

TPMI™ - Thermopile Sensor Module

With Integrated Signal Processing



Description

In recent years, thermopile detector technology has opened up a large variety of industrial and commercial applications for non-contact, infrared temperature measurements. Aside from well-known thermopile applications in ear thermometers and hand held pyrometers, new applications include temperature control in microwave ovens or other household appliances such as toasters and hair dryers, home and automotive climate control, and a growing number of other industrial functions.

Most of these applications require an accurate signal output independent from ambient temperature variations. Up to now, this was achieved by external analog signal-processing circuits or, for high accurate devices, by an external microcontroller. However, with growing high-volume applications, there is a strong demand for miniaturization and simplification of the circuitry.

PerkinElmer Optoelectronics now satisfies this demand by providing the very first fully integrated and pre-calibrated thermopile module, TPMI, in a TO-5 size housing. Depending on the temperature range, an accuracy up to ± 1 °C is achievable. Its modular design, where optics, spectral filter ranges, PCB geometry, and connectors can be chosen individually, makes it the ideal infrared solution for the flexible implementation of remote temperature measurement into any application.

Features

- Smart thermopile sensor with integrated signal processing
- Adaptable for specific measurement tasks
- Integrated, calibrated ambient temperature sensor
- Output signal ambient temperature compensation
- Fast reaction time
- Various optics and IR filters available
- Digital serial interface for calibration and adjustment purposes
- 8 bit resolution
- Analog front-end/back-end, digital signal processing
- E²PROM configuration and data storage
- Two configurable comparators with high/ low signal for remote temperature threshold control
- TO-39; 6 pin housing

Applications

- Miniature, remote non-contact temperature measurement (pyrometer)
- Temperature-dependent switch for alarm or thermostatic applications
- Residential, commercial, automotive, and industrial climate control
- Household appliances featuring a remote temperature control, i.e., microwave ovens, toasters, or hair dryers
- Temperature control for laser printers and copiers



Introduction

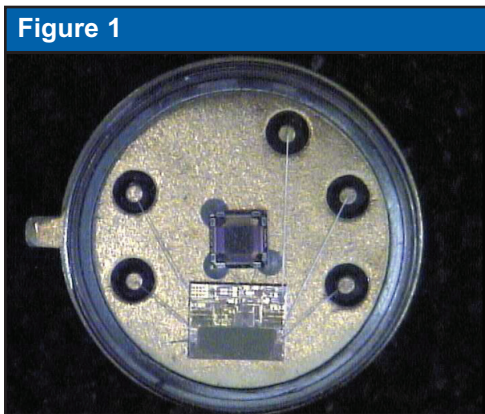
The new integrated thermopile module consists of a thermopile chip and an ASIC, for signal processing, ambient temperature measurement and compensation of the object temperature, in a TO-5 sized housing. The implemented serial communication interface allows fully automated trimming and calibration of the sensor. The compact device has only 6 connection pins, from which only 3 are needed in remote temperature measurement applications.

This sensor is offered either as single component with integrated optics or on a printed circuit board (PCB) with mirror optics and connectors. The TPMI targets applications where high accuracy, compact size, long term stability and low cost are essential in industrial, home appliance or automotive applications.

The new TPMI solution is a significant improvement over the current PerkinElmer thermopile module (TPM), which employs an external discrete circuit on a PCB for the amplification of the signals and for the necessary ambient temperature compensation. In short, the new TPMI offers the following advantages over the current solution:

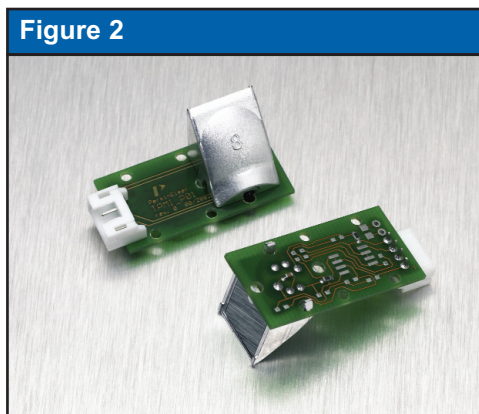
- Compact TO-5 sized housing; calibration of ambient temperature sensor and object temperature output performed within ASIC,
- No external components required; PCB version for upgrade compatibility to current thermopile modules available (see Fig. 3),
- Effective shielding of low level sensor signals against electromagnetic interferences,
- Output pins carry amplified signals in the voltage range, which make the sensor module insensitive against humidity and leakage currents on PCB or assembly.

Figure 1



The hybrid setup of the PerkinElmer thermopile module with integrated read-out ASIC.

Figure 2



TPMI on printed circuit board (PCB) with mirror optics. No external components are required. The PCB, however, allows the possibility to add external low pass (integrating) filters. The shown version is compatible to the PerkinElmer TPMF1 thermopile module.

Design Concept

The design of the new integrated thermopile sensor module includes at first the thermopile detector chip itself. Further, the ambient temperature sensor and the signal processing electronics, usually required in addition to the thermopile detector, are integrated in a mixed analog/digital ASIC with the following features:

- Adjustable low noise amplifier for amplification of the signal generated by the thermopile chip,
- Temperature reference sensor with subsequent signal processing,
- Calculation stage for thermopile signal independence from ambient temperature,
- Bi-directional serial digital interface for ASIC trimming and calibration,
- Programmable memory registration for non-volatile storage of the trimming and calibration adjustments,
- Minimized supply current for reduction of self heating of the sensor

Figure 1 shows the hybrid setup of the thermopile chip and the mixed signal ASIC on a TO-39 baseplate with 6 connection pins. The user can choose among a variety of caps in different heights and window openings, with or without an integrated mirror or lens. The introduction photo on page 1 shows a lens design. Figure 2 illustrates a module with mirror optics configured on a PCB.

Details

The signal voltage generated by the thermopile detector is preamplified by a programmable low noise amplifier. The amplification is adjustable in several gain ranges, each range allowing a 8-bit adjustment in the amplification.

Depending on the object temperature being higher or lower than the actual ambient temperature of the thermopile, the thermopile voltage signal can be positive or negative. In order to allow signal processing of negative voltages with a single voltage supply system, the internal amplifiers are referred to an internal bandgap reference of 1.225V.

For offset voltage trimming of the amplification, the preamplifier is followed by a programmable trimming stage, generating an offset voltage.

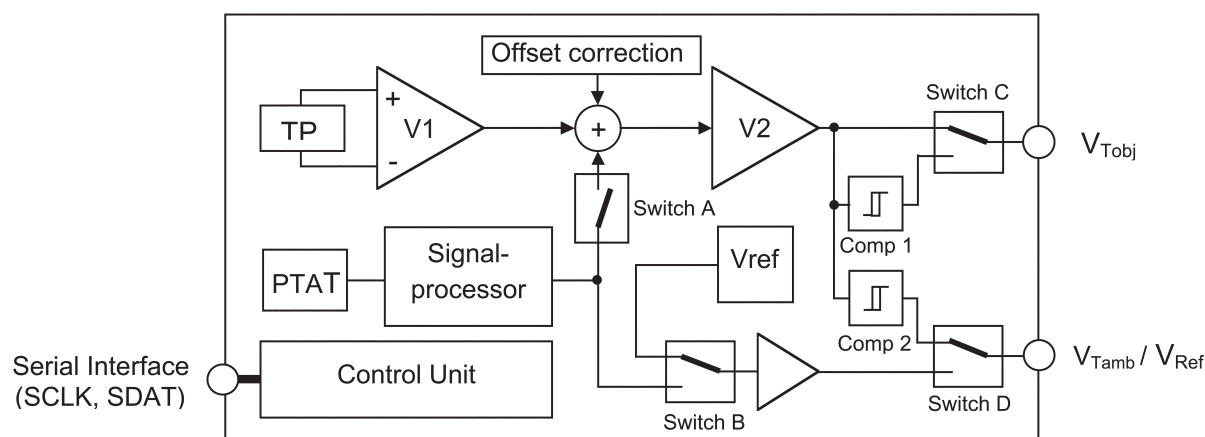
The internal temperature of the thermopile sensor is recorded by a calibrated temperature sensor with linear

characteristics. The signal of this temperature reference is amplified and processed by a polynomial processing unit to adapt it to the non-linear $\sim T^4$ shape of the amplified thermopile curve in order to achieve the optimum of ambient temperature compensation. The characteristics of the temperature reference signal (offset and slope) are adjusted by PerkinElmer during the production process.

The output signal (the object temperature range) can be adjusted in a wide range to suit the application requirements. Optionally, via an analog switch, the temperature compensation can be disabled.

The TPMI additionally features two comparators with programmable set points and hysteresis, which make an easy remote temperature control in industrial processes possible. It can use the TPMI as a temperature dependent switch for alarm purposes.

Figure 3: Schematics of the TPMI



TP: Thermopile

PTAT: Temperature Sensor

V_{Tobj} : Output voltage object temperature

V_{Tamb} : Output voltage ambient temperature

V_{Ref} : 1.225 V reference voltage

The ambient temperature compensated signal representing the object temperature is supplied to the output V_{Tobj} . The temperature reference signal or alternatively the bandgap reference voltage is available on a second output pin, V_{Tamb} . Both outputs are short circuit stable.

The control unit offers a bi-directional synchronous serial interface to access the configuration memory for the adjustment of ASIC parameters, the trimming of the ambient temperature sensor, the calibration of the thermopile detector, and to permanently store information.

After power-on, the stored information is automatically copied to random access registers that can be changed via the serial interface. Any changes made to the registers are lost after power interruption or will be overwritten with the permanently stored data after the TPMI is powered up the next time. This gives flexibility to the calibration of the sensor in the factory and opens up the opportunity to deliver the customer a plug & play device, which is possible to be adapted according to the specific application requirements.

Ambient Temperature Compensation

The thermopile sensor generates a voltage U_{TP} , which is proportional to the incident net radiation P_{rad} :

$$U_{TP} = S \cdot P_{rad} = S \cdot K \cdot \varepsilon \cdot (T_{obj}^4 - T_a^4)$$

with S = sensitivity, K = instrumentation factor containing the Stefan-Boltzmann constant and the view angle, ε = emission factor.

The equation shows that for a fixed ambient temperature, the thermopile output voltage U_{TP} is proportional to T_{obj}^4 . As also seen from the equation, the output signal will vary when the ambient temperature changes and, therefore, the TPMI will need to compensate this effect. Because the ASIC has good thermal contact with the thermopile sensor, it measures exactly the ambient temperature with its integrated linear temperature sensor. In order to achieve a best fit to the thermopile T^4 characteristics, the linear temperature signal will be further processed into a polynomial behavior, which approximates the characteristic to the required T^4 behavior over a large temperature range.

Measurement Results and Achievable Accuracy

In mass production, the TPMI Modules are calibrated under controlled ambient conditions. Different black body temperatures are used for calibration and testing. This procedure ensures a precise adjustment of the output curve and an excellent reproducibility from batch to batch. The PerkinElmer TPMI is indeed a consumer type pyrometer head, but due to the sophisticated adjustment procedures for an device with 100°C range an absolute accuracy of better than ± 2.5 K over the whole ambient temperature range of 10 to 60°C is achievable. In fact, an accuracy of ± 1 K at the calibration point is accomplished. For the TPMI, the achievable measurement accuracy depends mainly on the measurement range (higher range induces lower accuracy) and the ambient temperature span (below 10°C and above 70°C deviations occur). It has to be noted, however, that under dynamic conditions, i.e. object or ambient temperature changes, the specified values might temporarily not be met due to temperature inhomogeneities over the sensor module.

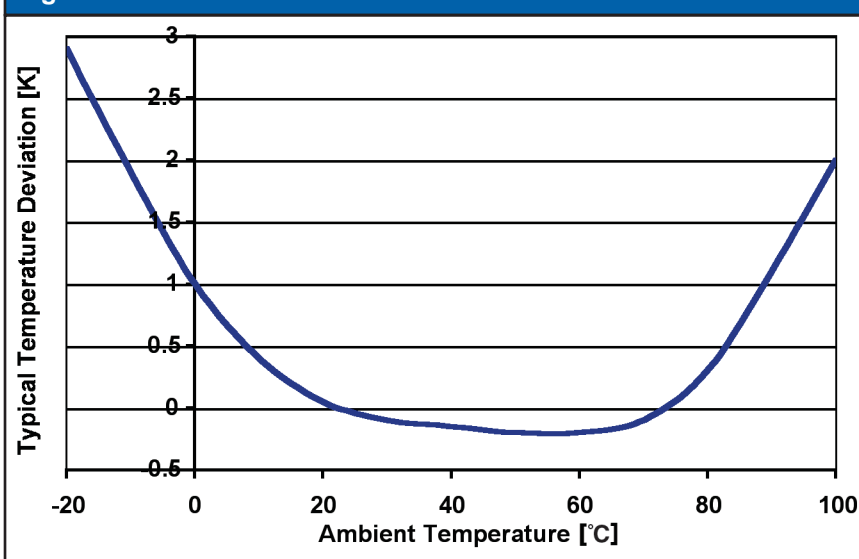
The curve in Figure 4 shows a typical deviation of the measured temperature as a function of ambient temperature variation. For temperatures between 10°C and 80°C the V_{TObj} output is relatively independent from

This voltage is added to the thermopile signal in the compensation stage. It has to be noted that the ambient temperature compensation needs to be adapted to each individual application. In particular it is determined by:

- The viewing angle, which depends on the optics, i.e. the aperture, the optical lens or mirror,
- The emission factor, which is dependent of the material and surface of the measured object,
- The sensitivity of the thermopile chip and its temperature coefficient, which should be as small as possible (note: PerkinElmer thermopiles are designed to have an extremely small temperature coefficient),
- The total temperature range to be measured

These factors need to be determined first in order to assess the needs of the customer. PerkinElmer can provide assistance in finding the optimum conditions for an individual mass production part.

Figure 4



Typical measurement error as a result of ambient temperature variation. Note the wide interval ranging from 10°C to 80°C, where the object temperature deviation is smaller than 0.5°C.

changes of $T_{ambient}$. Above 80°C the V_{TObj} characteristics becomes nonlinear related to $T_{ambient}$, which is caused by a decreased approximation of the T^4 by the ambient temperature measurement. The same effect occurs at ambient temperatures below 10°C.

Table 1. Characteristics of the PerkinElmer TPMI

Parameter	Typical	Units	Conditions
Supply voltage, VDD	5	V	TA = 25°C
Supply Current, IDD	1.5	mA	TA = 25°C, VDD ; R _{load} > 1 MΩ
Operating Ambient Temperature, TA	-25 to +100	°C	
Analog Output Resistance	60	Ω	
Analog Output Load, R _{load}	>50	kΩ	
Serial Clock Frequency	10 to 100	KHz	
Response Time after Power On	0.5	s	
Temperature Accuracy	±2.5	K	TA = 10 ... 70 °C
Power supply rejection ratio PSSR	70	dB	
Output noise	120	μV/√Hz	Gain ≈ 1000≈
Bandgap voltage reference	1.225	V	
Gain resolution	8	bit	

Conclusion

This technical note describes the first programmable and pre-calibrated, fully integrated thermopile module (TPMI) with ambient temperature compensation in TO-5 housing. The new product is designed with a powerful integrated circuit (ASIC), combining the thermopile sensor with signal processing and interface for calibration and configuration on a small space.

Digital calibration via a serial interface enables a plug & play function. Memory cells and register access offer a maximum of flexibility to change factory calibration or settings for adaptation of the sensor to the specific application.

With its superior performance over today's thermopile modules with discrete external circuit, the PerkinElmer TPMI has the potential to advance fast into existing and new applications.

For development purposes, an application kit is available, which enables the access of all features via a PC based program.

For more information e-mail us at opto@perkinelmer.com or visit our website at www.perkinelmer.com/optoelectronics
All values are nominal; specifications subject to change without notice.

Table 2. Sales Offices

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