New Fiber Optic Temperature Sensors Replace Thermocouples in Critical Medical, Food, Industrial, and Energy Applications

Presented by **Dennis Horwitz**, President

Sensors Converge, June 2025

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Seminar Outline

- ❑ Overview of Standard Electrical Temperature Sensors (TC and RTD)
- ❑ Electrical Sensors versus Fiber Optic Sensors
- ❑ Overview of Fiber Optic Temperature Sensors
- ❑ About FOTEMP (GaAs) Thermometry and Products
- ❑ Case Study #1: Medical - RF Radiotherapy and MRI
- ❑ Case Study #2: Biomedical – RF Induction Heating of Magnetic Nanoparticles
- ❑ Case Study #3: Food Processing – Microwave Ovens
- ❑ Case Study #4: Energy – Health Monitoring of Transformers
- ❑ Case Study #5: Energy - Bus Bar Monitory
- ❑ Case Study #6: Semiconductor – Better Process Monitoring for Better Yields
- ❑ Fiber Optic Do's and Don'ts
- ❑ Summary – What have we learned?
- ❑ Questions and Answers

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Today's Trends in Medical, Industrial, and Aerospace 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 and predictive maintenance
Medical Devices	Surgical & biopsy robots, treatment delivery, MRI, patient rehabilitation	Need variety of sensors, low cost, and small size, enhance health and 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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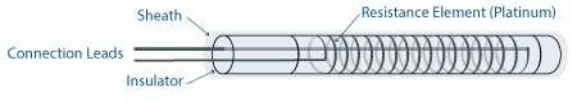
Overview of Electrical Temperature Sensors

Type	TC (Thermocouple)	RTD (Resistance Temperature Detector)
		
Theory	Two different metals produce a voltage which can be read to determine local temperature.	Changing the electrical resistance of metals as temperature increases or decreases.
Advantages	• Low Cost • Widest Temperature Range • Durability	• Minimum Vulnerability to EMI & RFO • Accurate and Stable Results • Repeatability
Drawbacks	▪ Relative Temperature Difference ▪ Poor Long-Term Stability ▪ Susceptable to Electrical Noise	▪ Moderate Cost ▪ Self Heating ▪ Slow Response Time

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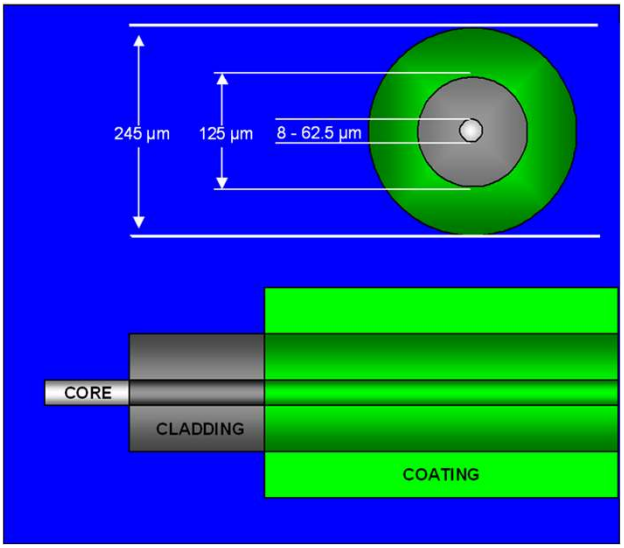
What is Fiber Optics?



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 850nm FBGs
- 50 or 62.5µm for multimode, 1mm for POF
- 200µm for FOTEMP

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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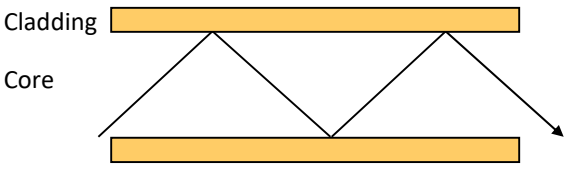
What is a Mode? Singlemode versus Multimode

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.

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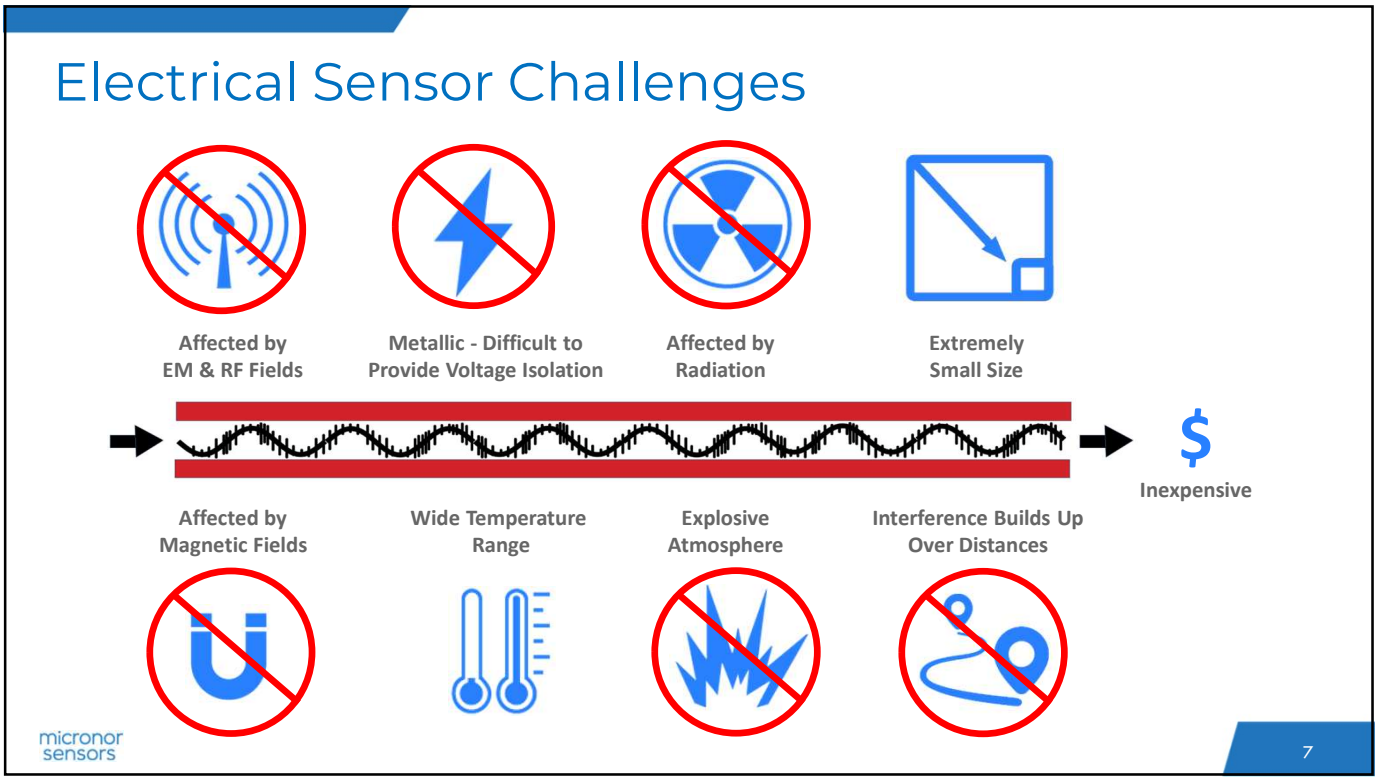
Electrical Sensor Challenges
Affected by EM & RF Fields
Metallic - Difficult to Provide Voltage Isolation
Affected by Radiation
Extremely Small Size
$
Inexpensive
Affected by Magnetic Fields
Wide Temperature Range
Explosive Atmosphere
Interference Builds Up Over Distances
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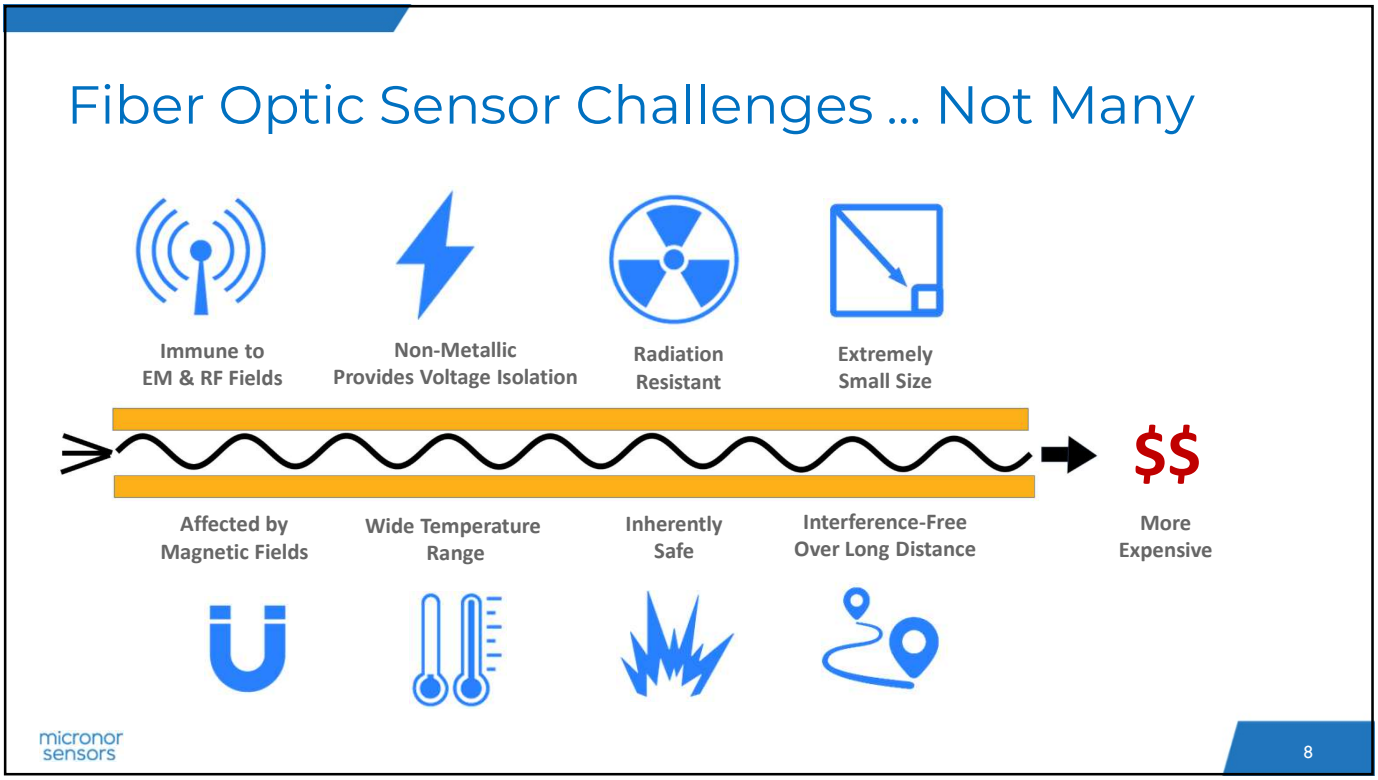
Fiber Optic Sensor Challenges ... Not Many
Immune to EM & RF Fields
Non-Metallic Provides Voltage Isolation
Radiation Resistant
Extremely Small Size
$$
More Expensive
Affected by Magnetic Fields
Wide Temperature Range
Inherently Safe
Interference-Free Over Long Distance
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Why do we need Optical Immunity Sensors?


Medical (MRI)


Aerospace

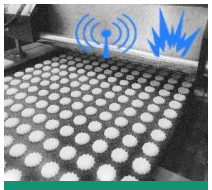

Power & Energy


Life Sciences


Semiconductor


Fusion Energy


Test Chambers & Labs


Food & Beverage

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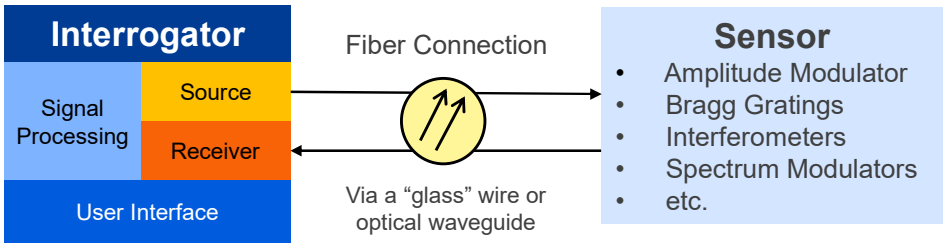
What is a Fiber Optic Sensor?

"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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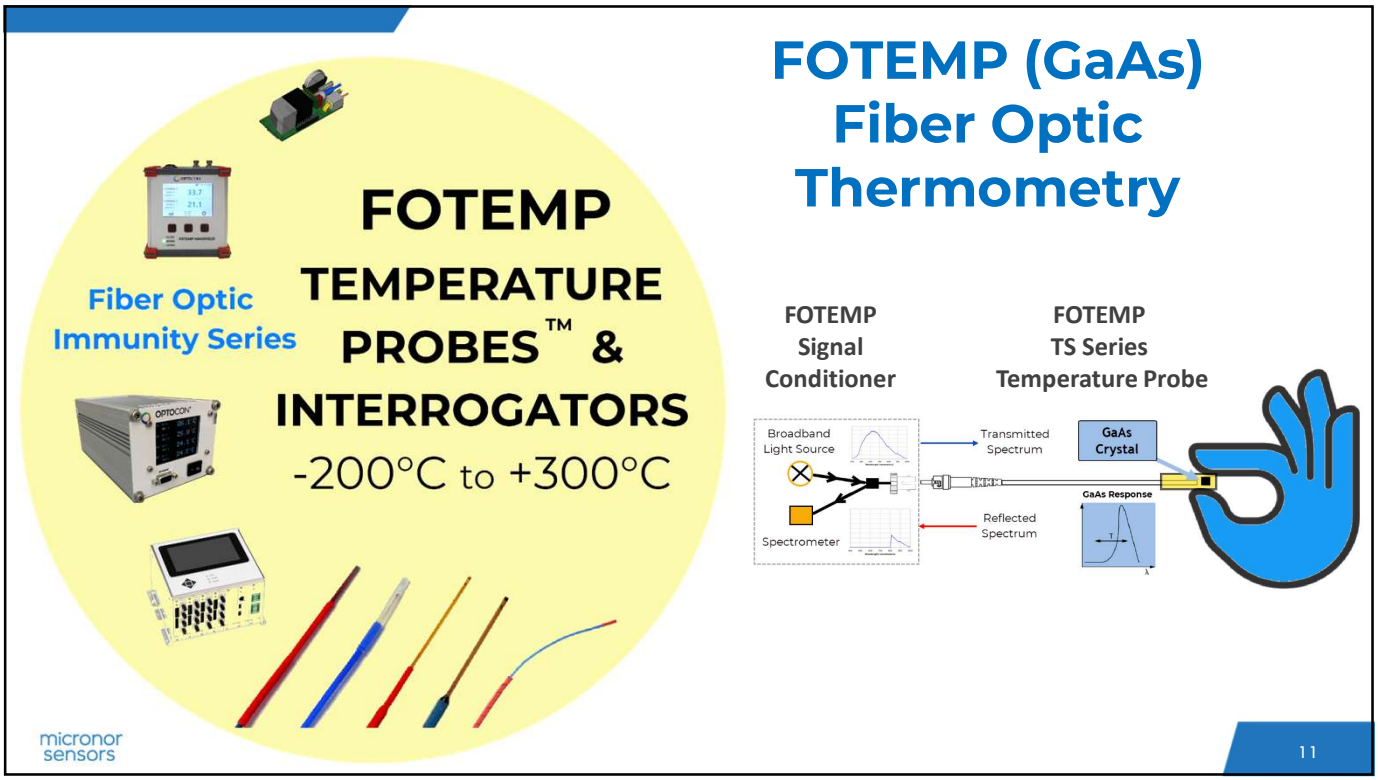

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Performance Comparison of Key Thermometry Technologies

Typical Characteristics	K-Type Thermocouple	FOTEMP (GaAs)
Measurement Range	-270°C to 1260°C	0.315nm/°C -200°C to +300°C
No. of Measuring Points per Sensor	1	1
Measurement Uncertainty (2σ)	±2.2°C	-200°C..-100°C, ±6 K -100°C..-40°C, ±1 K **°5°C...95°C, ±0.3 K** 150°C...250°C, ±1 K 250°C...300°C, ±3 K Best in class of all Fiber Optic Thermometer Systems.
Resolution	0.1°C	0.1°C
Update Rate	0.1 Hz	1-ch = 4 Hz 4-ch = 1 Hz
Max Distance	50m	2000m
Wire Used	Metallic	Multimode Glass Fiber 200/220
Ease of Integration	Plug-and-play	Plug-and-play

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Application Comparison of Key Thermometry Technologies

Environment	K-Type Thermocouple	GaAs
Benign, Short Distance <30m	✓	✓
Benign, Long Distance	✗	✓
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	✓

✓ Recommended

● Provisional

✗ Not Recommended

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Gallium Arsenide (GaAs) Thermometry

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INTERROGATOR

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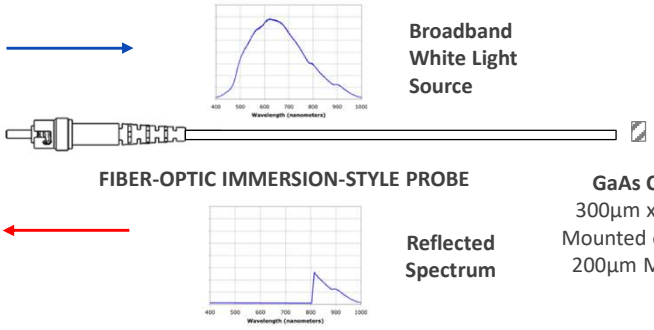
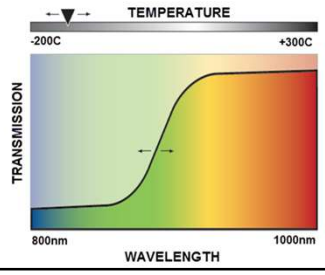


Principles of Operation

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} = 1.423*eV* ⇨ 300°K = 872nm

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

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FOTEMP TEMPERATURE PROBES™

MODEL	TS2p Smallest	TS3 General Purpose	TS4 Harsh Chemicals	TS5 Medical & SFF	TST Transformers	SmartSpacer Disc, & Busbar
Key Features	Smallest size, for direct contact measurement or micro-vial immersion, Bare GaAs crystal (300µm x 300µm) and fastest measurement, Non-Conductive.	Semi Rigid Probe, Immune to EMI/RFI and Microwave Emissions, Non-Conductive.	High Accuracy, Corrosion Resistant, PTFE Coated, Non-Conductive.	Flexible Probe, Small Form Factor, and Compact Size, Non-Conductive.	Specifically Designed for Use in Oil-Filled & Dry Transformers, Non-Conductive	Non-conductive accessories used to embed TST and TS3 probes in transformers, busbar and switchgear.
Applications	RF environments, High Voltage applications, Semiconductors & Medical Testing	General Use: Food, Microwave Oven, and RF Environments	Harsh Chemical and Liquid Immersion	Medical Environments, Catheter Instrumentation, Semiconductor, Small FF	Oil-Filled Transformers	General Use: Transformer Windings, Bus Bars, & other Switchgear.
Continuous Temperature Range	–200 °C to +260 °C	–200 °C to +260 °C	–200 °C to +260 °C	–200 °C to +260 °C	–200 °C to +260 °C	Temperature depends on material, max +180 °C
Short-term Temp Range (max 1hr)	+260 °C to +300 °C	+260 °C to +300 °C	+260 °C to +300 °C	+260 °C to +300 °C	+260 °C to +300 °C	
Accuracy (1σ)	± 0.2 °C	± 0.2 °C	± 0.2 °C	± 0.2 °C	± 0.2 °C	---
Thermal Response	20 °C/s	12 °C/s	7 °C/s	19 °C/s	19 °C/s	---
Probe Dimensions	D1: 0.45 mm D2: 1.70 mm D3: 1.30 mm	D1: 1.0 mm D2: 1.70 mm D3: 1.30 mm	D1: 1.0 mm D2: 1.7 mm D3: 1.3 mm	D1: 0.55 mm D2: 1.70 mm D3: 1.30 mm	D1: 1.70 mm D2: 1.30 mm D3: 3.00 mm	SmartSpacer & SmartDisc for use with TST probes. SmartBusbar with TS3.
Other Dimensions	L1: 2 mm L2: 42 mm L3: 2–20 m	L1: 15-550 mm L2: 20 mm L3: 2–20 m	L1: 15-550 mm L2: 10 mm L3: 2-20 m	L1: 15-550 mm L2: 20 mm L3: 2-20 m	L1: 10 mm L2: 15 mm L3: 2-20 m	Consult drawings
Cable Coating	Polyimide / PTFE	Polyimide / PTFE	PTFE	Polyimide / PTFE	PTFE	NOMEX T994, PEEK or Transformer Board
Connector Type	ST	ST	ST	ST	ST	---
STOCK PRODUCTS (L1 and L Lengths)	TS2p-02	TS3-15MM-02 TS3-15MM-05 TS3 for SmartBusbar	TS4-20MM-02 TS4-20MM-05	TS5-20MM-02, -06 TS5-50MM-02, -06	TST2D for SmartDisc TST2J for SmartSpacer	EOF0200 SmartSpacer EOF0256 SmartDisc ZM0060 SmartBusbar

98-OPTC-27-E
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FOTEMP Sensor Connectivity & Mounting Accessories

FOTEMP to DIST to Feedthrough to TS

MODEL	DIST-CXXX-YY FOTEMP FO Extension Cables	MR320A General Purpose ST Bulkhead (F-to-F)	EOF0008 (NPT) EOF0246 (Metric) Single Port (F-to-F) Hermetic Feedthrough	EOF0049 (2 Port) EOF0050 (1 Port) KF40 Flange (M-to-M) Hermetic Feedthrough	Sensor Spacers Inter-Winding, Disc, or Busbar
Key Features	Ruggedized Extension Cable: • DIST-C320, General Purpose • DIST-C900, Industrial Grade • DIST-CABLE, High Temperature • All cables include MR320A	Standard ST Bulkhead Adapter, not for vacuum or pressurized applications	Threaded Hermetic Feedthrough, SAE NPT or Metric, For pressure or vacuum vessels, oil-filled transformers	KF40 Flange, Fiber Optic Hermetic Feedthrough, for Vacuum Chamber Applications	Non-conductive accessories used to embed TST probes in transformers, busbar and switchgear.
Applications	RF environments, High Voltage applications, Semiconductors & Medical Testing	General Purpose, for lab, plant or process monitoring applications	For Vacuum or Pressurized Chambers/Vessels. Oil-Filled Transformers	For Vacuum or Pressurized Chambers/Vessels	General Use: Transformer Windings, Bus Bars, & other Switchgear.
Temperature Rating	CXXX cable: –55 °C to +85 °C CABLE cable: –200 °C to +300 °C ST Connector: –40 °C to +85 °C	–40 °C to +85 °C	–40 °C to +120 °C	–40 °C to +120 °C	Temperature depends on material, max +180 °C
Key Characteristic1	CXXX cable: PUR, UL94-V0 CABLE cable: PTFE		SAE Thread: ¼"-18 NPT Metric: Thread: M14 x 1.5		J-Spacer & Disc-Spacer for use with TST2J probe
Key Characteristic2	CXXX bend radius: 27mm CABLE bend radius: 60mmn		Vacuum rating: 10-6 Torr	Vacuum rating: 10-6 Torr	Flush Mount and Magnetic Busbar Spacer for use with TS3 probe
Key Characteristic3			Pressure rating: EOF0008: 200 bar, 2'900 psi EOF0245: 2 Bar, 29 psi		Materials: NOMEX T994, PEEK or Transformer Board
Fiber Type	200/220	Any Fiber Size	200/220	200/220	TS series sensors
Connector Type	ST	ST	ST	ST	---
STOCK PRODUCTS (Cable lengths in m)	DIST-C320-03, -05, -10 DIST-C900-03, -05, -10 DIST-CABLE-03 Custom lengths upon request.	MR320A	EOF0008 (SAE NPT) EOF0245 (Metric)	EOF0049 EOF0050 Requires 2x MR320A per port	EOF0200 Trafo J-Spacer EOF0256 Trafo Disc Spacer ZM0017 Busbar (Magnetic) ZM0060 Busbar (Flush-Mnt)

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FOTEMP® SIGNAL CONDITIONERS QUICK GUIDE

MODEL	FOTEMP-MN30 Most Popular	FOTEMP-C15	FOTEMP-HD20 Portable Handheld	FOTEMP-C20 Bench Top Most Popular	FOTEMP-T20 Multi-Channel to 16 Ch	FOTEMP-T30 Transformer Apps
Description	Small Form Factor OEM Module	OEM Module, Bench Top, Chassis or DIN Rail Mount	Handheld, Portable	Compact Bench Top	DIN Rail, Chassis Mount or Bench Top	Transformer-specific Monitoring System
No. of Channels	1 or 2	1, 2 or 4	1 or 2	4	4, 8, 12, or 16	2, 4, 6, 8, 12, 16
Measurement Range	–200 °C to +300 °C	–200 °C to +300 °C	–200 °C to +300 °C	–200 °C to +300 °C	–200 °C to +300 °C	–200 °C to +300 °C
Measurement Uncertaint (2σ, 5°C to 95°C)	± 0.3 °C	± 0.3 °C	± 0.3 °C	± 0.3 °C	± 0.3 °C (Std Apps) ± 1.0 °C (Trafo Apps)	± 1.0 °C (Trafo Apps)
Applications	Embedded OEM Application	Industrial Process, Switchgear, Generator, Transformer	Laboratory, Industrial, Process Monitoring	Laboratory, Industrial Process Monitoring	General Purpose, Industrial Process, Switchgear, Generator, Transformer	Transformer Hotspot Monitoring
Sample Rate/channel	250ms	250ms	250ms	250ms per Active Channel	1 sec for all channels	1 min for all channels
Internal Data Logging?	Yes	No	Yes	No	Yes	Yes
Data Logging Storage	MicroSD Card	No	MicroSD Card	No	MicroSD Card	USB Stick
Analog output	---	Std=0-10V Option=4-20mA	---	Std=0-10V Option=4-20mA	M= 4-20mA, V=0-10V (First 8 Channels Only)	4-20mA
Relay output	---	Option=4	---	Option=4	Standard=4	Standard, 1 per Channel
Interface	P0=USB-C (Pwr & Com) P1=ExtPwr/UART/RS232 & RS485/Modbus	P1=USB+RS485/Modbus	USB-C	P1= USB+RS485/Modbus	P1= USB+RS485/Modbus P2= USB+Ethernet/Modbus	RS485/Modubus/RTU & Ethernet/ModbusTCP
Power Supply	P0= USB-C (5V 3A) P1= 9-24VDC, 350mA	24 VDC (includes AC power supply)	Internal Li-Ion battery Ext: USB-C or 24VDC	24VDC (includes AC power supply)	24VDC/Max 40W	24VDC/Max 40W
STOCK PRODUCTS A1-CAL= -20C to +150C A2-CAL= -40°C to +200C B-CAL= -40°C to +300°C C-CAL= -200°C to +300°C	**FOTEMP-MN30-1-P0-B**	Special Order 4 Weeks ARO	**FOTEMP-H2-1-P0-B** **FOTEMP-H2-2-P0-B** **FOTEMP-H2-2-P0-C**	FOTEMP-C20-P1-V-B FOTEMP-C20-P1-V-C	Special Order 4-6 Weeks ARO FOTEMP-T20-16-P1-A2 FOTEMP-T20-8-P2-A2	Special Order 4-6 Weeks ARO

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Case Study #1: 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 #2: Biomedical - RF Induction Heating of Magnetic Nanoparticles (GaAs)

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 Weidmann TS3 GaAs sensor (both non-metallic and RF-immune) for both temperature indication and closed loop control of the customer's process.

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Case Study #3 – Food Processing with 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.

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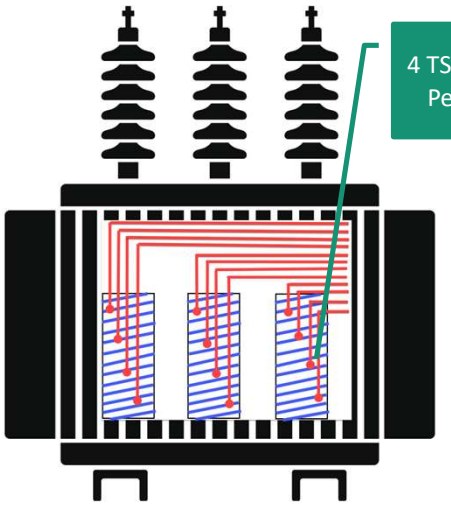
Case Study #4: Energy -Health Monitoring of Transformer Hotspots & Bus Bars

FO Attributes



CHALLENGE

Safe monitoring of generation and distribution transformers with internal potentials range from 15 kV to 50,000 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.

Most systems use 4-8 TST sensors per phase. Utility transformers have 3 phase windings.

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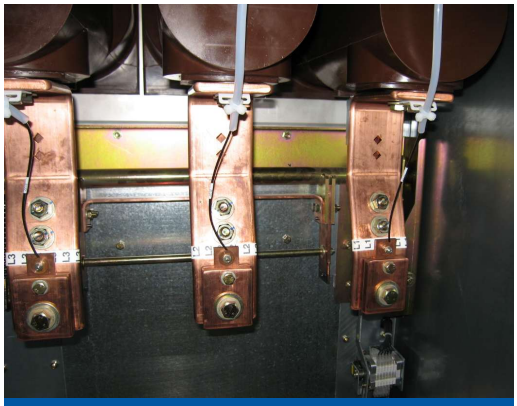
Case Study #5: Power – Bus Bar Monitoring

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

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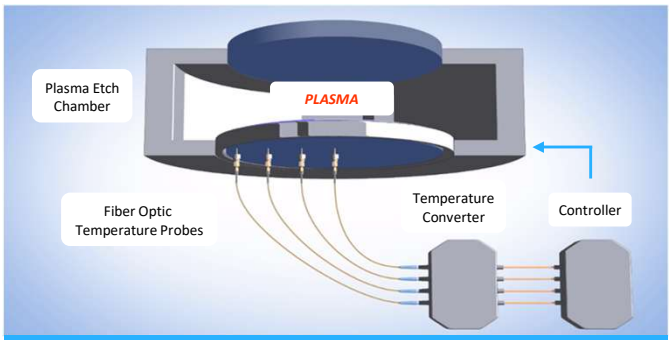
Case Study #6: Semiconductor Equipment Mfg

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.

CURENT SOLUTION

Current processes use single point fiber optic temperature probes, based on GaAs, Phosphoresence or Fluorescence. Working temperatures to 450°C and absolute accuracies down to ±0.2°C.

GaAs is the only technology that is absolute, based on intrinsic properties of GaAs. Phosphorescent and Fluorescent probes on based on well-characterized phosphor compounds which require calibration.

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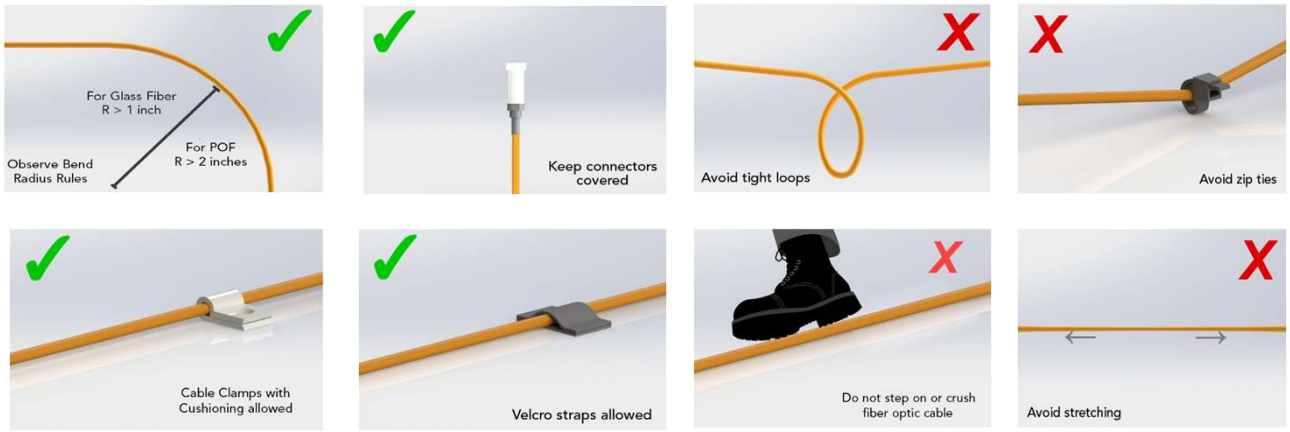
Fiber Optic Do's and Don'ts



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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 – beyond the capabilities of conventional electronics-based temperature sensors, i.e. where immunity to interference, e-fields, magnetic fields, rf fields, or long distances is required.
- ❑ 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.
- ❑ Reach out for a fiber optic sensor solution in your next project.

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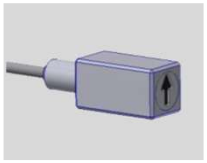
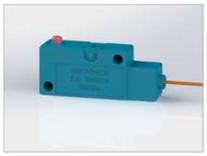
Micronor Sensors

Fiber Optic and Electromechanical Sensors



Fiber Optics

- ❑ Absolute and Incremental Encoders
- ❑ Emergency Stop
- ❑ Microswitch
- ❑ Accelerometer
- ❑ Precision Temperature (COMEM Optocon)
- ❑ Force and Strain (Lilikoi Innovation)

Electromechanical

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

MICRONOR® optical sensors

MICRONOR® mechanical products

COMEM OPTOCON® OPTICAL SENSORS AND SYSTEMS

LILIKOI Innovation

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