR386 with Omron VAL2 Roller Leaf Spring





- MR386 has same form factor as Omron/Honeywell V- series EM Micro Switch
- Compatible with all Omron and Honeywell V-series actuator accessories (leaf spring, roller leaf spring, wire leaf spring, etc.)
- Multiple FO Microswitches can be connected in linear or loop topologies using Multiple Controllers

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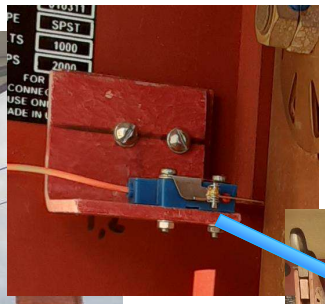
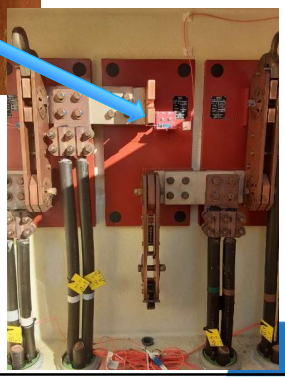
Case Study #4: St Louis Metro Railway System

Application: Remote Monitoring of HV Bypass Switch

FO Attributes





When manual bypass switch is engaged, the arm pushes down on extended actuator which depresses plunger. Status is monitored by the Control Center.

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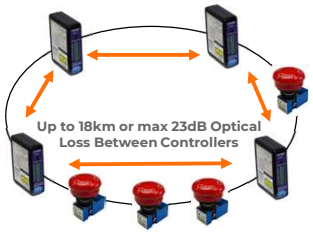
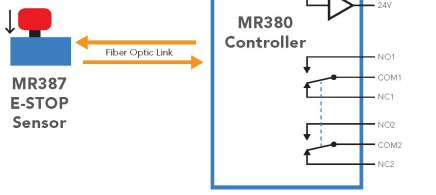
MR387 Series Fiber Optic Emergency Stop

Operates on basic principle of photo interruption (light on / light off)





- FO E-Stop available for use with SM, MM & POF
- Multiple FO E-Stops can be connected in linear or loop topologies, depending on networking requirements
- Controllers can also be used to extend distance of existing EM E-Stops
- Link lengths up to 18 km

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Case Study #5: LAX Consolidated Rent-A-Car Ctr

Application: FO E-Stop between Main and Utility Buildings

FO Attributes

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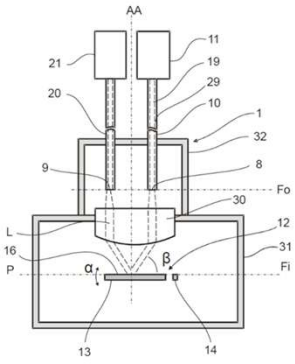
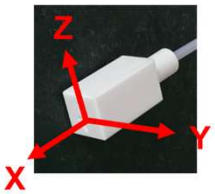
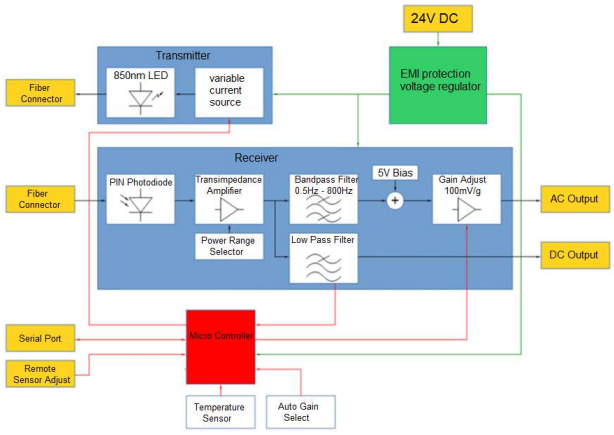
MR660 Multi-Axis Fiber Optic Acceleration/Vibration Sensor

A dedicated MEMS membrane/mirror is aligned with a specific axis and light is modulated only by that axis.







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Case Study #6: Electric Train Pantograph

Application: Pantograph & Catenary Vibration Anomalies

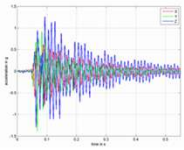
FO Attributes

CHALLENGE

Dynamically monitor pantograph operation in real time during train operation. A serious failure of pantograph can not only damage contact wires but can also inflict widespread damage on the catenary system network.

SOLUTION

Providing high voltage immunity and isolation, a multi-axis fiber optic accelerometer mounts directly on the pantograph to monitor system health in real time. Data is also used to monitor the health of the catenary system.



Customer: Swiss Railway

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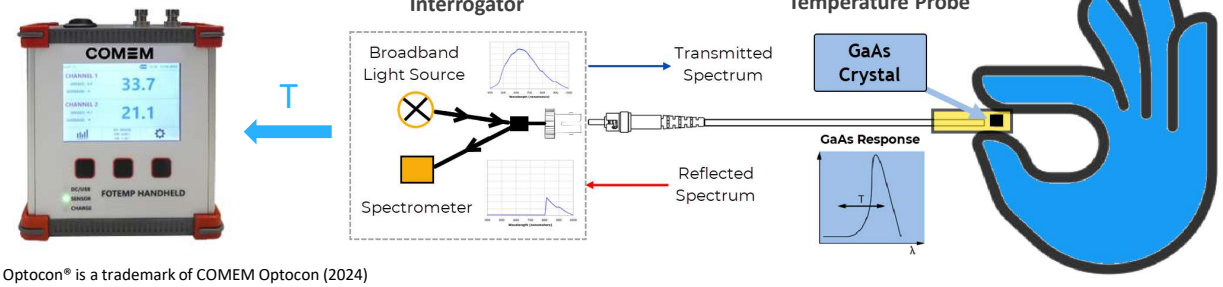
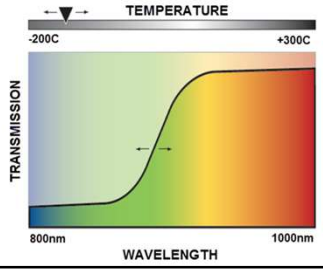
FOTEMP (GaAs) Fiber Optic Thermometry



Optocon® is a trademark of COMEM Optocon (2024)

Principles of Operation

1. GaAs is a non-metallic semiconductor crystal in which the effect of temperature is based on the inherent light absorption and transmission properties of the crystal.
2. Light source transmits light to the crystal. Some of the light is absorbed and the rest is reflected back to the spectrometer.



Optical beam probes the wavelength dependence of the intrinsic band-gap of GaAs which is dependent on absolute temperature.

$E_{gap} = 1.423eV$ ⇨ 300°K = 872nm

$dE_{gap}/dT = -0.452meV/°K$ ⇨ ≈ 0.315nm/°K

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Case Study #7: Induction Heating

Application: Measuring Temperature in RF Field

FO Attributes

CHALLENGE

Magnetic nanoparticles are heated with induction to selectively ablate tumor cells, powers from 1kW to 10kW, frequencies from 150kHz to 400 kHz. This non-contact selective heating only elevates the temperature of the material or tissue with ***embedded magnetic nanoparticles***. Requires RF immune temperature sensor to monitor actual temperature.

SOLUTION

Ambrell EASYHEAT® System is a compact induction heating system for the lab which offers COMEM Optocon's FOTEMP GaAs-based TS3 FO Temperature Probe (both non-metallic and RF-immune) for both temperature monitoring and control. Recently, customers have started to use Multipoint BRAGG FBG-based Temperature Probes for measuring gradients.

FOTEMP TS3 Probe

Multipoint BRAGG Probe

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Case Study #8: Microwave Oven & Reactors

Application: Measuring Temperature in MW Oven

FO Attributes

Microwave Food Processing and Process Development

CHALLENGE

Develop optimized process for meat thawing as well as production of partially cooked food product.

SOLUTION

A&B Famous Gefilte Fish uses the 4-Channel Bench Top FOTEMP signal conditioner together with FOTEMP TS3 series temperature probes.

A&B developed a proprietary microwave oven-based process for raw fish thawing as well as production of their partially cooked frozen gefilte fish product. For the latter, a microwave oven process was developed that precisely cooks and cools the product without rendering the proteins fully cooked.

FOTEMP TS3 Probe

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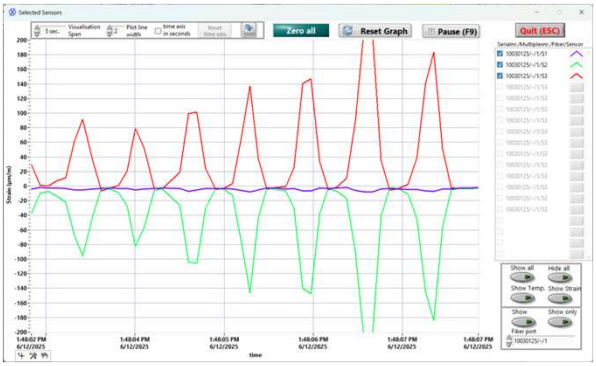
FEMTO FBG-Based Force and Strain Sensors

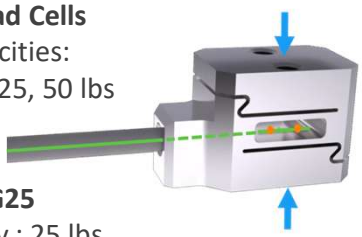
The FG25 Fiber Optic Load Cell can measure ± 25 lbf with 0.002% resolution

Force = E * strain * area
where E = Young's Modulus

Gripper and Grasper FO Load Cells



FG10 Series
FO Load Cells
Capacities:
2, 5, 10, 25, 50 lbs



FG25
Capacity : 25 lbs

Load
Compression

± 3500 με = ± 25 lbf

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Case Study #9: Robotic Touch Force Sensing

Application: Force of Loads, Gripping and Grasping

FO Attributes

APPLICATION

Closed-loop robotic touch and force feedback in Harsh Environments characterized by electromagnetic fields and interference.

CHALLENGE

Conventional strain gauge sensors are susceptible to errors and interferences:

- Changes in resistance due to temp and humidity
- Hysteresis, creep, or fatigue that reduce accuracy and repeatability
- Require Calibration, compensation or correction for differing loading conditions.

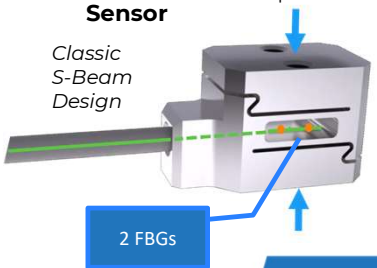
SOLUTION

FBG-based Load Cells, Gripper and Grasper force sensors provide electromagnetic immunity, high precision, accuracy, and reliability.

FG10
Optical Force Sensor

LOAD
Compression

Classic S-Beam Design



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Questions?

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V2.3

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