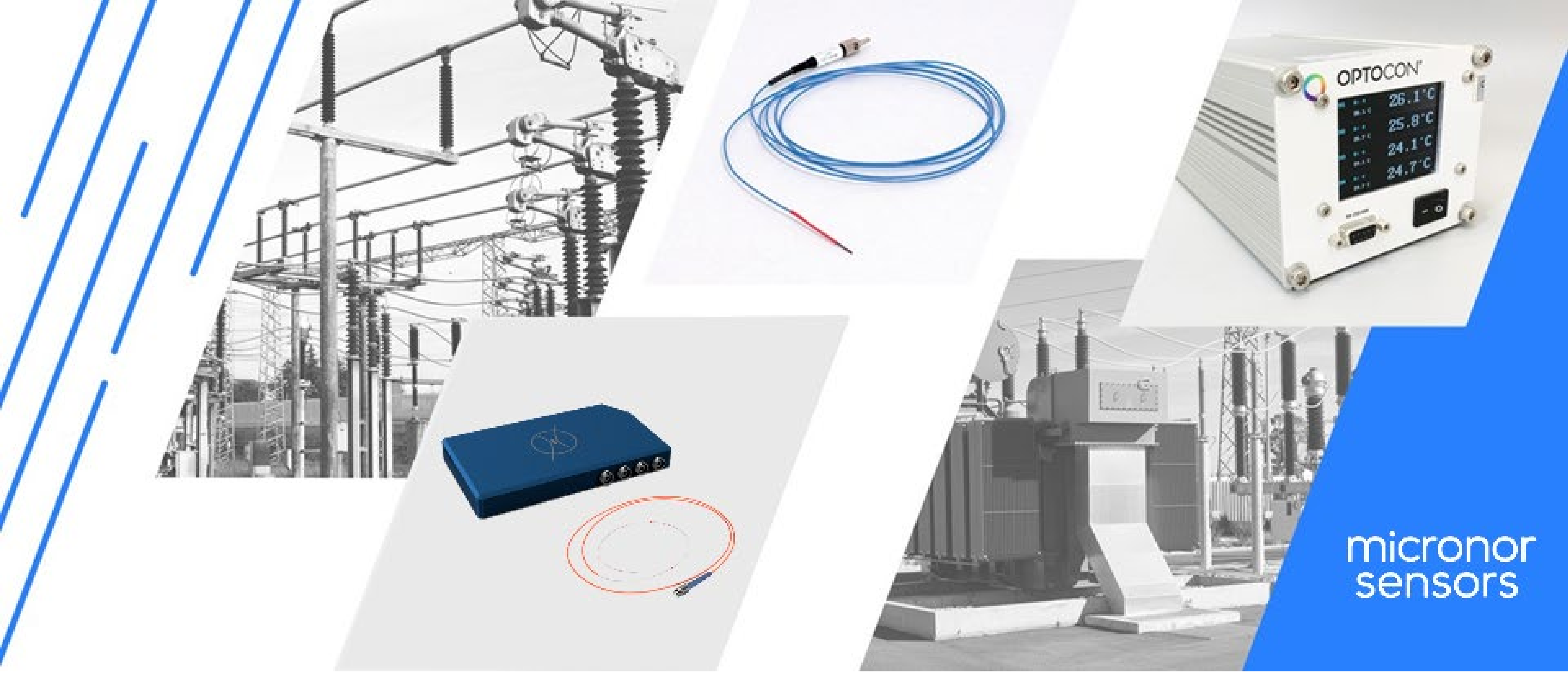


The Critical Role of Fiber Optic Temperature Sensors in Medical and Industrial Applications

TB Webinar February 10, 2021

Updated June 19, 2022

Presented by **Dennis Horwitz**, Technical Sales Manager

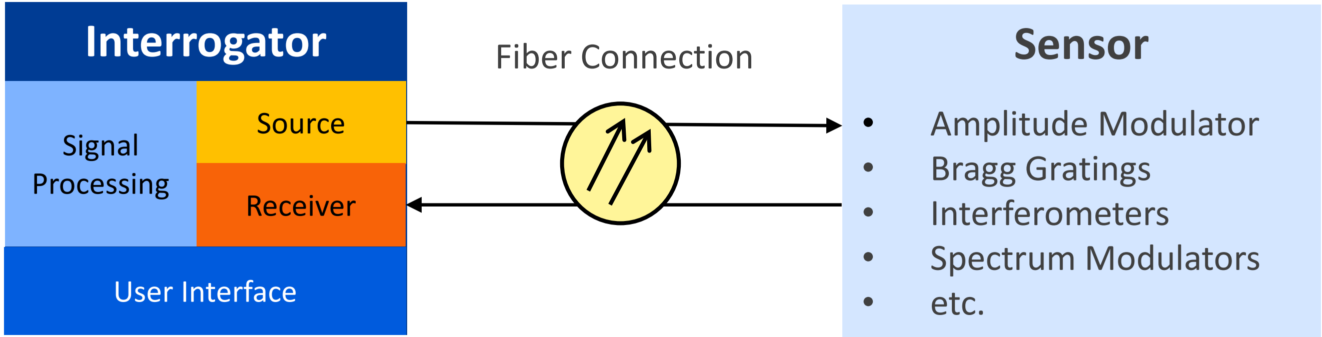
Webinar Outline

- What is a Fiber Optic Sensor?
- What is a Fiber Optic Temperature Sensor?
- Comparison of Key FO Thermometry Technologies – Single Point (GaAs, Phosphor) versus Multipoint (FBG)
- Case Study #1: Semiconductor Fabrication Equipment
- Case Study #2: Medical RF Radiotherapy
- Case Study #3: Medical MRI
- Case Study #4: Food Processing – Microwave Ovens
- Case Study #5: Power – Bus Bar Monitoring
- Case Study #6: Power – Health Monitoring of Transformer Hotspots (Discrete Single Point versus FBG)
- How To Design For Fiber Optic Temperature Sensors
- Summary – What we learned?
- Questions and Answers

What is a Fiber Optic Sensor?

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

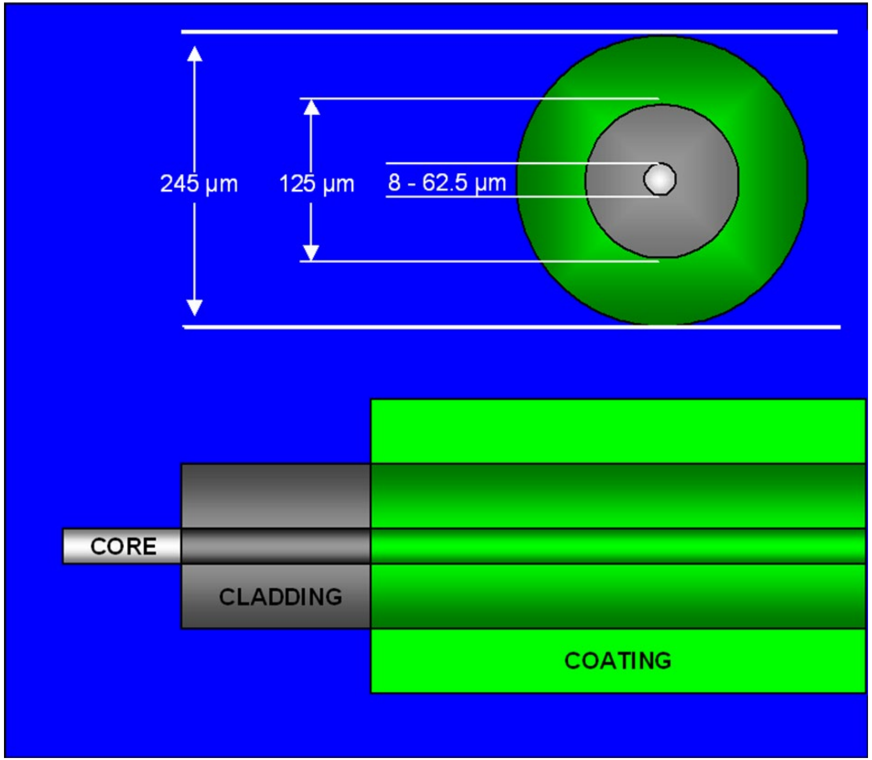
Since most Fiber Optic Sensors are not of transducer[(1)] type they require an interrogator



➡ Non-electric – No Interference

(1) transducer – a device that converts one form of energy into another.

What is Fiber Optics?



Core
- Carries the light signals
- Silica and a dopant, POF uses polymer
- 9µm for single mode
- 50 or 62.5µm for multimode, 1mm for POF

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

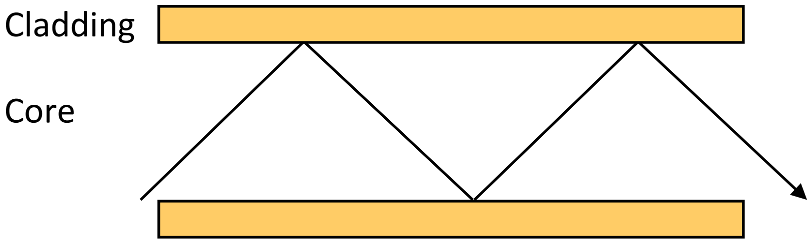
Coating
- Protects the bare fiber
- Acrylate (polymer) or Polyimide (for high temp)

What is a Mode?

What is a mode? Technically, a mode is a stable propagation state in an optical fiber. Dig into mode propagation theory and you will find that it is an effect caused by the wave nature of light.

Forget the technical jargon!

Simply, a mode can be considered as a light ray, or path in an optical fiber.

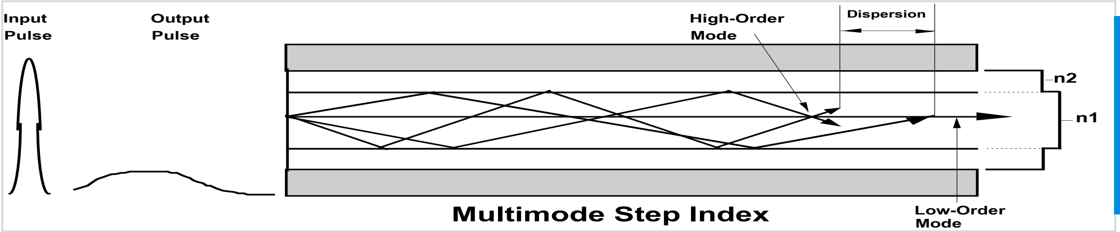


A mode in a step-index multimode fiber

A mode travelling in a singlemode fiber

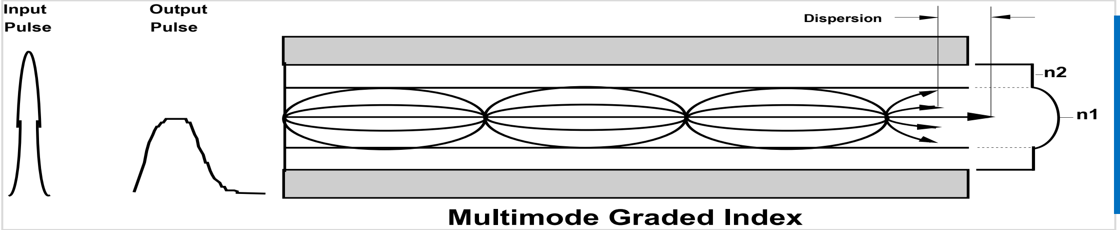
An optical source can emit many modes (light rays) varying by both launch angle and wavelength. Consider how a lamp emits white light (rays) composed of all colors of the spectrum and over a wide area.

What is Fiber Optics?



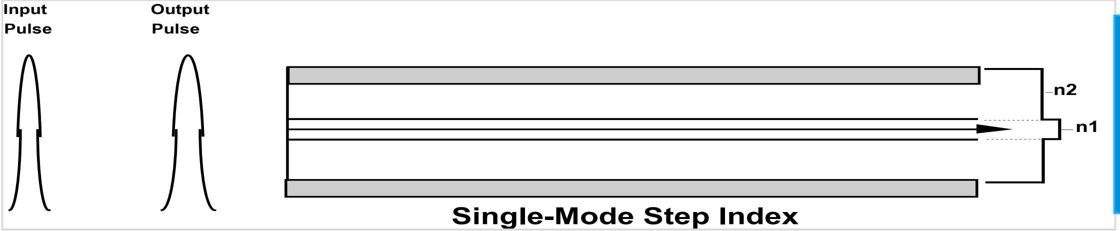
Multimode Step Index Fiber

- Short distance links, <100 m
- 10-100 Mb/s, Single λ
- POF (1mm) or HCS (200/230)



Multimode Graded Index Fiber

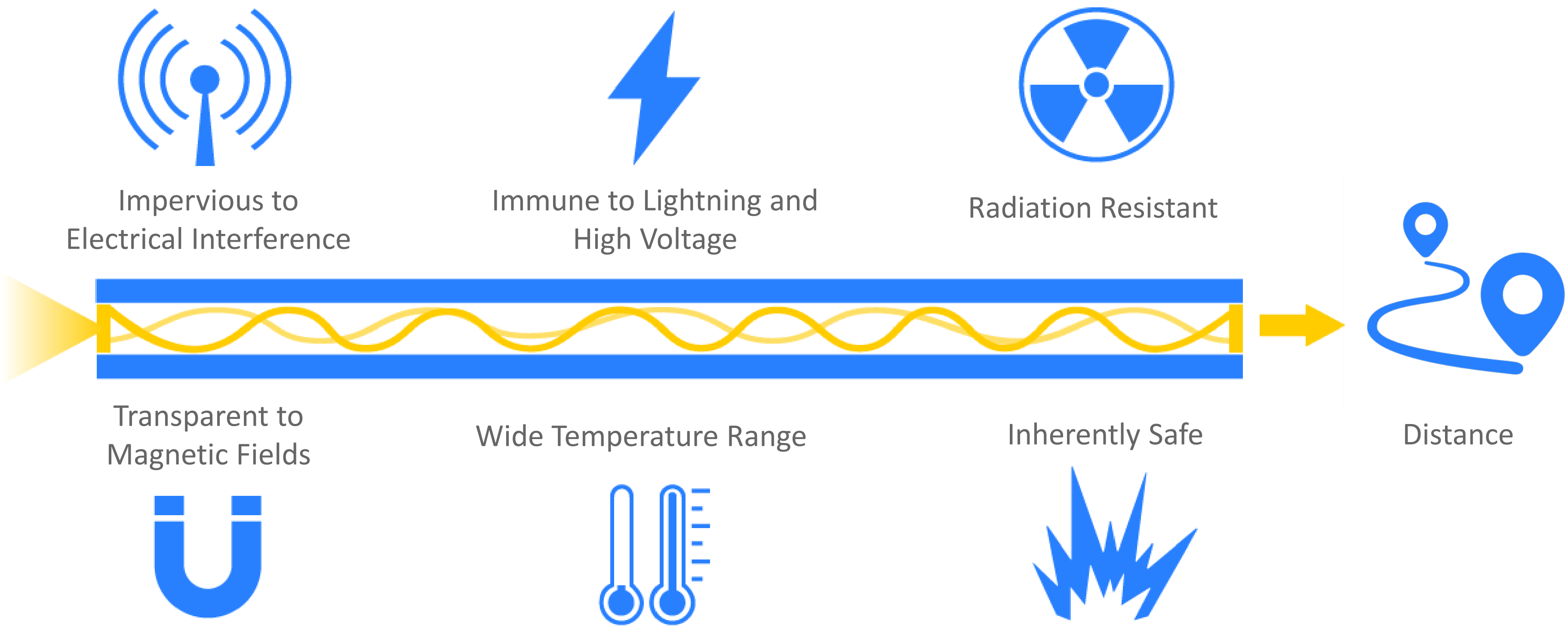
- Short-Medium distance links, 10m - 2000m
- 100 Mbs - 10Gb/s, Single λ
- 50/125 (OM2) or 62.5/125 (OM1/OM3)



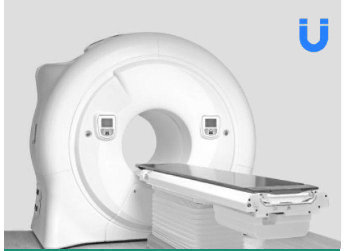
Single Mode Fiber

- Long distance links, 1000m -100km
- 2.5/10/40/100 Gb/s, Single λ or WDM
- 9/125

Why Fiber Optics?



Numerous Applications



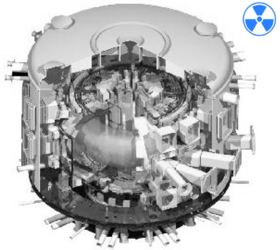
Medical (MRI)

Aerospace

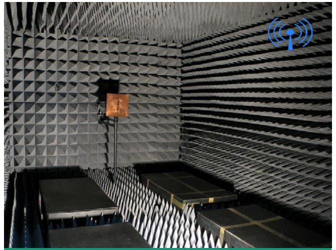
Power & Energy

Life Sciences

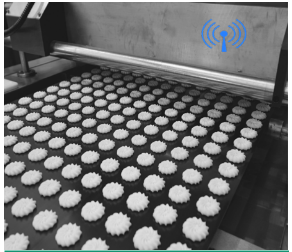
Semiconductor



Nuclear Energy

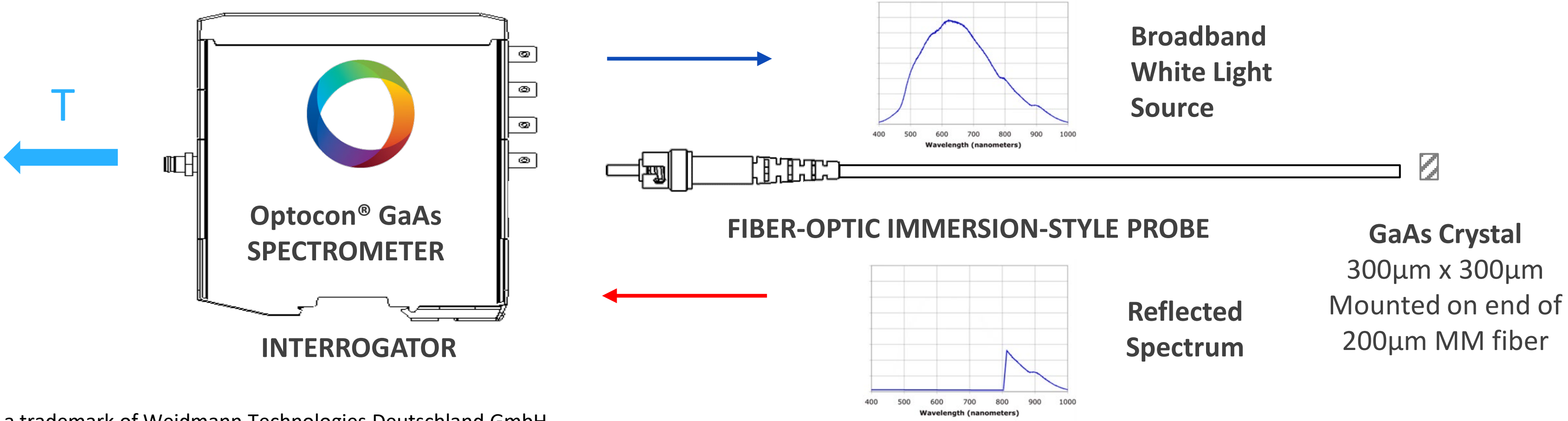


Test Chambers & Labs



Food & Beverage

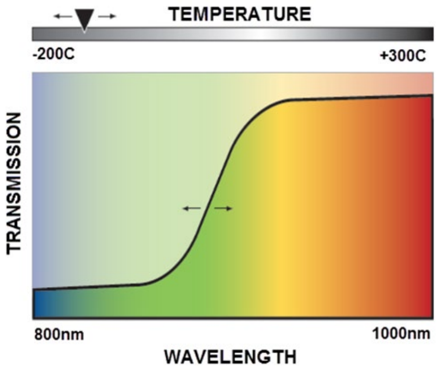
Gallium Arsenide (GaAs) Thermometry



Optocon® is a trademark of Weidmann Technologies Deutschland GmbH

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

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

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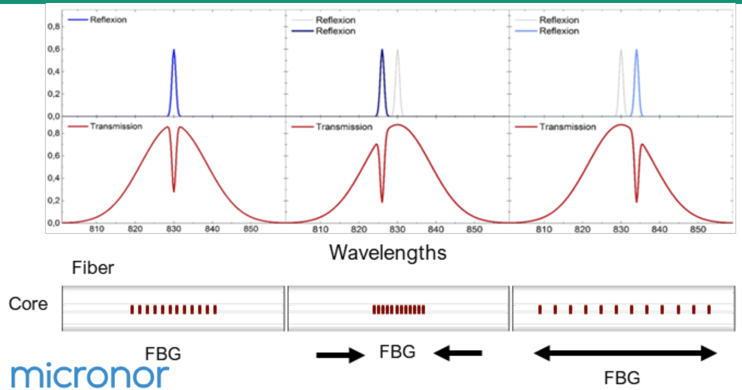
Multipoint Thermometry via Fiber Bragg Gratings (FBG)

FiSens® FBG System: Interrogator + Fiber Sensor Chain

FiSens® is a trademark of FiSens GmbH

Principles of Operation



1. Ultra-short fento-second laser pulses create high-precision nanoscopic FBG structures into the core of a single mode fiber
2. Multiple FBGs can be written anywhere along the length of the fiber, each tuned to a specific wavelength signature.
3. Thermal **and** mechanical force induce change in the specific reflected FBG wavelengths.
4. FBG Interrogator (integrated light source and spectrometer) analyzes the wavelength shift and converts to temperature, strain or pressure.

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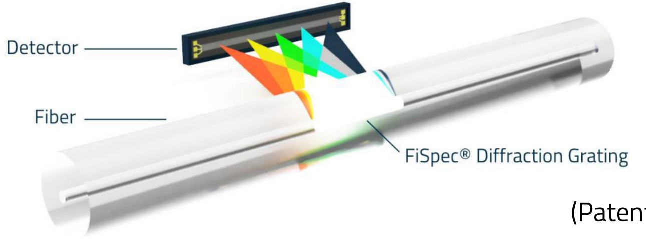
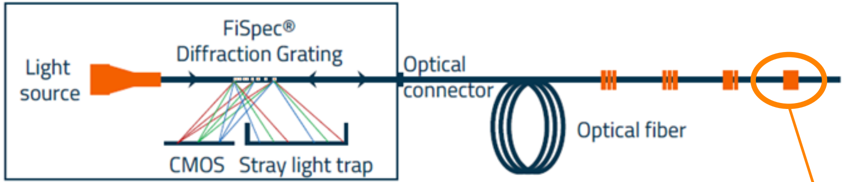
Fiber Integrated FBGX100 Spectrometer

All optical components of a spectrometer within a single optical fiber

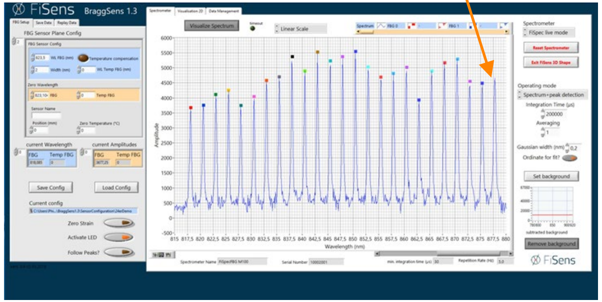
- Unique in-core grating for outcoupling and directly focusing onto image sensor with ultra-high diffraction efficiencies and light intensities
- World's smallest and most economical interrogation system for multiple FBs (array) with embedded light source
- Interrogate up to 30 FBGs, 808-880nm, Narrow or Wideband
- Sampling rate 1-100 Hz (applies to all FBGs)
- Measurement precision : 0.1°C or 1µε
- Quasi-monolithic design for highest shock-resistance and thermal stability
- FiSens patented technology



(Patent pending PCT/EP2018/054170)



BraggSens Software supplied, includes data logging function



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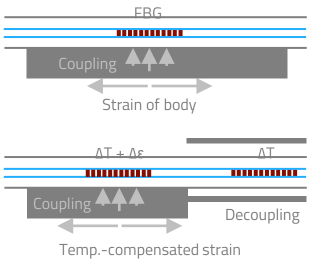
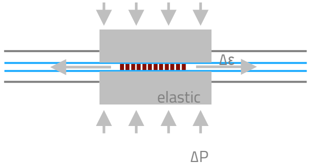
FBG Measurement Applications

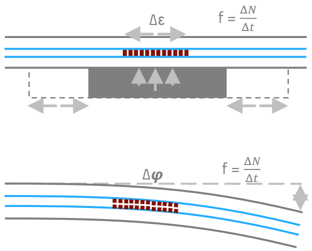
Strain



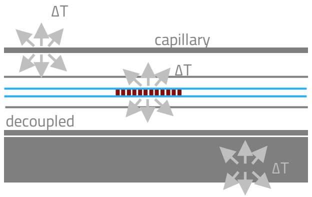
Pressure



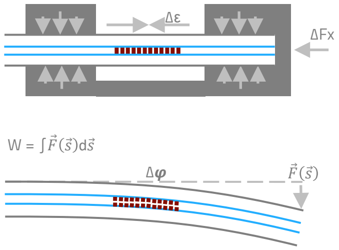
Vibration



Temperature



Force



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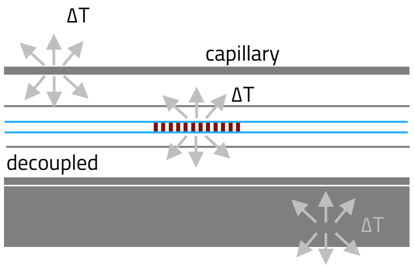
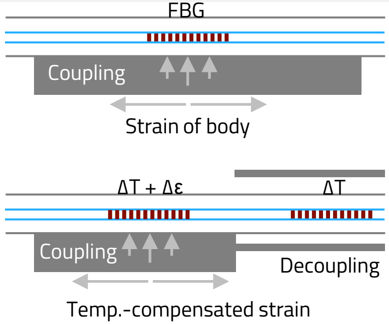
FBG Application Details

Parameter	Temperature, T	Strain, ϵ
Geometry	Strain-relieved bare fiber	Bare fiber
Mounting	Inside capillary, loop secured with Kapton tape	Embedded in material, glued to surface
Challenges	Strain also enlarges FBG	Temperature increase also enlarges FBG
Solutions	Choose geometry to avoid strain-related effects	Compensate for thermal expansion with 2nd FBG
Typical Applications	Structural health, wind turbine, switchgear, winding hot spot, injection molding	





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Performance Comparison of Key Thermometry Technologies

Typical Characteristics	K-Type Thermocouple	GaAs	FBGs
Temperature Range	-270°C to 1260°C	-200°C to +300°C	-150°C to +600°C
No. of Measuring Points per Sensor	1	1	1-30
Accuracy	±2.2°C	±0.2°C (1σ)	~1°C
Resolution	0.1°C	0.1°C	0.1°C – 0.5°C
Update Rate	0.1 Hz	1-ch = 4 Hz 4-ch = 1 Hz	1-300 Hz
Max Distance	50m	2000m	500m
Wire Used	Metallic	Multimode Glass Fiber 200/220	Single Mode SM800 5.6/125
Ease of Integration	Plug-and-play	Plug-and-play	Requires Hardware and Software Integration

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Application Comparison of Key Thermometry Technologies

Environment	K-Type Thermocouple	GaAs	FBGs
Benign, Short Distance <30m	✓	✓	✓
Benign, Long Distance	✗	✓	● < 500m
High Temperature > 300°C	✓	✗	✓
Low Temperature < -40°C	✗	✓	✓
EMI/RFI	✗	✓	✓
Magnetic Fields	✗	● (Requires offset factor for >1 Tesla)	✓
High Voltage	✗	✓	✓
RF Fields	✗	✓	✓
RF or Conductive Heating	✗	✓	✓
Microwave Oven	✗	✓	✓
Radiation (Nuclear)	● Requires Radiation Compensation	✓	● Requires Radiation Resistant Fiber

✓ Recommended

● Provisional

✗ Not Recommended

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Immersion versus Contact Probes

Sample Under Test	Immersion Probe	Spring-Loaded Contact Probe
Liquids	Yes	No
Powders	Yes	No
Gelatins	Yes	No
Tissue	Yes	Yes Surface Temperature Only
Rigid Samples (Plastic, Metal, Composite)	Yes Affixed To Surface via Tape or Adhesive or Clamp	Yes

FO IMMERSION PROBE

FO CONTACT PROBE

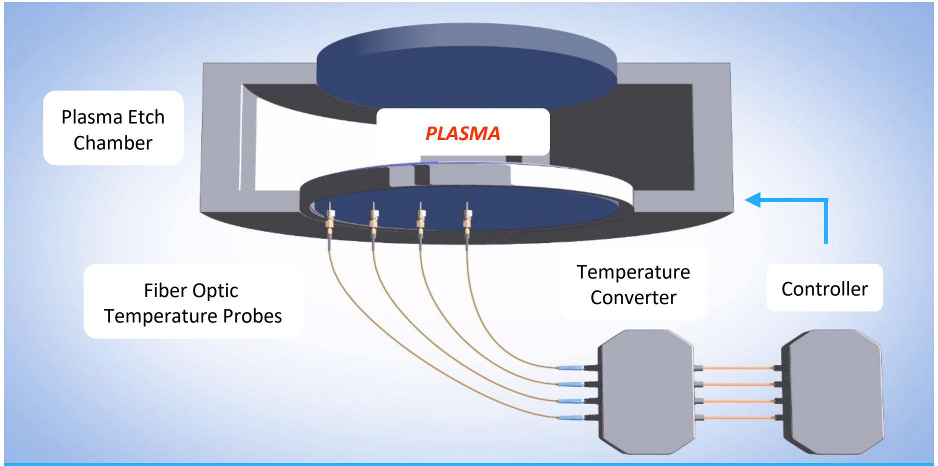
Poll Question #2

What type of fiber optic temperature sensor have you used?

(a) Phosphorescent/Fluorescent
(b) Gallium Arsenide (GaAs)
(c) Fiber Bragg Gratings (FBGs)
(d) Have not used

Case Study #1: Semiconductor Equipment Mfg

FO Attributes



Application Diagram: Temperature Sensing Inside Etch Chamber

CHALLENGE

Precisely measuring temperature in Plasma Etch Vacuum Chamber during wafer etching. Monitoring and controlling temperature improves wafer yields and lowers costs. Requires immunity to RF and plasma fields.

SOLUTION

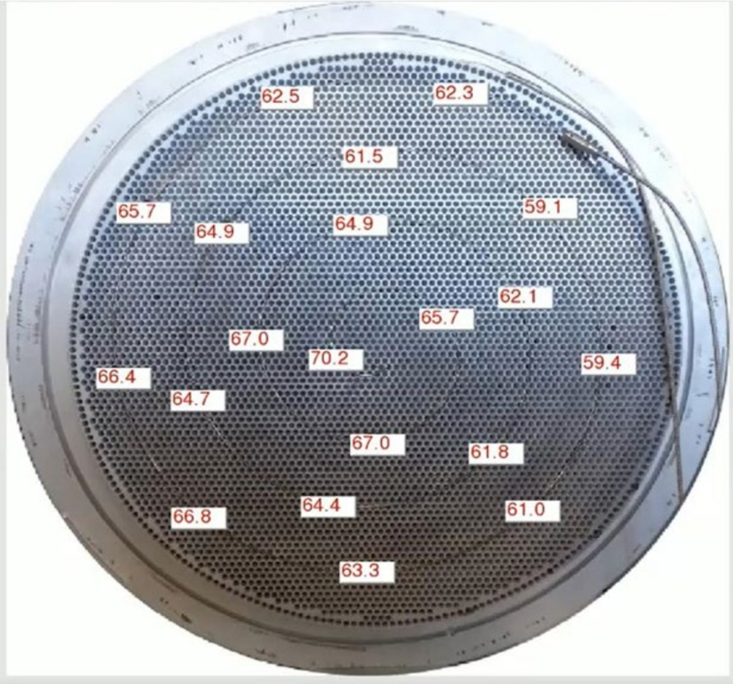
Photon Control develops and manufactures customer specific, spring-loaded contact probes for their semi customers based on proprietary FluoTemp™ phosphorescent technology. Working temperatures to 450°C and absolute accuracies down to ±0.2°C.

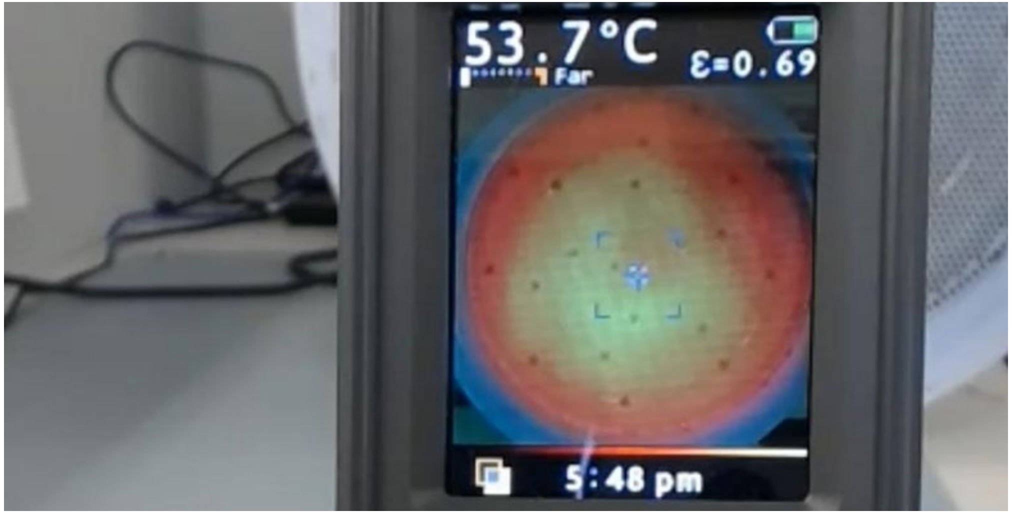
Automation and Inline Process Monitoring
Are Critical For Lowest Cost/Highest Yields in Semi Applications

Silicon Wafers on a Horizontal Batch Reactor

Multipoint FBGs Promised More Comprehensive Temperature Feedback in Semi Manufacturing Processes

FBG Demo on Plasma Shower Head





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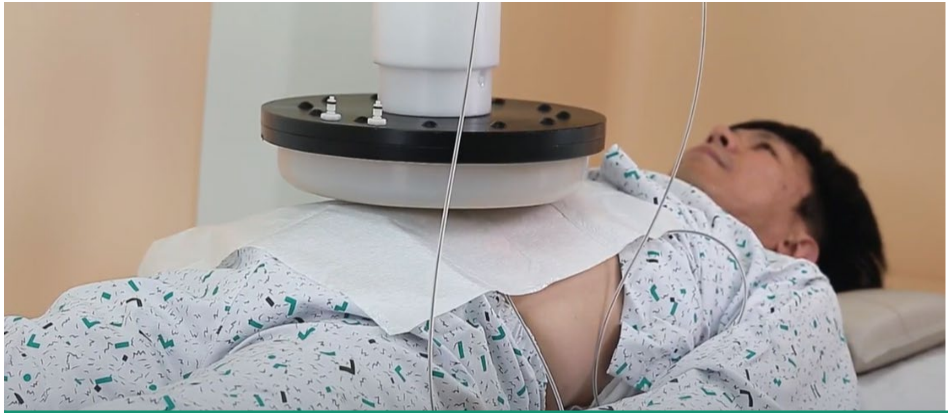
Case Study#2: Medical – RF Radiotherapy

FO Attributes



Patient Monitoring during hyperthermia cancer treatment

CHALLENGE

Monitor patient skin temperature during High-RF Field hyperthermia cancer treatment. Requires immunity to RF fields. Measurement range is 0-80°C (23°F to 176°F).

SOLUTION

TS5 temperature probe is taped to patient's skin during hyperthermia (RF heating) cancer treatment

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Case Study #3: Medical – MRI

FO Attributes

CHALLENGE

Monitor patient skin temperature, ambient temperature as well as internal MRI hardware. Magnetic field strength up to 9 Tesla (T). There is also emerging cancer imaging technology requiring sensing of nanomagnetic fields emitted by targeted magnetic nanoparticles which tag and detect cancer.

SOLUTION

Photon Control immersion-type NY2 FluoTemp. Non-metallic design is both immune and invisible to magnetic fields – large or small.

Case Study #4: Food Processing - Microwaves

FO Attributes

Commercial Microwave Oven and Industrial Microwave Conveyor Drying Machine

CHALLENGE

Measuring temperature of food and similar samples while being heated in Microwave Oven. Food can absorb microwaves, but metal can only reflect. This can cause a dangerous arcing condition between the metal object (conventional temperature probe) and the metal walls of the microwave oven. Monitor temperatures to 200°C.

SOLUTION

Fiber optic temperature sensors are both non-metallic and immune to microwaves.

Compared with traditional natural defrost thawing, flooding or water thawing, microwave defrosting has advantages of short time, uniform internal/external heating, kills bacteria, and no loss of nutritional components.

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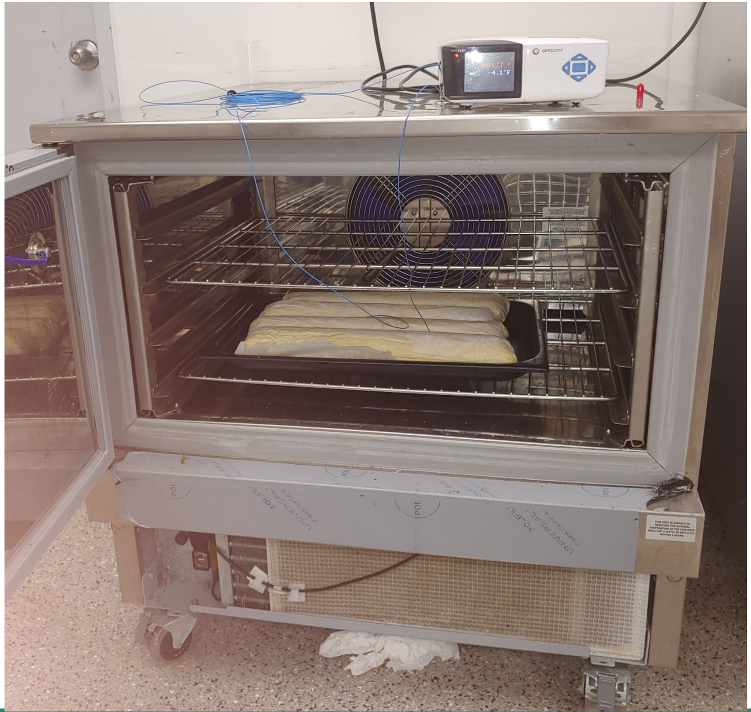
Gefilte Fish: Using Microwave Ovens

FO Attributes



Microwave Food Processing using TS3 GaAs Temperature Probe

CHALLENGE

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

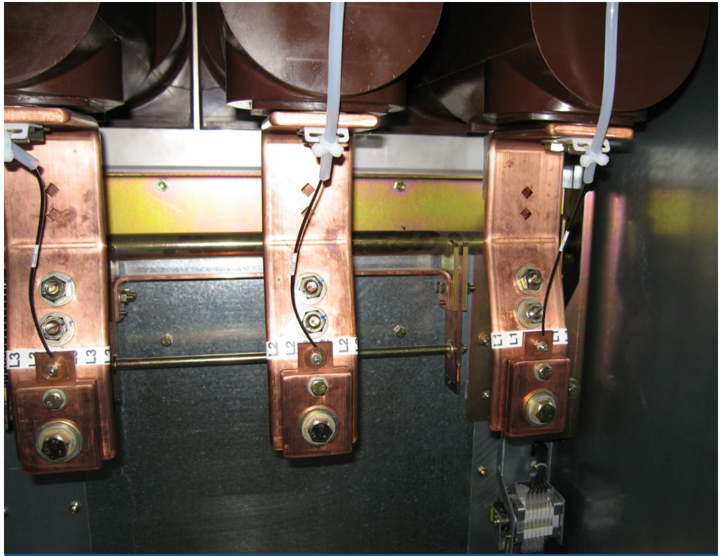
SOLUTION

A&B Famous Gefilte Fish uses multichannel Bench Top FOTEMP signal conditioner together with TS3 series GaAs 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.

Case Study #5: Power – Bus Bar Monitoring

FO Attributes



Probes mounted on busbars for monitoring

CHALLENGE

Safe monitoring of temperature of Distribution Bus Bar with potential of 1500V.

SOLUTION

Discrete temperature sensors coupled to each bus bar for early hotspot detection.

Converters mounted inside Switchgear

Case Study #6: Health Monitoring of Transformer Hotspots

FO Attributes

CHALLENGE

Safe monitoring of generation and distribution transformers with internal potentials range from 15 kV to 10,000 kVA.

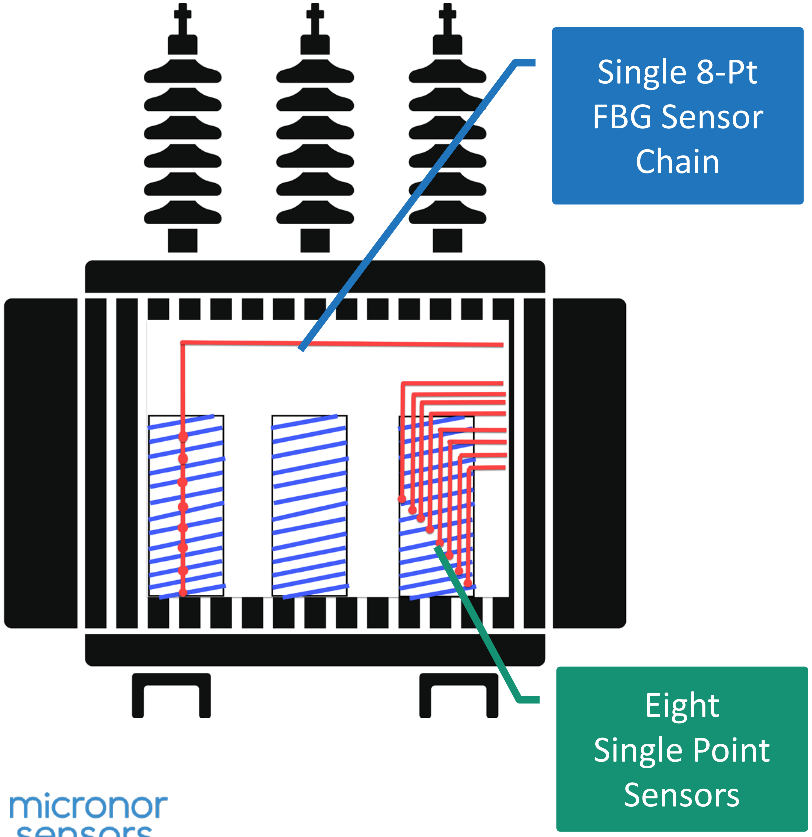
SOLUTION

Fiber optic temperature sensors provide inherent immunity to high voltages.

Real-time Hotspot Temperature Sensing monitors health of the transformer, improves reliability, and prevents unscheduled system failures and outages.

Power – Better Hotspot Monitoring

FO Attributes



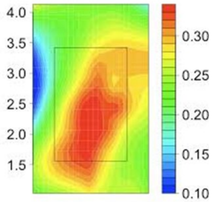
CURRENT SINGLE POINT SOLUTION

Typically 24 discrete single point sensors per transformer, 8 points per winding.
Installation Issues: Must deal with 24 sensor cables.

FUTURE FBG-BASED SOLUTION

One 30-point FBG Sensor Chain per phase, 3 transformer windings per transformer, total of 90 measurement points.
Performance Benefits: 3+ times more thermal coverage for 2/3 price of conventional system. High resolution Heat Map provides for more comprehensive system monitoring.
Installation Benefits: Smaller form factor converter plus only 3 FO cable connections to manage + higher reliability.

US Quarter shown for size comparison



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How To Design For
Fiber Optic Temperature Sensors

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A 8-Step Design Methodology

1. Choose appropriate Fiber Optic Thermometry solution consistent with the application, installation, operating environment, and distance requirements.
2. Choose specific Sensor Package compatible with media or environment to be monitored.
3. Observe Bend Radius limits of fiber/cable used, especially where special routing is involved.
4. Choose Appropriate Connector Type(s).
5. Choose Appropriate Fiber/Cable.
6. Choose Appropriate Interconnect and Feedthrough Solution.
7. How to Route Fiber (Do's and Don'ts)
8. Choose Converter/Controller with Desired Interface

1. Choose Best Technology for the Application

Environment	K-Type Thermocouple	GaAs	FBGs
Benign, Short Distance <30m	✓	✓	✓
Benign, Long Distance	✗	✓	● < 500m
High Temperature > 300°C	✓	✗	✓
Low Temperature < -40°C	✗	✓	✓
EMI/RFI	✗	✓	✓
Magnetic Fields	✗	● (Requires offset factor for >1 Tesla)	✓
High Voltage	✗	✓	✓
RF Fields	✗	✓	✓
RF or Conductive Heating	✗	✓	✓
Microwave Oven	✗	✓	✓
Radiation (Nuclear)	● Requires Radiation Compensation	✓	● Requires Radiation Resistant Fiber
Plug and Play?		✓	● OEM Application requires Hardware

✓ Recommended

● Provisional

✗ Not Recommended

2. Choose Proper Sensor Package Consistent with Surface, Sample or Atmosphere to Monitor

1. Sensors must be installed and make desirable thermal contact with surface or media to be monitored – Immersion or Contact type?
2. Sensor packaging must meet the “survival” needs of the Harsh Environment.
3. For sterilization in autoclave, sensor must survive these high temperatures.
4. For corrosive chemical and oil/gas applications, sensors must be chemical resistant. Example, TS4 sensor.
5. For transformer hotspot monitoring, note application specific mounts that are available. Example, Weidmann Smart Spacers® for installation in transformer windings. Also transformer installations must mitigate build-up of air bubbles.
6. For critical Thermal Vacuum applications (Semi WFE, Space, etc.), sensor materials must meet low outgassing requirements, characterized as Total Mass Loss (TML<1%) and Maximum Collected Volatile Condensable Material (CVCM, <0.1%).

Immersion versus Contact Probes

Sample Under Test	Immersion Probe	Spring-Loaded Contact Probe
Liquids	✓	✗
Powders	✓	✗
Gelatins	✓	✗
Tissue	✓	● Surface Temperature Only
Rigid Media (Plastic, Metal, Composite)	● For Permanent or Semi-Permanent Surface Measurement, Affixed To Surface via Tape or Adhesive or Clamp	✓

FO IMMERSION PROBE

FO CONTACT PROBE

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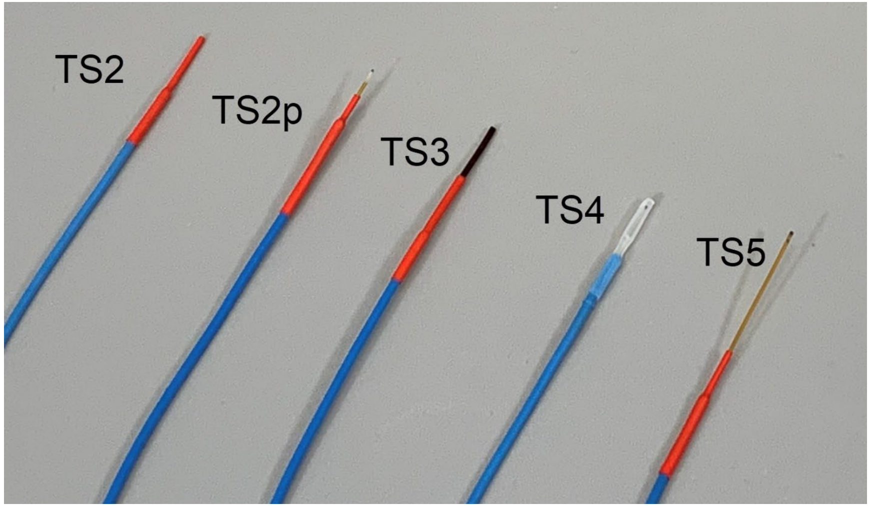
✓ Recommended ● Provisional ✗ Not Recommended

Selecting A GaAs Probe

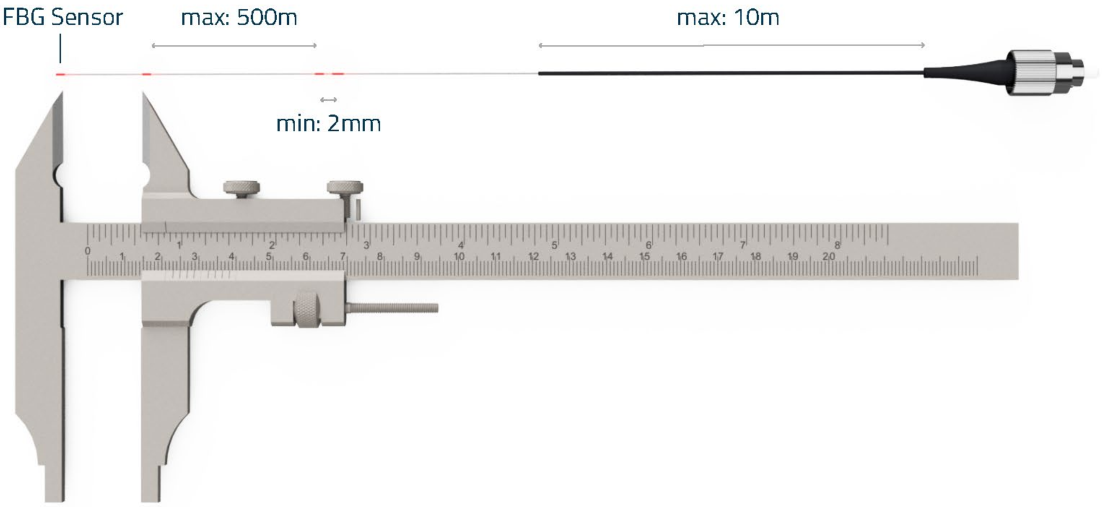


Sensor Series	Description
TS2	GaAs, General Purpose/Transformers, -200C to +300C
TS2p	GaAs, Bare GaAs Chip for Measuring Temperature of Very Small Surfaces, 0.3mmx0.3mm, -200C to +300C
TS3	GaAs, General Purpose/Microwave Ovens, Ø1mm Rigid Polyimide-Tubing Extended Tip (L1), L1 Length Option=10-130mm, Std=10mm, -200C to +300C
TS4	GaAs, Harsh Chemical/Nuclear, PTFE Chemical Resistant Tip Overcoating, -200C to +200C
TS5	GaAs, General Purpose/Medical/Catheters, Ø0.55mm Polyimide-Tubing Extended Tip (L1), L1 Length Option=10-600, Std=20mm/50mm, -200C to +300C
TS5m	GaAs, Medical/Catheters, Minimum probe diameter for catheter applications, Ø0.55mm tip tapers to Ø1.3mm, 200C to +300C

How To Specify an FBG Sensor Chain

Up to 30 FBG at arbitrary Positions

Position Tolerance: 0,3%/m



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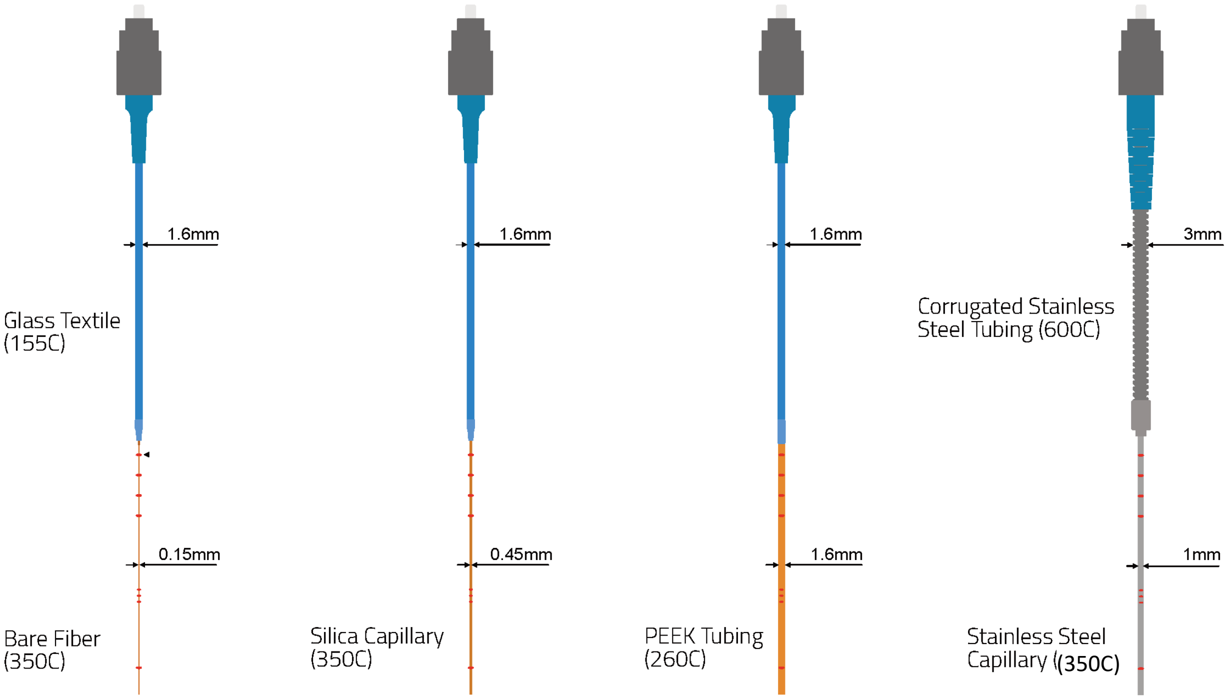
How To Specify an FBG Sensor Chain



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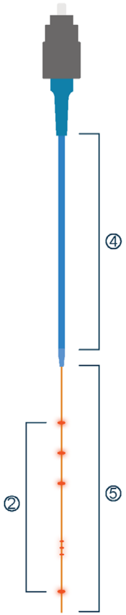
How To Specify an FBG Sensor Chain

Step 1



Ⓐ FBG Array Part Number

① **Sensor Type**
T - *Temperature*
S - *Strain*

③ **Spectral Range**
N - *Narrow [808-865]*
W - *Wide [808-880]*

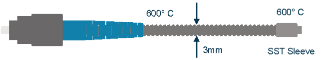
⑤ **Sensor Capillary**
FI - *Bare Fiber*
PE - *PEEK Tubing*
SSC - *SST Capillary*
SI - *Silica Capillary*

T - 5 - N - GL - FI

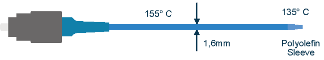
② **FBG Quantity**
1 - 1 FBG
2 - *2 FBGs*
...
30 - *30 FBGs*

④ **Lead-in Protection**
GL - Glass Textile
SST - SST Corrugated Tube
HY - Hytrel Buffer
PVC - Standard PVC Tube

④ SST - Stainless Steel (1.4301) Corrugated Tube

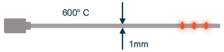


GL - Glass Textile

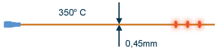


⑤ FI - Bare Fiber with Polyimide Coating

SSC - Stainless Steel (1.4301) Capillary



SI - Silica Capillary



PE - PEEK Tubing

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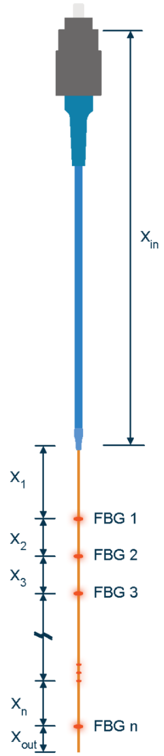
How To Specify an FBG Sensor Chain

Step 2



Ⓑ FBG Array Distance Code

X_{in} · X_2 · X_n

2000 - 50 - 10 - 10 - ... - 10 - 5

X_1 · X_3 · X_{out}

Length/Bending Limitations

	SST	PVC	GL	HY	FI	SSC	SI	PE
Min Bending Radius	**15mm**	**10mm**	**7mm**	**7mm**	**7mm**	**100mm**	**20mm**	**40mm**
Max length	**10m**	**10m**	**5m**	**5m**	**500m**	**3m**	**2m**	**10m**

How To Specify an FBG Sensor Chain
Step 3 (Optional)

Ⓒ Customized FBG Wavelength Code (only if custom sensor type: "C")

810 - 840 - 845 - ... - 870

WL_1 = 810, WL_2 = 840, WL_3 = 845, WL_n = 870

CWL Tolerance: 0,15nm

CWL Range: 800-900nm

How To Specify an FBG Sensor Chain
Custom Wavelength Selection Table for Temperature

For Temp - Wide Configuration 1/28/2021

Channel	WL	Array 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
	805 Kompensation																														
1	810	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	812.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
3	815	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
4	817.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
5	820	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
6	822.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1
7	825	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
8	827.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1
9	830	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1
10	832.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
11	835	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1
12	837.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
13	840	0	0	0	1	0	0	0	1	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	842.5	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
15	845	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
16	847.5	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
17	850	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
18	852.5	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
19	855	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
20	857.5	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
21	860	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
22	862.5	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
23	865	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
24	867.5	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
25	870	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
26	872.5	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
27	875	0	0	0	0	0	1	1	1	1	1	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
28	877.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
29	880	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1
30	882.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1
31	885	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
32	887.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

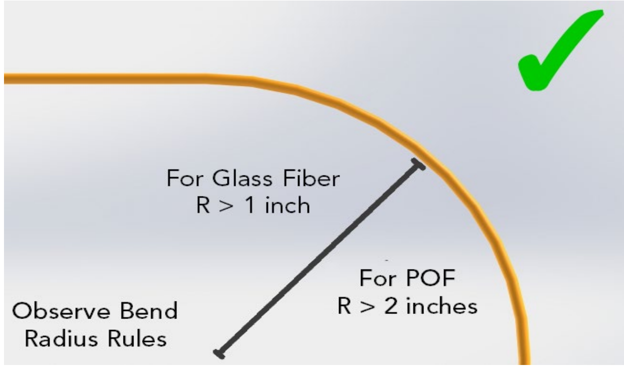
How To Specify an FBG Sensor Chain
Custom Wavelength Selection Table for Strain

For Strain - Wide Configuration

Channel	WL	Array 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
	805 Kompensation																														
1	810	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	812.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
3	815	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
4	817.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
5	820	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
6	822.5	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1
7	825	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
8	827.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1
9	830	0	0	0	0	1	0	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1
10	832.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
11	835	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1
12	837.5	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
13	840	0	0	1	1	1	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	842.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
15	845	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
16	847.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
17	850	0	1	1	1	1	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
18	852.5	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
19	855	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
20	857.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
21	860	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
22	862.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
23	865	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
24	867.5	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
25	870	0	1	1	1	1					1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
26	872.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
27	875	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
28	877.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
29	880	0	0	0	1	1	0	0	0	0	0	1	1	1	1	1							1	1	1	1	1	1	1	1	1
30	882.5	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1
31	885	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
32	887.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

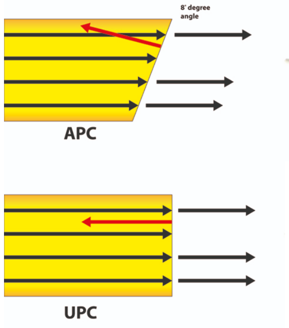
3. Observe Bend Radius rules where application requires complex sensor routing

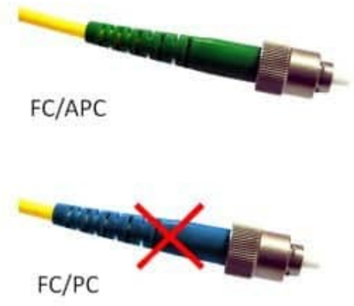
1. If option is available, POF is ideal for tight routing.
2. Polyimide-coated Glass fiber used in TS sensors has 40mm bend radius.
3. Polyimide-coated Glass fiber used in SM800P FBGs have 7mm bend radius.



4. Choose Appropriate Connector Types

Non-Environmental ST-UPC Connector





Non-Environmental FC Connector

- ❑ Standard sensors typically use ST-UPC or FC-APC single fiber connectors.
  - ❑ PC or UPC polish (physical contact, signified by black or blue boot)
  - ❑ APC (angled physical contact, signified by green boot).
- ❑ Choose appropriate connector type consistent with the application, industry standards and operating environment (tactical, festoon, mining, mud oil resistant, shipboard, aerospace, etc.)
- ❑ Design link with purposeful interconnection points for ease of installation and troubleshooting

5. Choose Appropriate Cable

Telecom Grade Cable

Mil-Tac Ruggedized Jumper Cables

Heavy Duty Mil-Tac For Outdoor Environments

- ❑ Choose appropriate cable type consistent with the application, industry standards and operating environment (tactical, festoon, mining, oil rigs, shipboard, aerospace, vacuum, etc.)
- ❑ Sensors use non-standard telecom/datacom fibers – so be sure cable incorporates same fiber type.
  - ❑ GaAs sensors uses 200/220/240 Step Index Low OH- multimode fiber
  - ❑ FiSens FBGs use SM800P (850nm) 5.6/125/145 single mode fiber

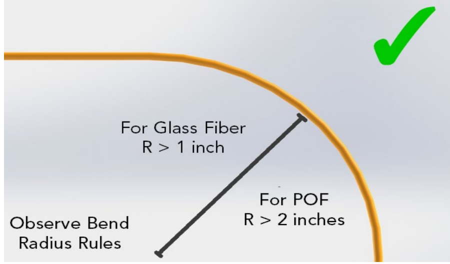
6. Choose Appropriate Interconnect & Feedthrough Solution

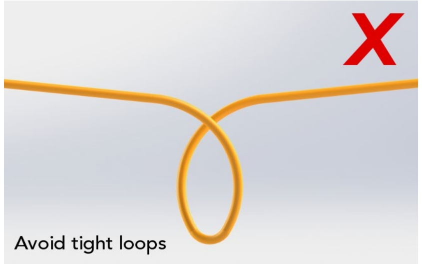
DIN Rail Mount Patch Panel
4-Channel ST Type Shown

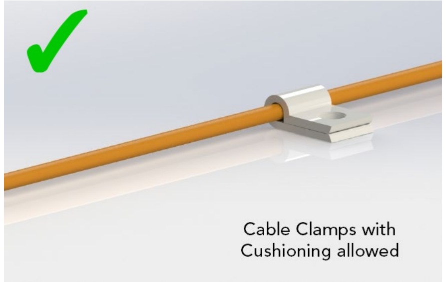
Bulkhead Adapters
FC and ST shown

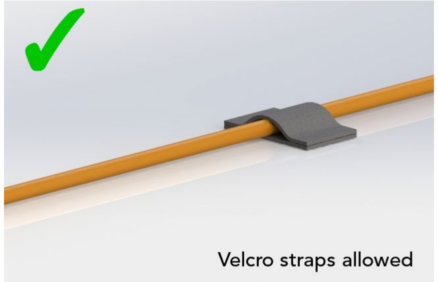
Hermetic/Vacuum Feedthrough
ST and Custom Fiber Feedthroughs shown

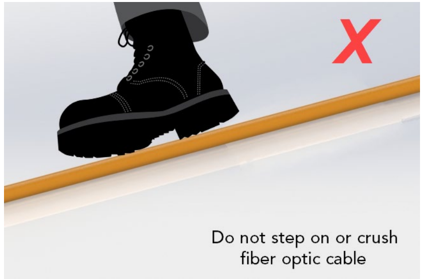
7. How To Route Fiber (Do’s and Don’ts)

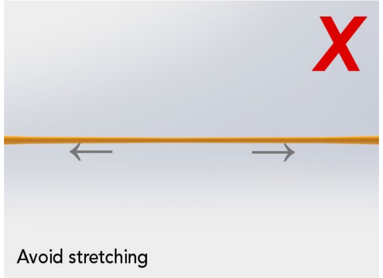












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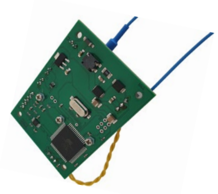
8. Choose Converter with Desired Interface

1. How many channels are needed?
2. Where will the unit mount?
   – Bench Top
   – DIN Rail Mount
   – Module or PCB for Embedded OEM
3. Do you need a Display?
4. Interface requirements?
   – Analog Output: 0-10V or 4-20mA
   – Digital Communications: USB, RS232, UART, SPI, RS485/ModbusRTU, Ethernet/ModbusTCP, EtherCat

GaAs
FOTEMP1-H
(1 Channel)



GaAs
FOTEMP-Mini

GaAs
FOTEMP-PLUS
(1-4 Channels)

GaAs
FOTEMP-OEM
(1-4 Channels)

GaAs
FOTEMP-T2
(4-16 Channels)

FBG
Interrogator

GaAs
INSULOGIX-T3
(4-16 Channels)

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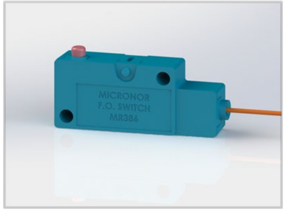
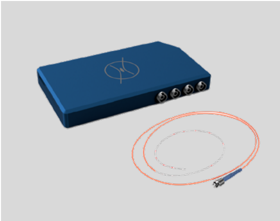
Fiber Optic and Electromechanical Sensors





Fiber Optics

- ❑ Absolute and Incremental Encoders
- ❑ Emergency Stop
- ❑ Microswitch
- ❑ Accelerometer (Micronor AG)
- ❑ Temperature (Photon Control FluoTemp and Weidmann FOTEMP GaAs sensors)
- ❑ Temperature and Strain (FiSens FBGs)

Electromechanical

- ❑ Position Transducers/Feedback Units
- ❑ Rotary Limit Switches
- ❑ Optical/Magnetic Encoders
- ❑ Resolvers
- ❑ Cam Timers/Motorized Potentiometers
- ❑ HMI – Handheld Pendants and MPGs

Summary

- MYTH: Fiber optic sensors are not fragile, glass things. FO is very robust and reliable.
- Fiber optic temperature sensors solve many environmental and packaging challenges in the unique operating conditions of many medical and industrial applications.
- Fiber optic temperature sensors enhance applications where thermocouples are incompatible and offer real-time monitoring solution improving the operation and reliability of the overall system, i.e. RF Ablation, MRI, Transformer Hot Spot Monitoring, etc.
- Different temperature sensing technologies are available to provide an optimized solution for a given application and operating environment, i.e. TCs, GaAs, FBGs.
- Deploying fiber optic temperature sensors involve unique design considerations versus (or taken for granted) electronic sensors, i.e. connectors, cabling, cleanliness, etc.
- Reach out for a fiber optic temperature sensor solution in your next project.

Questions?

Dennis Horwitz
President
Micronor Sensors

Direct +1-805-242-4296
dennis@micronor.com

micronor sensors

Micronor Sensors, Inc.
2085 Sperry Ave, Suite A-1
Ventura, CA 93003
USA

Main +1-805-389-6600
Sales sales@micronor.com