Electronic Interface for Thermopile Infra-Red Detectors

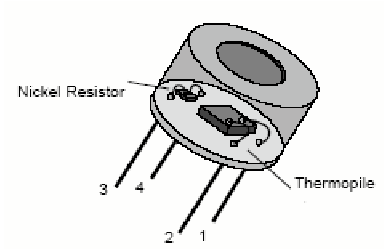
Ahmad Atghiaee, Gerard C. M. Meijer
Electronic Instrumentation Laboratory, EEMCS Faculty, Delft University of Technology
Mekelweg 4, 2628 CD, Delft, the Netherlands
Phone: +31 (0)15 2785026 Fax: +31 (0)15 2785755
E-mail: a.atghiaee@ewi.tudelft.nl

Abstract—**This paper reports a simple, high resolution and low cost electronic interface for a thermopile (TP) Infra-Red (IR) sensor. The input referred noise of the interface is 670 nV, which corresponds to 0.07 ºC of object temperature, in a full range of ±4 mV. A Nickel resistor as a reference for sensor temperature, is measured with resolution of 0.1 Ω in a full range of 1kΩ. The effect of electrical time constant of thermopile in combination with interface, has been investigated. The measurement time is about 140 ms. A chopper amplifier with gain of 15 and frequency of 8 kHz is used. The "constant factor" of sensor has been predicted to be 3.3x 10^{-13} V/K^4.**

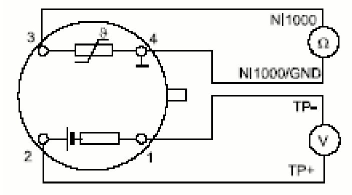
Keywords—CMOS analog interface, thermopile, IR detector.

I. INTRODUCTION

IR detectors are widely used in many applications. Thermal imaging, temperature measurement, personnel detectors, astronomy, agriculture and medical tomography, are some examples. Thermopile (TP) as an IR sensor, is an appropriate option [1]. It is low cost, reliable, easy to use in room temperature and with a wide spectral optic range. The calibration of the setup is not so easy because the output voltage of TP is a non linear function of the sensor temperature and object temperature and also a function of the distance, effective area and some other physical parameters of object and sensor. Fig. 1 shows structure and electrical equivalent circuit of a typical thermopile. There is a Nickel resistor inside, which can measure the temperature of the sensor itself. A large number of works have been done in IR detection by others [3], [4]. In most applications, the input referred noise of the electronic is important. Some market ready products are available, which [5] is one of the newest one from Melexis. So reducing the noise, itself, is a challenge for the interface which is a feature that has been improved with a rather simpler circuit, compare to related works [4], [5]. For this reason a simple and accurate circuit has been designed and tested. Chopping and dynamic element matching techniques, auto-calibration method, precision analog CMOS switches and advanced post signal processing, help the interface to work properly. In this setup, a Universal Transducer Interface (UTI) [6] and a thermopile from HLplanar [2] has been used. The interface input capacitance should not generate a high time constant with thermopile output impedance, typically 50 kΩ.



(a)



(b)

Fig. 1. A typical thermopile (a) Structure. (b) Electrical equivalent circuit (courtesy of HLplanar [2]).

II. SYSTEM DESCRIBTION

A. Design considerations

The circuit consists of two parts, one is used to measure the output voltage of thermopile and the other one, to monitor the value of the Nickel resistor, Fig. 2. As it was mentioned, the measurement of Nickel resistor is necessary to calculate the temperature of the sensor. The output of thermopile is multiplexed by a frequency of around 8 kHz. This, up converts the spectrum of the TP signal to 8 kHz, as a carrier frequency.

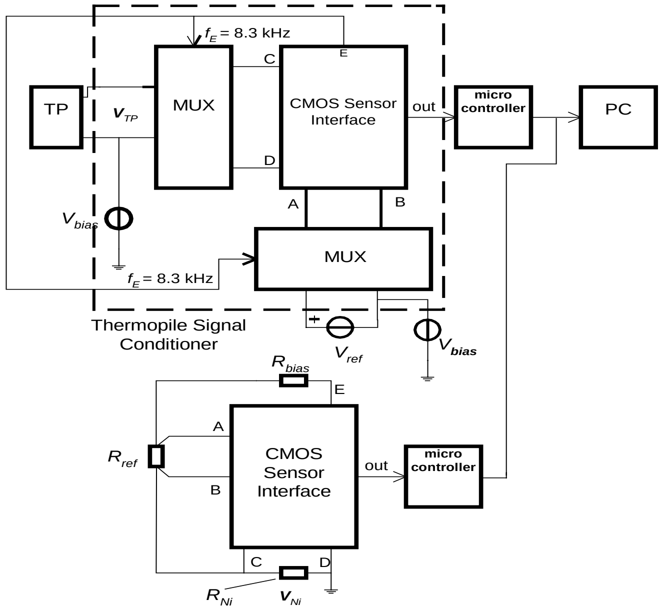


Fig. 2. Block diagram of the interface.

This is close to corner frequency of input flicker noise of an instrumentation amplifier, Fig. 3, which forms the input stage of the CMOS sensor interface in the applied mode. Two UTIs, work as CMOS sensor interface [6]. This interface has different modes for different front-ends. Inside the CMOS sensor interface, the modulated TP signal, is amplified. The switched capacitor (SC) integrator, which is part of a Martin Oscillator [6], converts this voltage to a charge while demultiplexing is performed as well. So in the output of SC integrator, the spectrum of TP signal is again down converted but the spectrum of flicker noise and offset of the instrumentation amplifier, are up converted. So there would be no overlapping between the noise and offset spectrum in one hand and the spectrum of TP signal on the other hand. Which means the effect of the unwanted signals are eliminated. The same happens for Nickel resistor voltage drop, V_{Ni}. The output of the interface, point "out" in Fig. 2, is a time modulated signal in

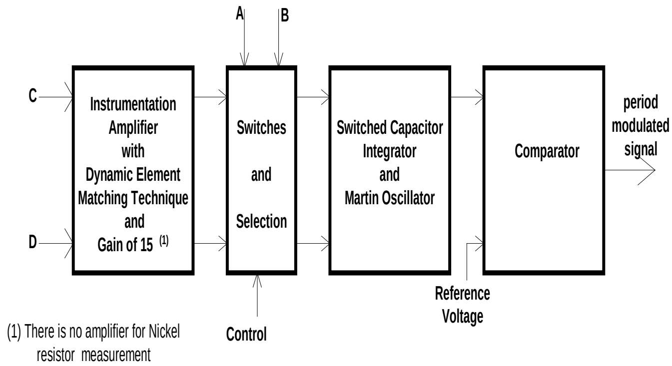


Fig. 3. The block diagram of the CMOS sensor interface.

which its duration is proportional to the amplitude of the input signal. i.e. $T_x(V_{TP})$ and $T_x(V_{Ni})$[1]. The measurands are calculated in a micro controller and computer[6], [7].

B. System Analysis

The noise of the whole interface, including TP, is limited by the thermal noise of the TP, which is related to its electrical resistor, 38 kΩ, in this work. So we can write:

$$V_{nTP} = (4kTBR_{TP})^{0.5} = 125 \text{ nV rms} \quad (1)$$

where
$k =$ 1.38x10^{-23} J/K
$T =$ 300 K
$B =$ 25 Hz, bandwidth of the sensor.
R_{TP} =38 kΩ
V_{nTP} = rms thermal noise of thermopile in V

There are low pass filters in UTI and later in post signal processing which limits the BW of the electronics.

Using a higher gain instrumentation amplifier, more than 15 as is shown in Fig. 3, gives a lower input referred noise.

The total time constant of the TP in combination with input capacitor of the circuit, is:

$$\tau = R_{TP} \times C_{in} = 38 \text{ k}\Omega \times 40 \text{ pF} = 1.52 \text{ µs} \quad (2)$$

considering the multiplexing period :

$$1/f_E = T_{mux}/2 = 62.5 \text{ µs} \quad (3)$$

[1] It means, there are "time based durations", proportional to amplitude of unknown signals, i.e. V_{TP} and V_{Ni}. Which is voltage generated across TP and voltage, dropped, across Nickel resistor.

shows that we can meet the requirement :

$$\tau << T_{mux}/2 \quad (4)$$

From (4), we predicted that the mentioned time constant should not make a problem for the circuit, else we had to add an additional buffer, for instance, to eliminate the mentioned effect [7].

For the sensor itself, there is a well known equation that shows how its voltage is related to the temperature:

$$V_{TP} = k(T^4_{obj} - T^4_{TP}) \quad (5)$$

where
V_{TP} = the thermopile output voltage.
T_{obj}=the absolute temperature of the object .
T_{TP}=the absolute temperature of the TP.

Factor *k*, in (5), is related to the physical properties and mostly from the sensor and object[1]. From these properties [2], we have calculated a value of :

$$k = 3.333 \times 10^{-13}\ V/K^4 \quad (6)$$

In this calculation :

Distance between object and sensor = 5 cm
Effective area of the sensor = 0.49 mm^2
Effective area of the object = 20 cm^2
Sensor temp.= Ambient temp.= 25˚C
Effective emissivity = 1

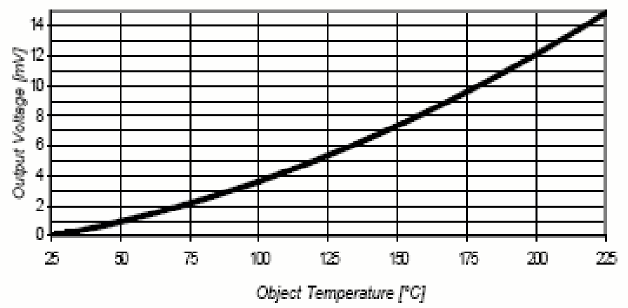


Fig. 4. Output characteristics of the thermopile which is used in the setup, (courtesy of HLplanar [2]).

Fig. 4 shows the dependency of output voltage of the sensor, V_{TP}, to the temperature of the object in the same condition as for (6) and (5), which has been given by its manufacturer [2].

C. Test results

The system, described in previous section, has been implemented and tested. Fig. 5 shows a view of the whole setup. The most important features of the system, are summarized in Table I. In this table a comparison is also made with some other related works. For the noise performance, an improvement , at least, two times could be observed. The input referred noise of the interface is measured, 670 nV.

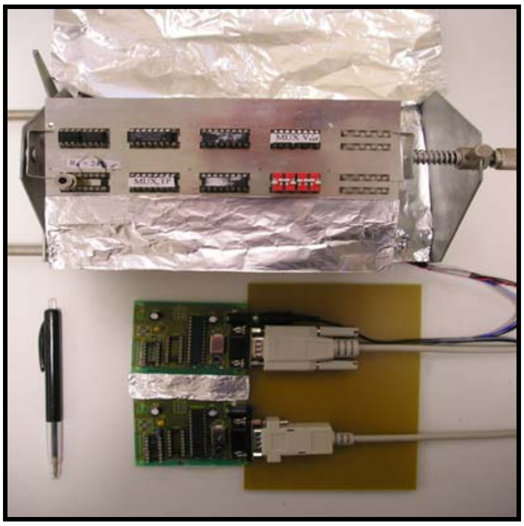


Fig. 5. A view of the setup.

To measure this noise, the thermopile has been removed and instead, a 38 kΩ resistor is replaced.The wavelength in Table I, is the optical wavelength, given by manufacturer [2]. During the test a non linearity has been observed with an average value of 4.5%, which is a systematic error. The Nickel resistor, used in the thermopile in the present system, is much more compatible for thin film technology and most suitable for integration in a chip compare to, for instance, a thermistor used in [5]. The measured time constant of the sensor is low enough, 1.52 µs, compare to $1/f_E$. From (5) and (6) the corresponding temperature values for resolution and inaccuracy are, 0.07 ºC and 0.15 ºC, respectively. The *k* factor which can be derived from Fig. 4, is the same order of magnitude as that was calculated in (6).

Table I Features of the system and a comparison with other works.

Parameter	This work	Ref. [3]	Ref. [4]	Ref. [5]
Input referred noise of the interface	134 nV/√Hz, 670 nV, 12.5 bits	390 nV/√Hz	1.5 μV	8 bits
Measurement time	140 ms	350 ms	300 ms	500 ms
B.W. of the system	25 Hz	500 Hz	25 Hz	500 Hz
Wavelength	5 μm to 14 μm	8 μm to 15 μm	5 μm to 14 μm	7.5μm to 13.5 μm
Temperature range	0 ºC to 100 ºC	NA	0 ºC to 100 ºC	0 ºC to 50 ºC
Voltage range of the sensor	- 4 mV to + 4 mV	NA	- 4 mV to + 4 mV	NA
Sensor output impedance	50 kΩ ± 15 kΩ	60 kΩ± 40 kΩ	50 kΩ ± 15 kΩ	44 kΩ to 75 kΩ
Temperature during test	25 ºC	25 ºC	25 ºC	25 ºC
Sensor response time	40 ms	6.5 ms	40 ms	NA
Type of reference resistor	Nickel	NA	Nickel	Thermistor

III. Conclusion

We have presented an interface system for a thermopile IR-detector. The interface has been implemented and tested with and without its sensor. It can be used to monitor the temperatures in the range of 0 ºC to 100 ºC with resolution of 0.07 ºC. Its non linearity has an average value of 4.5%. The measurement time is 140 ms and the BW of the system is 25 Hz.

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