AUTOMOTIVE TEMPERATURE SENSING

Keystone Thermometrics
967 Windfall Road
St. Marys, PA 15857
(814) 834-9140 • (814) 781-7969 (fax)
Authors: Nasser Y. El-Awar, David J. Geer, Theodore J. Krellner, Peter J. Straub
Presented on September 14, 1999

Abstract

Temperature sensors have been commonplace in a variety of automotive applications, enabling the enhancement of automotive systems. The ongoing trends to improve the system's performance and efficiencies, the driver convenience, and reduction of emissions continue to drive new temperature sensor applications. This paper will discuss the market drivers, trends, applications, technologies, and packaging (single function and multi-functional integration) advancements of both existing and emerging automotive temperature sensors.

Introduction

Thermistor-based temperature sensors have been used in automotive applications since the late 1940's to send signals to gauges and later to electronic control modules. As the system's complexity increased, the number and type of temperature sensors increased, and the performance requirements also became increasingly stringent.

After reviewing the current drivers, trends, and applications of automotive temperature sensors, this paper will focus on two key developments of thermistor based temperature sensors:

1. The development of leadframe technology as a sub-assembly to improve traditional single-function temperature sensors, as well as multi-functional sensors (i.e. the integration of more than one sensing element into the same package or housing).
2. Thermistor based temperature sensor for high temperature applications (1000°C), such as exhaust gas and catalytic converter temperature sensing.

Temperature Sensor Drivers

Similar to other automotive sensors, there have been three primary drivers that have contributed to the growth of temperature sensors throughout the vehicle. They are:

- Mandates
- Technical advancements
- Customer wants/desires

Typically, mandates are initiated by the government and are usually environmental or safety related. Environmental regulations tend to concentrate on emission control and fuel economy. These regulations drive the need for more complex and additional systems. The objective is to optimize the performance of the engine and powertrain while minimizing the impact on fuel consumption and emissions. Although the safety regulations have provided significant sensor growth, environmental regulations have been a stronger driver for temperature sensor applications.

In addition to mandates by external forces, technical advancements have had a significant impact on the proliferation of temperature sensors. The growth of automotive electronics has fueled the need for sensory devices within the vehicle to provide feedback of the parameters being controlled. This proliferation of electronics and the increase of inputs/outputs on existing electronics have increased the need for temperature sensors in the engine management and HVAC systems. This expansion of the electronics throughout the vehicle and to lower end vehicles was enabled by the continual decrease in cost of electronics.

The end customer "wants" have also driven the need for electronics and sensors within the vehicle. The customer's desire for information regarding the vehicle and its surroundings, and the desire for more automatic control of systems that interface with the driver have lead to the increased use of temperature sensors. Specifically, the HVAC system has driven the use of temperature sensors beyond the high-end vehicle segment.

Temperature Sensor Applications:

Temperature sensors provide a key parameter to the electronic module to enable feedback of the system's current state of operation. The two systems of the vehicle that are primary users of temperature sensors are the engine/powertrain management system and the HVAC system. Additionally, many of the electronic modules require temperature compensation that is satisfied with a board-mounted thermistor.

The engine/powertrain management system uses a number of temperature inputs to enhance the performance of the engine, control emissions, and optimize efficiency. The most common applications are the:

- coolant temperature sensor
- intake air temperature sensor
- transmission oil temperature sensor
- cylinder head temperature sensor

The coolant temperature sensor measures the temperature of the coolant and interfaces with the electronic control module (ECM) on a 5-volt circuit. This sensor provides feedback to the ECM regarding the temperature of the coolant at a single point on the engine. Similarly, the cylinder head temperature sensor provides the temperature of the metal at a single point on the engine. Using this temperature data and previous engine calibration information, the ECM controls the operation of the engine management system to achieve optimal engine control.

Engine intake air temperature is also a key temperature used by the ECM. Similar to the coolant sensor, this sensor interfaces with the ECM on a 5-volt circuit. Typically the sensor is located in one of three areas: the air cleaner, the intake air duct, or the intake manifold. This sensor is often integrated with the mass air flow sensor or manifold absolute pressure sensor to provide a multi-functional sensing unit.

In automatic transmissions, a temperature sensor monitors the temperature of the automatic transmission fluid. This input enables the control system to enhance the transmission's operation. It also maintains an optimal fluid temperature to reduce degradation and potential overheat conditions.

An emerging application for temperature sensing is the exhaust gas or catalytic converter sensor. This application is more demanding than the previously mentioned sensors due to the temperature range required. In many of these applications, the sensor is required to operate from –40°C to 1000°C.

Historically engine/powertrain temperature sensor applications have been common. The recent expansion of automatic HVAC control and driver information feedback have led to significant increase of temperature sensors for the HVAC system. The most common applications for the automatic HVAC control are:

- outside air temperature sensor
- inside/cabin temperature sensor
- duct air temperature sensor

The outside air temperature sensor monitors the temperature of the air external to the vehicle. The sensor interfaces with the HVAC control unit and/or display module to enable automatic HVAC control or outside temperature display.

The inside/cabin temperature sensor provides the temperature within the passenger compartment of the vehicle. This temperature, coupled with the outside air temperature, is a key parameter to providing an automatically controlled cabin environment.

Duct sensors of the HVAC air delivery system are increasing due to temperature zoning within the cabin and further HVAC control system strategy refinements. These sensors further enhance the automotive HVAC system by providing additional measurement locations.

Obviously, the applications for temperature sensors are beyond those mentioned above. Each sensor has resulted from the need to know more information about a system or the environment. As electronic systems become more complex, additional specialized applications will also emerge to satisfy the control system's need for information.

Temperature Sensor Trends

Similar to other sensors and automotive components, temperature sensors are not unique to the typical trends of automotive. The ever-increasing demands placed on automotive temperature sensors have led to trends that can be characterized in one of two categories: the sensing element or the packaging. Proper packaging is essential to the successful operation of the sensing element. Trends in temperature sensors are classified below for simplicity.

Trend	Sensing Element	Packaging	Comments
Smaller	X	X	Smaller elements enable increased response times, smaller packages enable mounting in desired locations
Faster	X	X	Continual desire for real time response to a temperature change
More accurate, Inter-changeability	X		Reduction of error and variability from part to part
Increased stability	X		Increased life expectations and reduction of performance degradation over time
Lighter		X	Less weight
Fastenerless mounting		X	Ease of assembly
Electronic integration/ “smart”		X	Bus interfacing, remote electronics
Hotter operating temperatures	X	X	Underhood temperatures increase
Lower cost	X	X	Automotive requirement
Multi-functional sensing (w/existing elements)		X	i.e., temperature and pressure
Multi-functional sensing (w/new sensing elements)		X	i.e., temperature and humidity

Leadframe

Thermistor-based temperature sensing elements benefit from robust engineering. This process yields products or services that perform satisfactorily over the entire range of environments that may be encountered. Products designed with robust engineering practices routinely satisfy customer’s requirements by reducing variation in product performance. Elements of robust design should be addressed using present Design Failure Mode Effects Analysis (DFMEAs). Design weaknesses are assessed using the risk priority number (RPN) and appropriate corrections implemented, resulting in a design that provides a higher quality product to the consumer. Design is only one element of robust engineering, the other is manufacturing. By observing the Process Failure Mode Analysis (PFMEAs), manufacturing methods can be enhanced, not only by the design but also by the manufacturing method. This reduces variability, streamlines manufacturing and enhances performance and quality.

The goal of the robust engineering approach for thermistor elements is to reduce the complexity, increase the integrity of thermistor assemblies, and provide a product that is more uniform and facilitates automated assembly by the customer. To achieve this, the product function, potential failure modes and manufacturing techniques (internal and external) require attention to detail, as described below.

Function (Design Objective) – to provide a consistent electrical output that varies as a function of temperature change. It is also desirable to provide a consistent time response and a reliable mechanical interface to the customer’s wiring harness.

Potential Failure Modes – design mechanism that can fail and affect the function of the device as described. These can be interconnections from the thermistor, the connector terminal, or thermistor location in respect to the final sensor package.

Internal Manufacturing – opportunities to reduce manufacturing steps and reduce assembly complexities that will provide more robust manufacturing capabilities, reduce cycle time and improve manufacturing yields.

External Manufacturing – to provide the customer with a device that allows automated assembly of the thermistor components into completed sensors and provides reliable shutoffs for overmolding.

To address these requirements, lead frames provide the best solution over alternative thermistor attachment technologies. These are standard crimp and weld, loop and solder, crimp only or solder only manufacturing technologies.

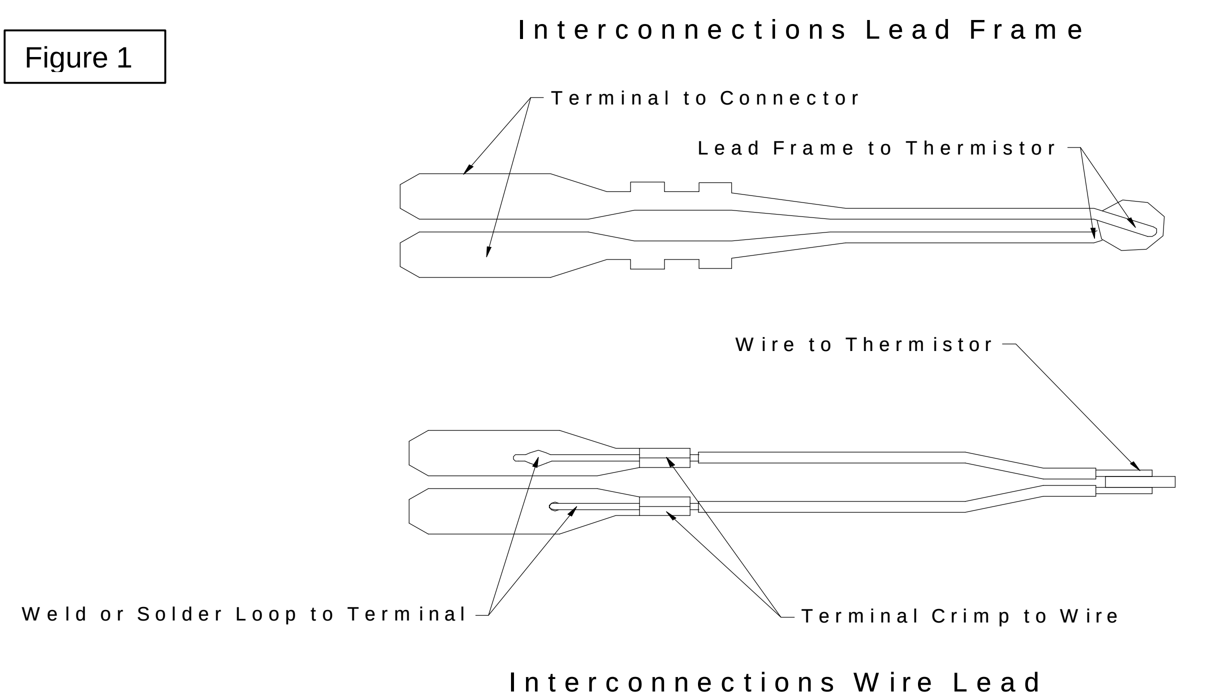
By producing thermistor elements with lead frames, a more consistent length can be achieved. Typically overall lengths can be controlled to ±0.50 mm. With precise location the thermistor time response variability is reduced. When compared to leaded devices, lead frames improves consistency in time response by better than 10%. The lead frame is designed to provide the customer with the connector terminal as an integral part, not as an add-on or afterthought. These two aspects improve the first consideration of the robust engineering study, the function.

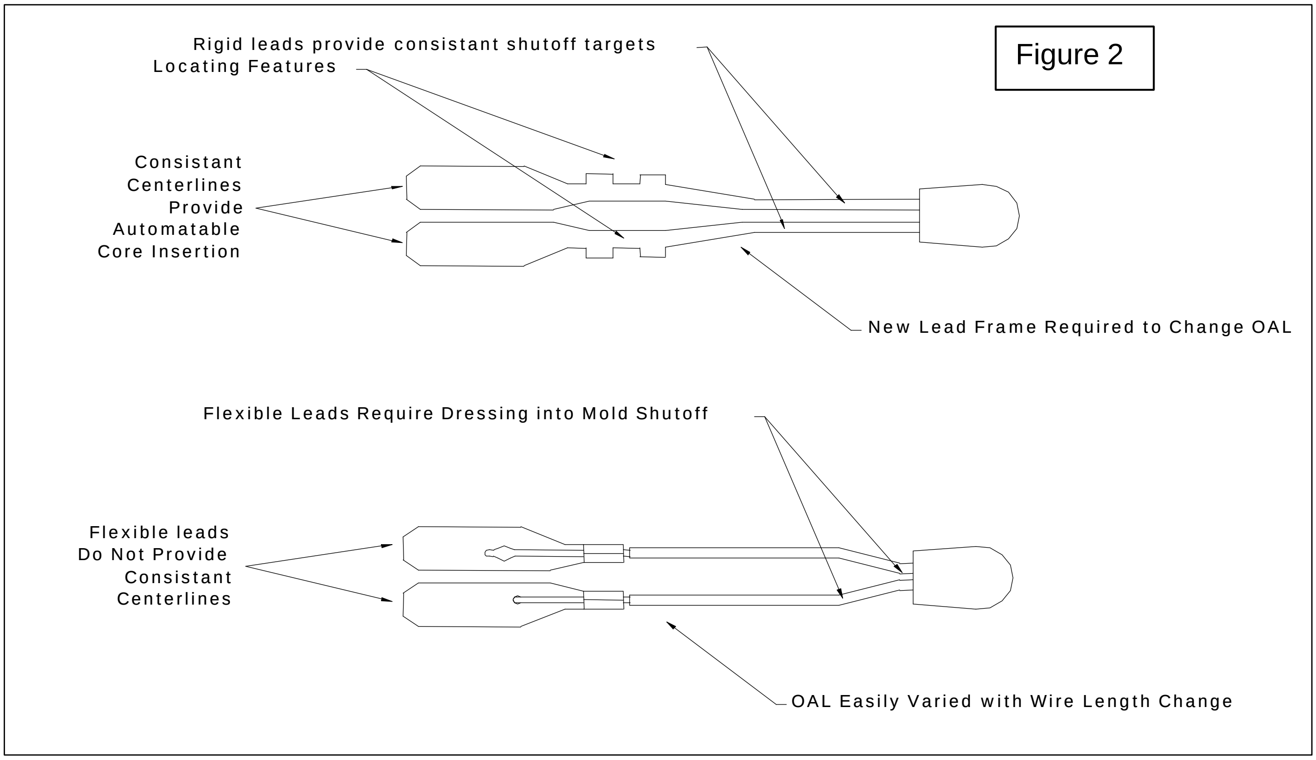
The next item addressed was the potential failure areas. In standard crimp and weld construction, there are eight separate interconnections to provide the electrical response from the thermistor to the wiring harness. Each of these joints is a possible source of failure, and the weld or solder is an added margin of safety for the crimped joint. The use of lead frames reduces the number of interconnects from the thermistor to the wiring harness to a total of four and eliminates potential failures of these additional connections. This is 50% reduction in the number interconnects. (*See Figure 1.)*

Internal manufacturing was also addressed by the use of lead frames. Manufacturing steps were streamlined. Throughput and efficiencies were addressed.

The most important benefits from robust engineering are the ability to provide the customer with a device that provides internal and post consumer advantages of quality and reliability. Post consumer advantages are addressed by providing a more robust, repeatable higher quality product that is less sensitive to external factors, such as vibration. Due to the robust nature of lead frames, they can readily automated sensor assembly, providing advantages of lower manufacturing costs. Lead frames provide consistent centerlines for automated pick and place into injection molding operations. In addition, it is possible to provide the consumer with product on continuous reels for automated loading. Lead Frames also provide wide target areas for mold shutoff and alleviate the necessity of dressing wires into the mold cavities by operators. (*See Figure 2).*

Figure 1





Rigid lead frames provide more reliable product location during molding. To facilitate the benefits of automation, future designs of lead frames devices should be keyed around common features in the lead frame to optimize manufacturing processes.

There are, however, drawbacks to lead frame technology. The greatest is the inflexibility of the overall length of the component. Length changes require new stampings to be developed, and tooling costs are incurred. With the foresight of future designs, flexibility may be able to be incorporated into the initial design to minimize future tooling charges.
In conclusion, robust engineering provides a unique solution to thermistor-based temperature products. Increased reliability, reduced complexity and total quality improvements are achieved.

Current and Future applications
As described above, the lead frame technology offers a number of benefits to designers of discrete single element temperature sensors. Currently, this technology is employed in temperature sensor applications ranging from coolant temperature, engine air temperature, transmission temperature, inside and outside air temperature. In each of these applications, the lead frame has enabled unique product designs and processing methods to improve the competed sensor's performance.

Although the lead frame was originally conceived for single element sensors, the design also offers the same advantages to the growing trend of multi-function integration of sensing elements into the same package or module. Some common multi-functional sensor applications are:

- T-MAF (Temperature and Mass Air Flow)
- T-MAP (Temperature and Manifold Air Pressure)
- Dual coolant sensors (integration of the coolant sensor and sender into one housing)
- Temperature and humidity sensors.

Its robust design is enabling product and process engineers to replace wired-thermistor components with lead frame components in these multi-functional sensors while reducing cost and complexity of the sensing system.

High-Temperature Sensor

Background:

Environmental concerns have driven legislative bodies in the U.S. and Europe to set and enforce stricter regulations on exhaust emissions of gasoline and diesel powered vehicles.

Studies have shown that cold start and warm-up stages account for a large percentage of polluting emissions. In order to meet LEV/ULEV [Low Emission Vehicle/ Ultra Low Emission Vehicle] requirements, technologies had to be developed to monitor and control the catalytic conversion process. Among several options, the heated catalyst technology is emerging as the most viable solution.

Lowered catalytic efficiency in aging catalysts and malfunctioning of exhaust systems control components also contribute to higher pollutant emissions during run time. In addition, OBD [On-Board Diagnostics] Systems regulations require monitoring of catalytic converter deterioration to maintain conversion efficiency in aging catalysts.

LEV/ULEV and OBD solutions require sensors capable of monitoring high temperatures in the order of 500°C – 750°C. This range extends to the maximum temperature of ~870°C, the upper limit on an efficient catalytic conversion process. These sensors are also required to withstand and detect high temperatures in the order of 1000°C – 1100°C, where total failure of the catalyst would occur.

There are various high-temperature sensing solutions. Of these, thermocouples, RTD's, and thermistors are considered primary options. Automotive standards and specifications drive one end of the selection process, while technological advances, manufacturing capability, and cost control the other end.

Automotive Industry standards focus on electronic interfacing, resolution, output characteristics [R or V vs. T], stability, response time, and physical properties including performance under all automotive environments.

Of the three solutions offered above, a thermistor-based high temperature sensor emerges superior to the others in meeting the standards at a comparable cost. The major automotive applications in temperature sensing – coolant, air intake, cylinder head, cabin HVAC – use a thermistor. In addition, automotive electronic circuits use thermistors for temperature compensation. In an environment where the thermistor is dominant, adding another sensor of the same family would be a logical selection. Thermistor electronic interfacing is a simple pull-up resistor/voltage divider circuit and an A/D converter. Thermocouples require cold junction voltage-compensation circuit and the use of thermocouple extension wires. Also, thermocouples have an output signal of μVolts/°C. Thermistors offer a large change in R as a function of temperature, translating into an output signal of mV/°C. Because of their low signal input, thermocouples and RTD’s require a higher resolution A/D converter.

Thermistor Solution

Continued development in high temperature material systems produced sensors suitable for operation from –40°C to 1000°C. This is done with a high degree of accuracy and repeatability that match or exceed automotive industry standards.

Description:

The high temperature sensor is composed of an NTC bead thermistor encapsulated in stainless steel or Inconel housing with flexible lead wires. *(See Figures 1 & 2)*.

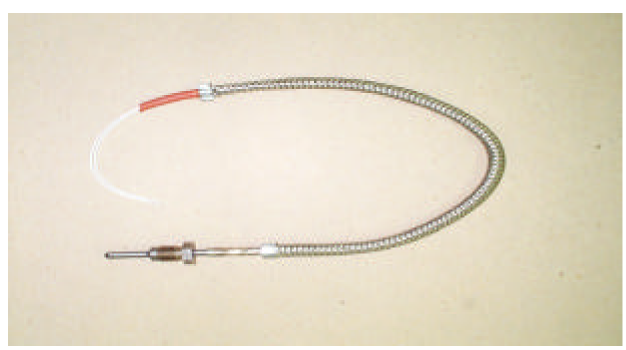


Figure 1

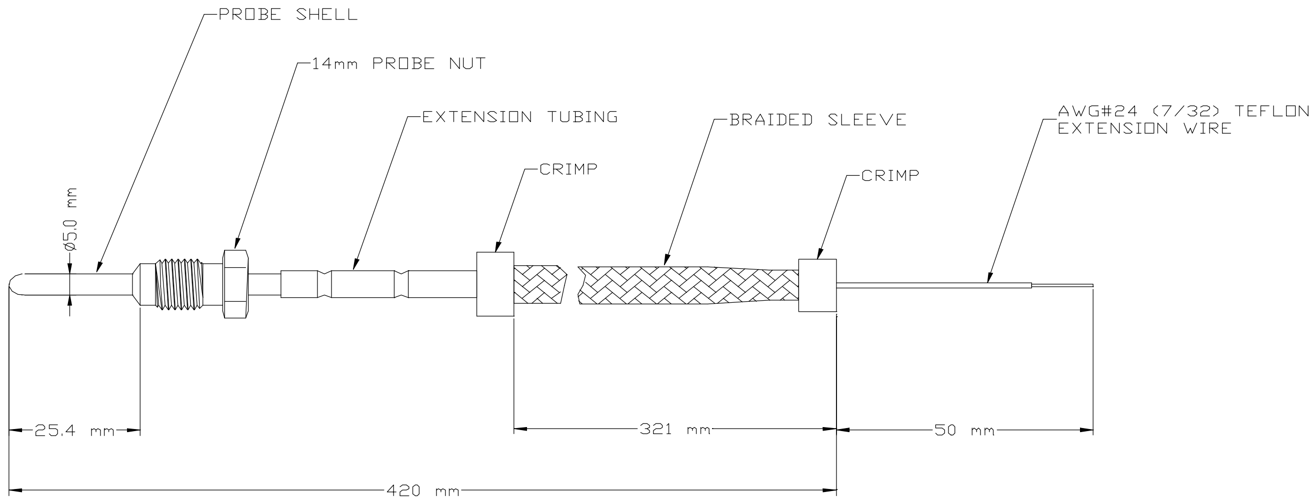


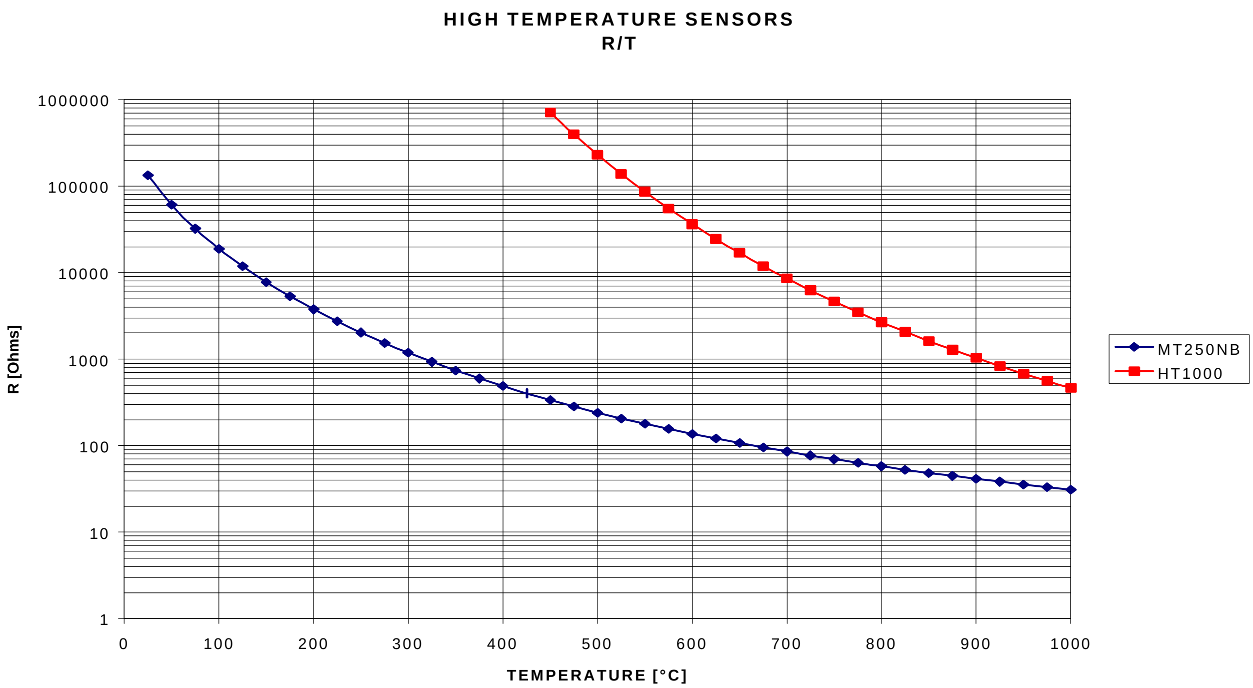
Figure 2

<u>Features</u>:
Reliable operation up to 1100°C
High sensitivity to temperature change
Corrosion resistance housing
Probe configuration designed for
automotive and appliance applications

<u>Options</u>:
Other mechanical configurations
Alternative temperature tolerances

<u>Data</u>:
Continuous operating temperature:
-40°C to +750°C
Maximum operating temperature:
1000°C for 50 hrs. with
1-hr. excursion to 1100°C
Tolerance: ± 5°C @ 300°C
Time Constant: 12s nominal

Resistance vs. Temperature Characteristics:



Conclusions

Thermistor-based temperature sensors have been the technology of choice for automotive temperature sensors. This technology has proven that it can adapt to the changing environment and the new applications required by the vehicle's systems. Additionally, the robustness of the element enables it to be packaged to reduce cost and improve performance of single and multi-functional devices. The base technology revealed its adaptability to the vehicle demands through the development of a device capable of withstanding exhaust gas temperature. This adaptability, added to its flexibility of electrical output, will enable the thermistor to maintain its position—with automotive system designers—as the preferred temperature sensing technology.