White Paper 2023

Comparison of Multicore Fiber Sensors to Legacy Electrical Sensors for Temperature Sensing Applications

White paper by K.C. Thompson PhD

Optical Sensing. Simplified.

TABLE OF CONTENTS

INTRODUCTION

Fiber optic temperature sensors have become increasingly popular due to their accuracy, high sensitivity, and immunity to electromagnetic interference. However, traditional fiber optic temperature sensors can be costly and complex, limiting their widespread adoption in many applications.

An emerging patented fiber optic temperature sensing technology offers a lower cost alternative while still providing significant advantages over traditional electrical temperature sensors. This technology leverages supermode interference to create a high dynamic range interferometer which achieves high accuracy and fast response times, making it a promising option for a wide range of temperature sensing applications.

In this white paper, we will compare Multicore Technologies' optical temperature sensors to commonly used electrical temperature sensors such as thermocouples, resistance temperature detectors, and thermistors. We will discuss the advantages and disadvantages of each technology and highlight real-world applications in which multicore fiber has demonstrated superior performance. Finally, we will provide recommendations for researchers and engineers interested in exploring the potential of this exciting new fiber optic temperature sensing technology.

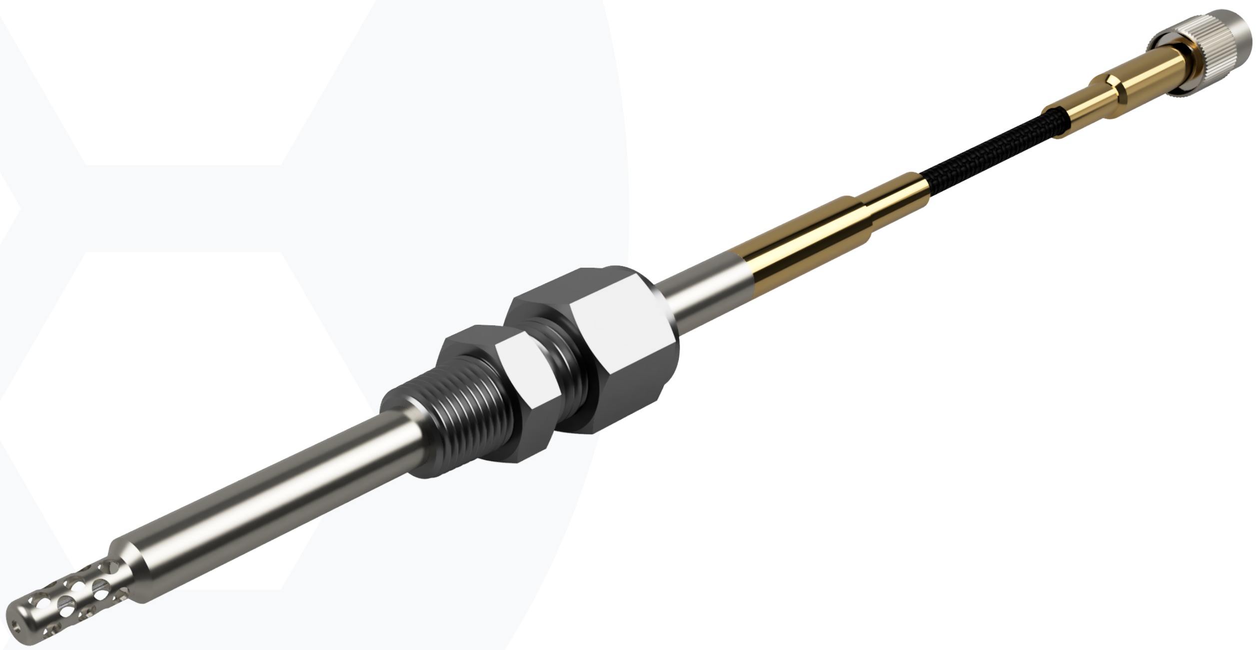
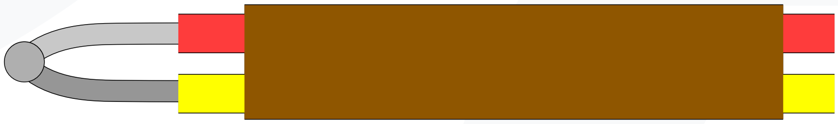


Figure 1: Automotive Packaged Temperature Sensor.

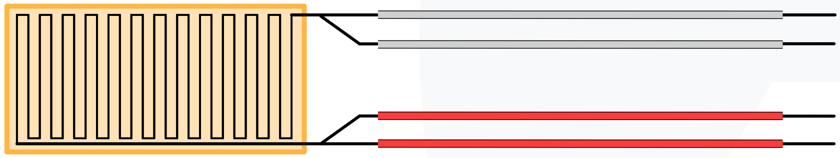
ELECTRICAL SENSORS

Electrical sensors for temperature measurement are widely used due to their simplicity, low cost, and ease of use. They work on the principle of changes in electrical properties of materials with temperature, such as resistance, voltage, or current. Some of the commonly used electrical sensors for temperature measurement are thermocouples, resistive temperature detectors (RTDs), and thermistors.

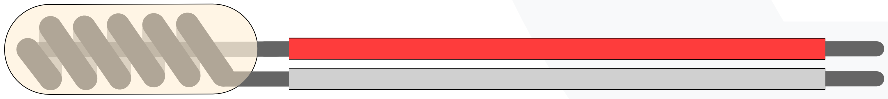
Thermocouples consist of two dissimilar metals joined at a point, generating a voltage proportional to the temperature difference between the measuring junction and the reference junction. They have a wide temperature range (-200 to 2300 °C) and fast response time (depending on construction). However, their output voltage is small and requires amplification and is extremely susceptible to noise and have low accuracy. In addition many environmental conditions and packaging factors can drastically reduce published ranges and increase cost and complexity of integration.



RTDs are made of metals with a positive temperature coefficient of resistance, such as platinum, nickel, or copper. They work on the principle that the resistance of the metal changes with temperature. RTDs have high accuracy and stability, a linear response, and a wide temperature range (-200 to 850 °C). However, they are relatively expensive, fragile, susceptible to noise and susceptible to self heating, and require a stable and accurate current source for excitation.



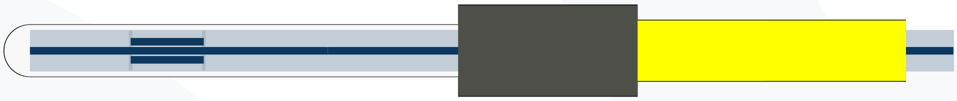
Thermistors are made of semiconductor materials with a negative temperature coefficient of resistance, such as silicon, germanium, or metal oxides. They work on the principle that the resistance of the semiconductor material decreases with increasing temperature. Thermistors have a high sensitivity and a fast response time, but their temperature range is limited (-100 to 300 °C, commercial units top out at 150° C), and they exhibit non-linearity and self-heating effects.



Overall, electrical sensors for temperature measurement are well-established and reliable, and have been used for many years in a variety of applications. However, they have limitations in terms of accuracy, range, and sensitivity compared to Multicore fiber sensors. The choice of the appropriate sensor depends on the specific application requirements and cost considerations.

MULTICORE SENSORS

Optical sensors for temperature measurement offer several advantages over electrical sensors, including high accuracy, sensitivity, and fast response time.



Principle of operation:

Multicore fiber (MCF) sensors use supermode interference generated by closely coupled optical cores to create an optically stable, high contrast, tunable interference pattern which is sensitive to changes in fiber temperature. The physics driving this temperature sensitivity, the thermo-optic effect, operates based on the refractive index of the optical fiber sensing element changing with temperature. This change in refractive index causes a repeatable shift in the interference pattern between two or more supermodes in the fiber. This wavelength shift in the interference pattern can be tracked in the wavelength domain with spectrometers using a broad light source or digitized by a photo-detector with a narrow line-width source in the power domain, to generate an electrical signal proportional to temperature.

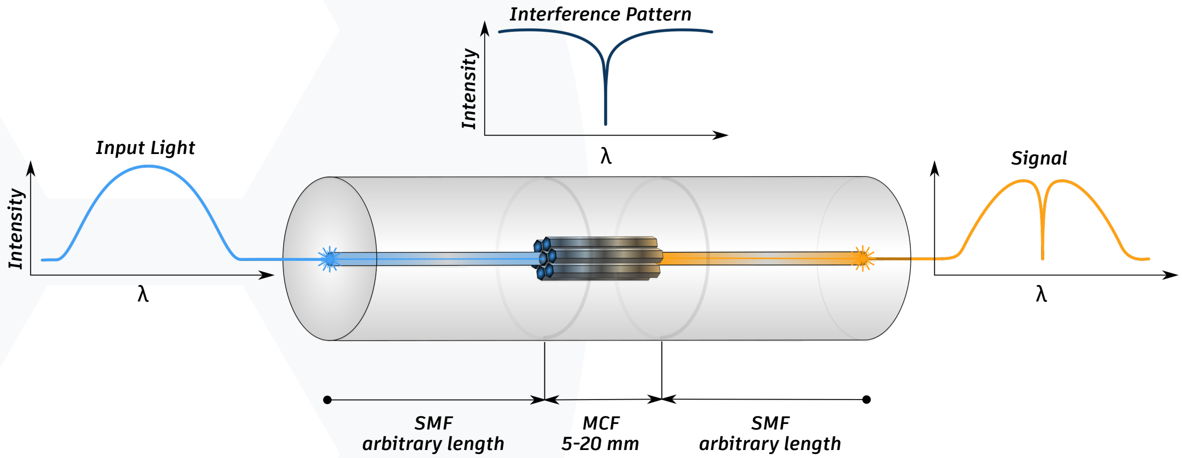


Figure 2: Operational schematic for Multicore fiber supermode interference sensing.

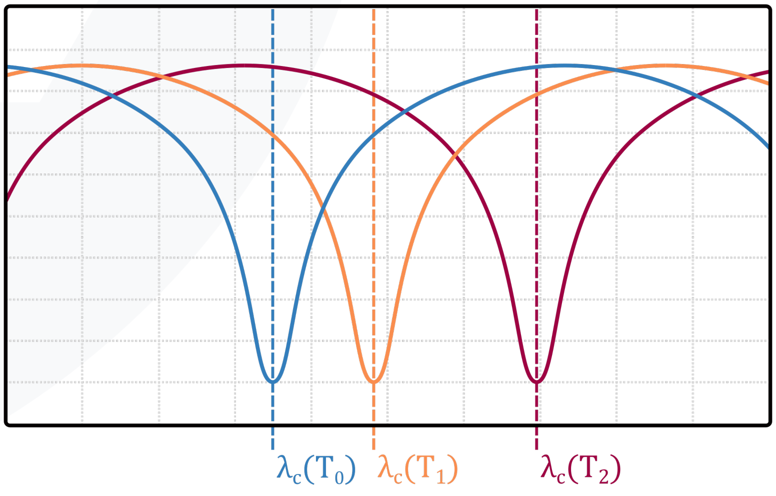


Figure 3: Example Multicore interference spectra experiencing a "Red Shift" as the fiber temperature is increased ($T_0 < T_1 < T_2$), this shift is repeatable and reversible.

ADVANTAGES

When comparing optical and electrical sensors for temperature measurement, there are several factors to consider, including accuracy, sensitivity, range, response time, and cost. Here is a more detailed comparison of these factors.

Accuracy:

MCF sensors have high accuracy due to the use of precise and stable laser sources, the ability to eliminate temperature/strain cross-sensitivity through signal processing techniques and thoughtful packaging similar to methods used in RTDs. In comparison, electrical sensors have lower accuracy due to factors such as self-heating, hysteresis, drift, environmental noise, and require frequent re-calibration to ensure accuracy. This is because optical sensors use light as a signal, which is not affected by electromagnetic interference or other environmental factors that can cause drift or hysteresis in electrical sensors. In the figure, the thickness of the lines represents the absolute error in °C that the sensor experiences at a given temperature. The Multicore fiber sensor experiences an error of 0.1 °C or 0.1% whichever is greater over its entire range which greatly exceeds even the most accurate RTD sensors.

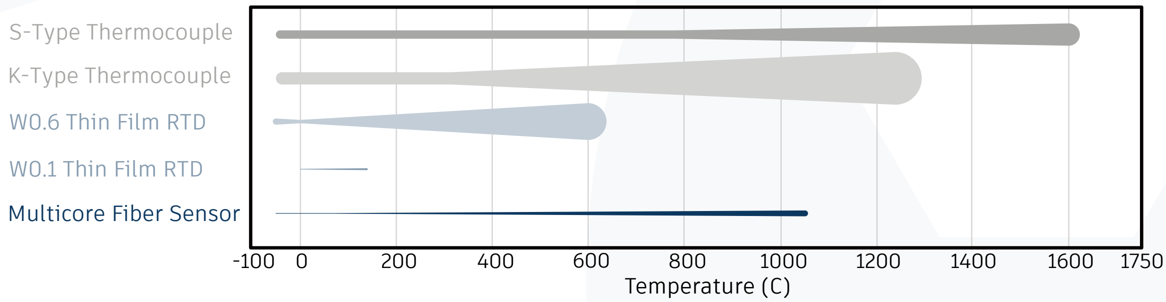


Figure 4: Comparison of Accuracy over the published Temperature Range for Legacy Electrical Sensors and Multicore Fiber based Temperature sensors where the line-width represents the error in °C at the temperature specified on the x-axis.

Sensitivity:

MCF optic sensors can detect temperature changes as small as 0.01 °C, making them suitable for high-precision applications. This high sensitivity comes from the ability to detect small changes in the refractive index caused by temperature variations. In contrast, electrical sensors have lower sensitivity due to their dependence on changes in electrical properties such as resistance or voltage, which are less sensitive to small temperature changes.

Cost:

MCF sensors are able to be cost competitive with most high accuracy electrical sensors due to the reduced cost of power based interrogation and simplification of fabrication techniques for the multicore fiber temperature elements. This enables multicore fiber sensors to be the first fiber optic sensing technology that can challenge electrical sensors which are relatively low cost and widely available.

Minimal drift and hysteresis:

MCF optic sensors are relatively immune to drift and hysteresis effects, which can be a significant source of error in electrical sensors. This is because optical sensors use light as a signal, which is not affected by electromagnetic interference or other environmental factors that cause drift or hysteresis in electrical sensors.

Range:

MCF sensors have an extensive temperature range, from -50 to 1000 °C, depending on the type of optical fiber used and the laser source. Electrical sensors have a wide range as well, depending on the type of sensor, such as thermocouples, RTDs, or thermistors, with ranges typically ranging from -200 to 1750 °C for thermocouples depending on gauge, -200 to 850 °C for RTDs, and -100 to 300 °C for thermistors. This makes Multicore sensors suitable for a wide range of applications, from biomedical research to aerospace and industrial process control.

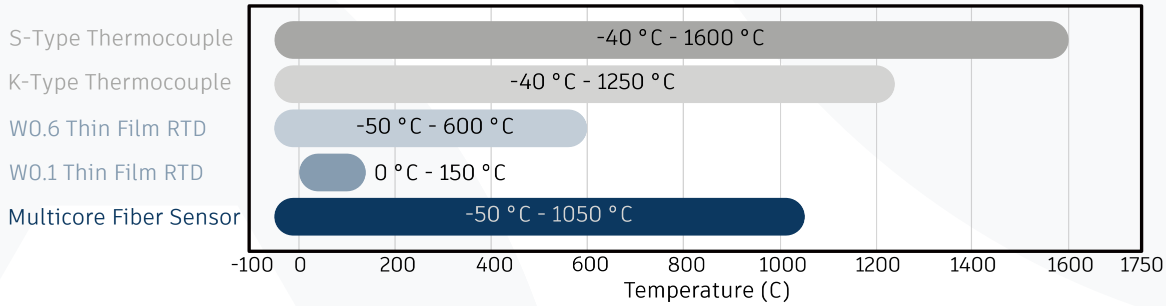


Figure 5: Comparison of Temperature Range for Legacy Electrical Sensors and Multicore Fiber based Temperature Sensors

Response time:

MCF sensors have a fast response time (τ = 0.11s), due to the high speed of light in optical fibers and low thermal mass for multicore fiber sensing elements. Electrical sensors have response times that can vary depending on the type of sensor but are generally slower than optical sensors due to factors like thermal mass and heat transfer rates. Electrical sensors can have similar response times to Multicore fiber sensors, but this comes at the expense of durability and temperature range where the fiber sensors have the fastest response time with no impact to performance.

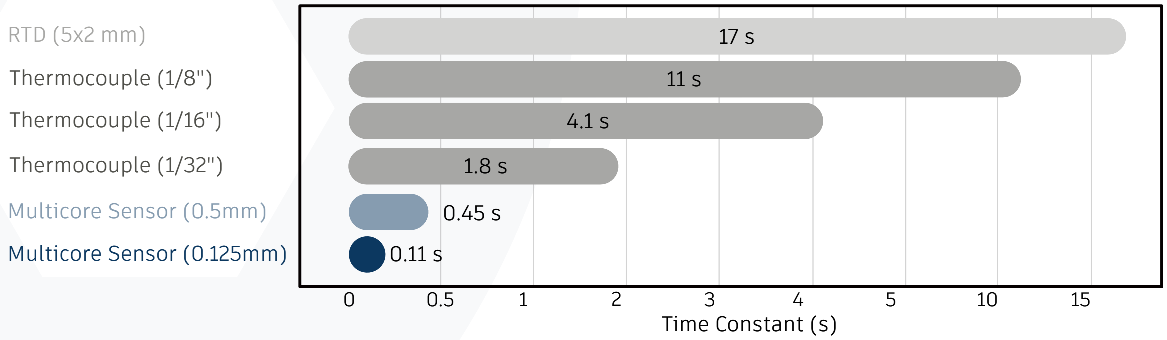


Figure 6: Comparison of published T63 time constant for common sizes of Legacy Electrical Sensors and Multicore Fiber based Temperature sensors where the 0.125mm diameter multicore fiber sensor is the theoretical maximum without fiber modification.

High spatial resolution:

MCF temperature sensors have a low volume form factor and can provide high spatial resolution temperature measurements at a localized scale. This can be useful for thermal mapping of complex structures such as electronic devices, biomedical tissues, or industrial machinery, where temperature gradients and hot spots can be accurately detected and monitored. The small form factor also significantly simplifies OEM-level integration of Multicore fiber-based temperature sensors and allows end users to measure temperature in environments that would not be possible with legacy electrical sensors.

Inherently Inert Package:

MCF optic temperature sensor elements are monolithically constructed of high strength glass which results in an inherently inert package which does not interact with the environment, or the material being measured, making them ideal for applications in harsh or corrosive environments featuring high voltage and strong electromagnetic interference. The inert packaging of these sensors makes them great for use in biological processes. Interactions with the sensor can affect the accuracy and reliability of measurements..

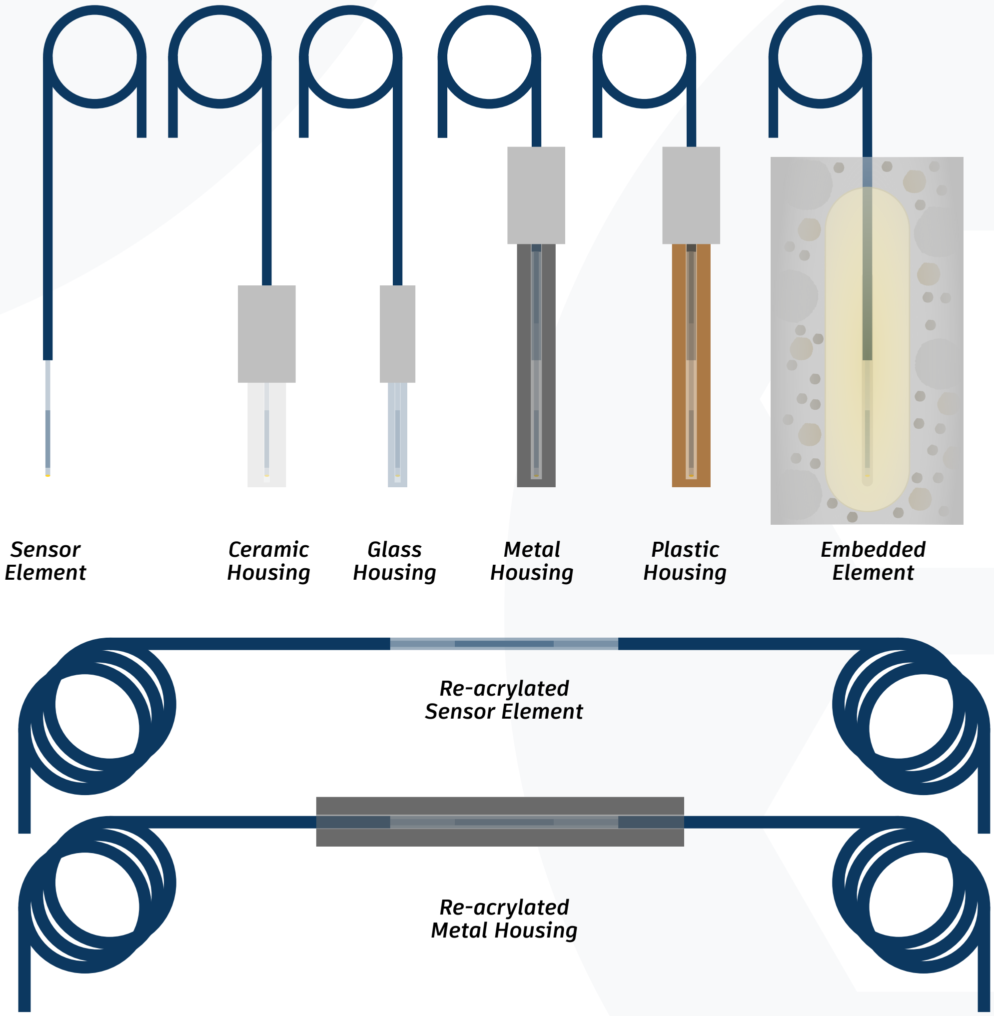


Figure 7: Illustrations of various method of packaging Multicore Sensor Elements.

MCF sensors offer several advantages over electrical sensors for temperature measurement, including high accuracy, sensitivity, and fast response time. These benefits are realized while removing the issues typically associated with optical sensing technologies of being relatively expensive due to requiring specialized expertise and equipment to design, fabricate and interrogate.

The choice of sensor depends on the specific application requirements, with cost and performance being key considerations.

APPLICATIONS

Multicore fiber sensors have several advantages over electrical sensors for temperature measurement in various applications.

Industrial temperature monitoring:

In industrial settings such as manufacturing, process control, and power generation, temperature monitoring is critical to ensure efficiency, safety, and product quality. MCF temperature sensors can provide accurate and reliable temperature measurements in harsh environments, where electrical sensors may be affected by electromagnetic interference or high temperatures. For example, MCF temperature sensors can be used for temperature monitoring in gas turbines, chemical reactors, high voltage electronics (transformers, generators, etc.) and boilers, in which high temperatures, corrosive gases, and high pressure are common.

Aerospace and Defense:

In aerospace and defense applications, temperature monitoring is crucial to ensure the reliability and safety of aircraft, spacecraft, missiles, and other systems. MCF optic temperature sensors can provide high accuracy, stability, and durability in extreme environments, including high altitude, low pressure, and high radiation. For example, MCF temperature sensors can be used for temperature monitoring in aircraft engines, space vehicles, and missile launchers, where high precision and reliability are essential.

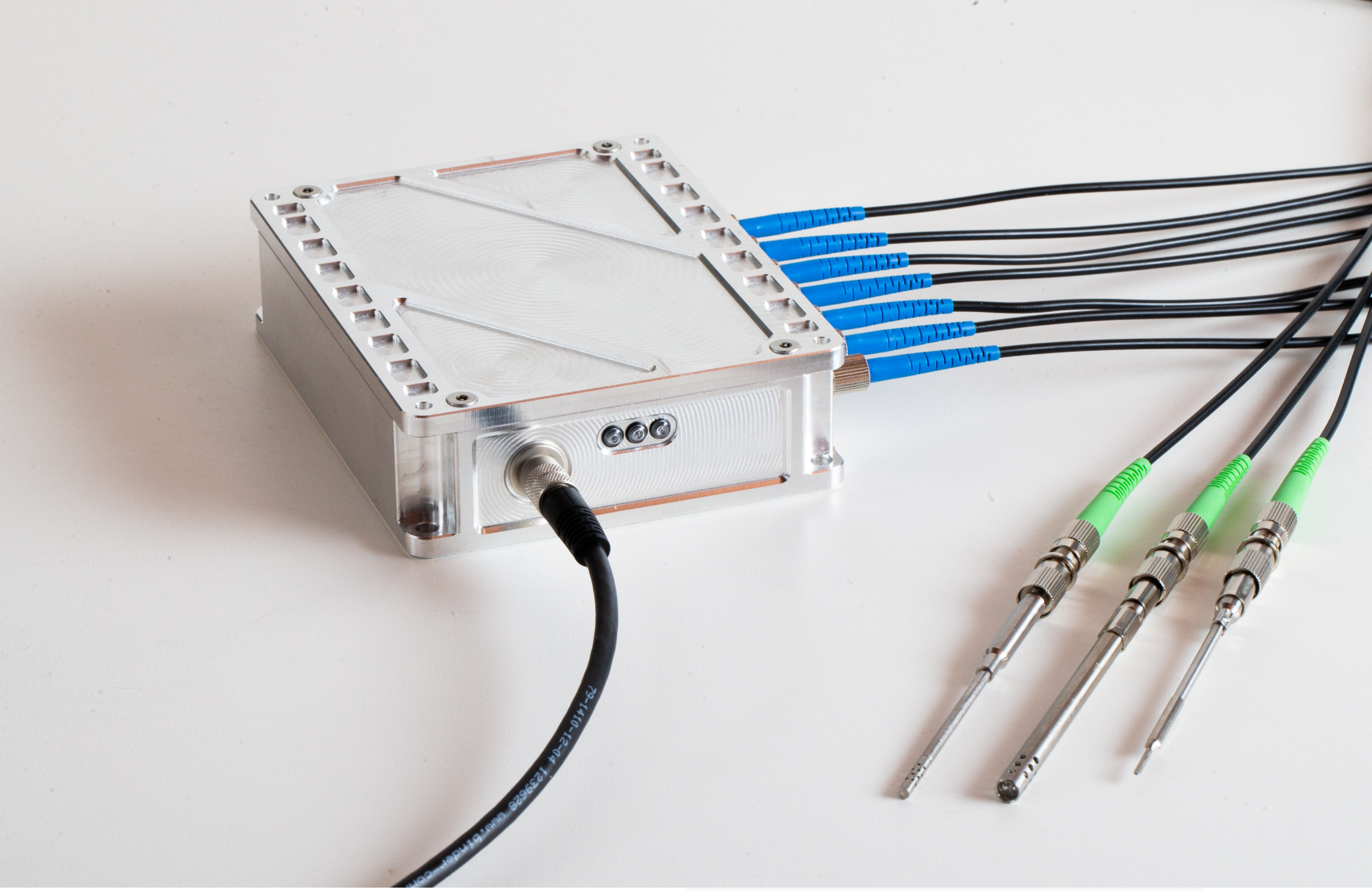
Biomedical and Life Sciences:

In biomedical and life sciences applications, temperature monitoring is important for various research and clinical applications, thermal therapy, cryopreservation, and tissue engineering. MCF temperature sensors can provide high spatial resolution and sensitivity, as well as minimal invasiveness, compared to electrical sensors. For example, MCF temperature sensors could be used for temperature monitoring in tissues, cells, and microfluidic devices, where high accuracy and non-invasiveness are required.

Harsh Environment Sensing:

MCF temperature sensors offer significant advantages in harsh environment sensing with their robust construction and immunity to electromagnetic interference. They are well-suited for use in extreme conditions featuring high temperatures, pressures, as well as noisy and corrosive environments. These sensors can be employed in industrial settings for oil and gas exploration, where accurate temperature measurements are crucial for monitoring equipment performance and ensuring operational safety. Similarly, in automotive industries, multicore fiber temperature sensors can be utilized to monitor temperature in critical components exposed to extreme temperatures and mechanical stress. Their ability to withstand harsh environments without compromising accuracy and reliability positions them as a valuable solution for various industrial and engineering applications.

In summary, MCF temperature sensors have several advantages over electrical sensors for temperature measurement in various applications, including industrial temperature monitoring, aerospace and defense, and biomedical and life sciences. These sensors offer high accuracy, stability, and durability in harsh environments, as well as high spatial resolution and sensitivity in non-invasive measurements.



RECOMMENDATIONS

We believe that our MCF optic temperature sensors offer a simple and cost-effective solution for high performance temperature sensing applications in a variety of industries. If you have any further questions or are interested in exploring the potential benefits of using MCF optic temperature sensors in your application, we encourage you to ***contact*** our team of experts at Multicore Technologies. We have extensive experience in developing and deploying optical sensing solutions, and we would be happy to discuss your specific requirements and provide tailored recommendations. At Multicore Technologies, we are committed to making optical sensing simple for our customers.