CCES: a new configuration for electrical substitution for bolometers

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Abstract: this paper presents a new configuration for electrical substitution for resistive bolometers. A recall of principal problems encountered in conventional heat feedback electrical substitution bolometry introduces this new configuration where the electrical substitution is directly applied to the sensing resistor itself through capacitive coupling. The capacitive coupling allows the independent setting of the electrical and thermal working points. Contrary to conventional one, this new method can be applied to all existing resistive bolometers without material changes (no extra heater needed). The configuration was designed, implemented and evaluated with a 120 µm thick glass membrane gold layer resistive bolometer. Experiments with optical stimulation were done to demonstrate the functionality of the configuration.

Keywords: electrical substitution, capacitive coupling, resistive bolometer, uncooled bolometer.

1. MOTIVATION

Recently, the demand for inexpensive and uncooled infrared detector has grown for both civilian and military application ; in this context, bolometers are known to be a simple and cheap solution. The absorption layer of the bolometer converts absorbed IR radiation into heat, which in turn changes the resistance of the sensing resistor of the bolometers [1]. Performances improvement of the resistive uncooled bolometers can be realized through the design of the sensor and through its implementation. For a given sensor, a first way, regardless of the responsivity is the electrical substitution [2]. By Joule effect in a resistive heater (RI^2_{Heat}) at the proximity of the sensing resistor (see bolometer part of Fig.1.a) it is possible to substitute heat to incoming IR power radiation. Thus the total amount of power $P_{total} = P_{Joule}+P_{radiation}$ can exactly balance the power lost through G_{th} to the thermostat assuming the output measured temperature ($V(T_B)$) is just kept the same value.

This principle can easily be automated through a closed-loop configuration (Fig. 1.a) that will lock output temperature ($V(T_B)$) to a constant reference one (V_{ref}). This allows further improvements by computation of an appropriate controller: static error can be canceled and response time can be shortened as for any physical system. Heat is the physical feedback used to keep the bolometer at a constant working temperature. The feedback power (P_{FB}) will exactly compensate incoming optical radiation power [2,3] ; i.e. $P_{total} = P_{FB}+P_{radiation}$ = constant.

Limitations of DC heat feedback electrical substitution is that it needs an additional heating resistor and that Joule effect is non linear, inducing measurement range limitation and dynamic response dependency on the working point.

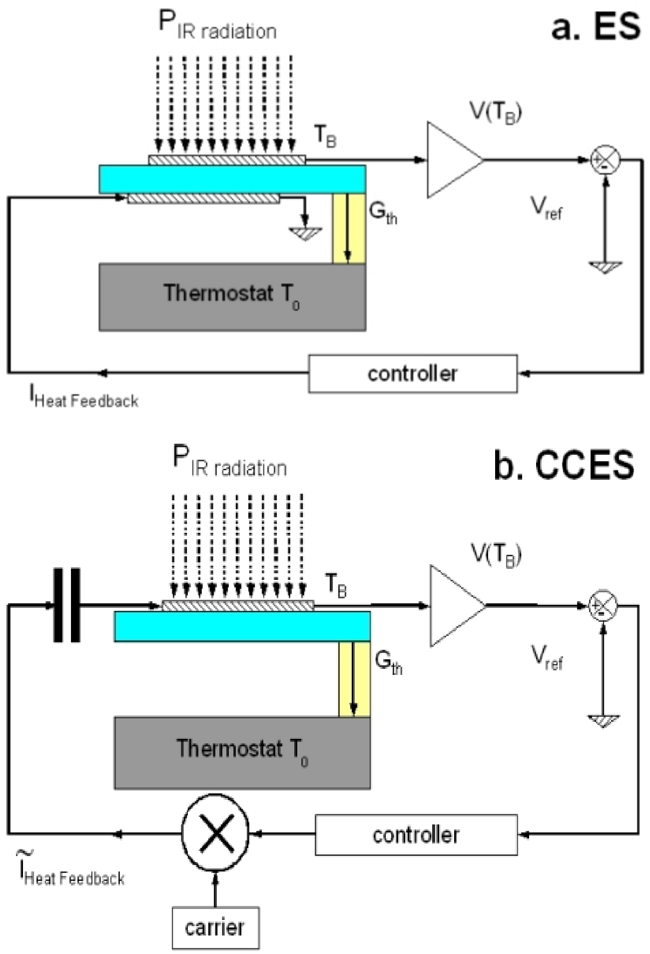

Figure 1: Electrical substitution configurations. a.: the conventional ES configuration using an additional resistor for feedback heating. b.: the proposed capacitive coupled CCES, using the sensing resistor itself for the feedback. Carrier frequency is typically between 100 kHz and 10 MHz

Here, we describe the new feedback configuration that does not require extra heater and which can be applied to every existing bolometer without any material change called capacitively coupled electrical substitution [4]. Only electronic readout has to be modified. The basic principle is to apply the feedback heat directly into the sensing resistor. The power is fed back by a modulated signal at frequencies out of bolometer thermal bandwidth to heat the sensing resistor and set the thermal working point. Capacitive coupling is thus required (Fig.1.b) to provide change in the electrical bias point. The system was first tested in analog modulation configuration [4] with the resulting non linearity from Joule effect. As PWM digital modulation is known to linearize the system [5] this solution was also developed and its functionality tested [6].

A bolometer has been specifically developed for the purpose of the evaluation of the performances of the method. Gold layers were patterned onto a glass membrane to form the sensing resistor and heaters. Then the membrane was assembled with an epoxy ring onto a copper holder for heat conduction to the thermostat and for easier handling (Fig.2).

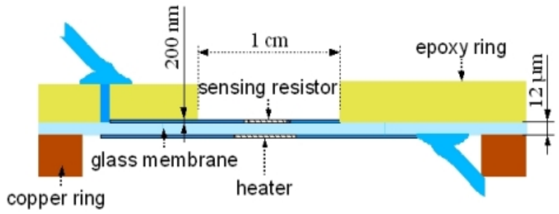

Figure 2: Schematic of the glass bolometer structure with sensing resistor on the upper side and heater at the bottom side for characterization.

2. EXPERIMENTAL SET-UP

The measurements were performed at room temperature under 20 mTorr vacuum pressure. The thermal conductance and thermal capacitance are $G_{th} = 1.25$ mW/K and $C_{th} = 14.5$ mJ/K respectively and were extracted from open-loop characterisation of the system. The sensing resistor (80 Ω) was used for the power feedback.

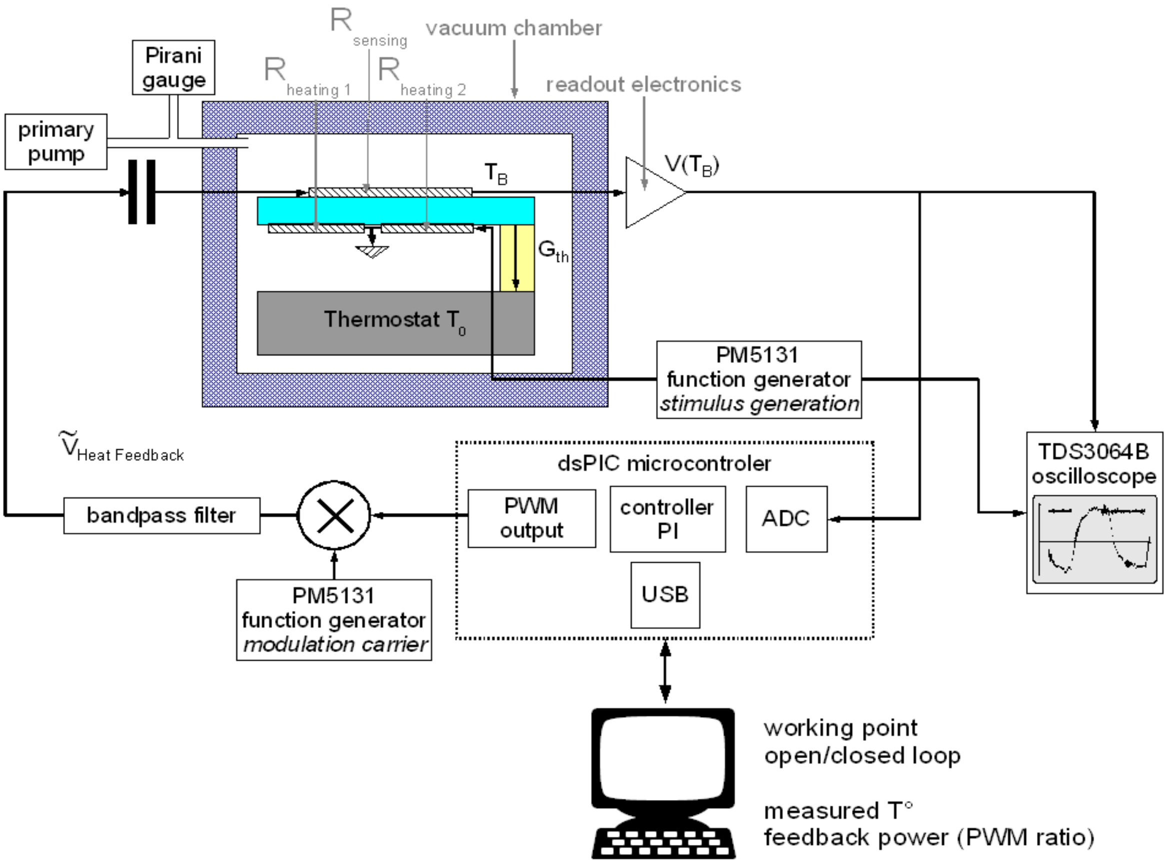

Figure 3: Set-up of the capacitively coupled electrical substitution configuration with a digital implementation

Both analog implementation (Fig 2) and digital implementation (Fig 3) of the capacitively coupled electrical substitution configuration were used for those experiments.

In the analog implementation the feed back power applied to the sensing resistor is determined by the RMS value of the modulation thus by $V^2_{control}$. The control signal $V_{control}$ is the output of the controller. This signal is the amplitude of the modulation at a frequency of 1 MHz in those experiments. To linearize the system, it is set at a working point around 1,2 K above thermostat.

In the digital implementation the feedback power applied to the sensing resistor is determined by the cyclic ratio of the pulsed width modulation signal delivered by a microcontroller. The pulsed with modulation signal corresponds to the control signal calculated by a proportional integral (PI) control algorithm. As in analog implementation this signal is modulated at 1 MHz with a constant amplitude carrier. Then the applied feedback power on the sensing resistor is due to the RMS value of the applied signal and can be expressed as:

$$P_{FB} = \frac{\tilde{V}^2_{Heat\,Feedback}}{R_{sensing}} \propto \frac{\alpha \cdot V^2_{carrier}}{2 \cdot R_{sensing}}$$

with α the cyclic ratio of the microcontroller PWM output, $V_{carrier}$ the amplitude of the carrier [6].

LEDs were used as optical radiation source. The optical power intensity was controlled through a pulsed width modulation of the power supply of the LEDs.

3. RESULTS

As analog and digital implementation have similar small signal dynamic responses we will present records of the digital implementation because signals of higher amplitude are accepted. Extracted parameters for all configurations are given.

As mentioned in [4], conventional ES configuration as well as CCES with analog modulation gave quite the same closed-loop dynamic response. With respectively 2.7 s and 2.4 s 95% rise time closed-loops exhibit a 10 times lower 95% rise time than open-loop (34.8 s) as expected for both controller designs.

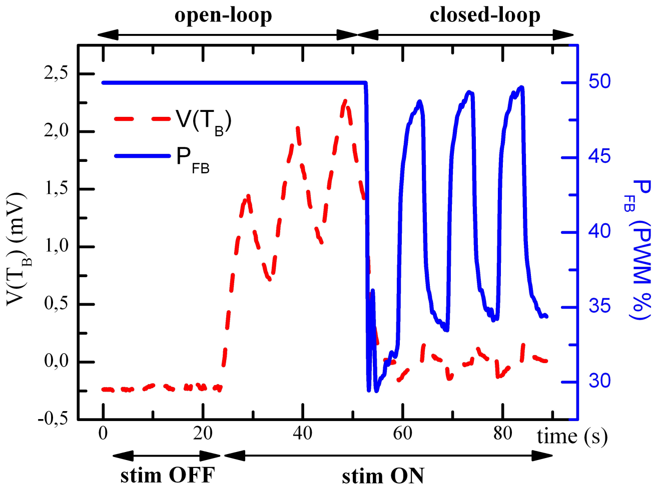

Figure 4: Response to a square shape stimulation with a 100 mHz frequency. The voltage on the left corresponds to the measurement of the temperature of the sensing resistor. Pfb on the right is the feedback power applied to the sensing resistor.

About digital CCES configuration, Fig 4 illustrates the typical response of the system in open-loop and closed-loop configuration. In open-loop, the feedback power P_{FB} applied is constant (here 50% of the maximum feedback power) and the temperature ($V(T_B)$) changes when the external optical radiation power is applied. In closed-loop, the temperature is controlled and kept constant (out of transitory) since the feedback power compensates the optical radiation power to keep the total amount of incoming power at the bolometer location constant. In open-loop case, a drift remained that could be explained by thermalization. As it is also present in closed-loop record, the origin shall be attributed to epoxy ring direct heating due to the incoming radiation.

In open-loop, the voltage $V(T_B)$ is the output of the system and gives the temperature of the sensing resistor. In closed-loop, the output of the system is the feedback power P_{FB} whose variations give a direct power reading of the power absorbed by the bolometer. Open-loop system record gives a time constant of 11.6 s. Closed-loop shows a zero static error as expected by integral correction in Fig 4. The time response difference between open-loop and closed-loop can be observed with a 95% rise time of 6 s. This only four time improvement is due to a controller designed for a strong robustness. The time response could be further decreases through controlled optimization.

Rise time data are summarized in Tab 1.

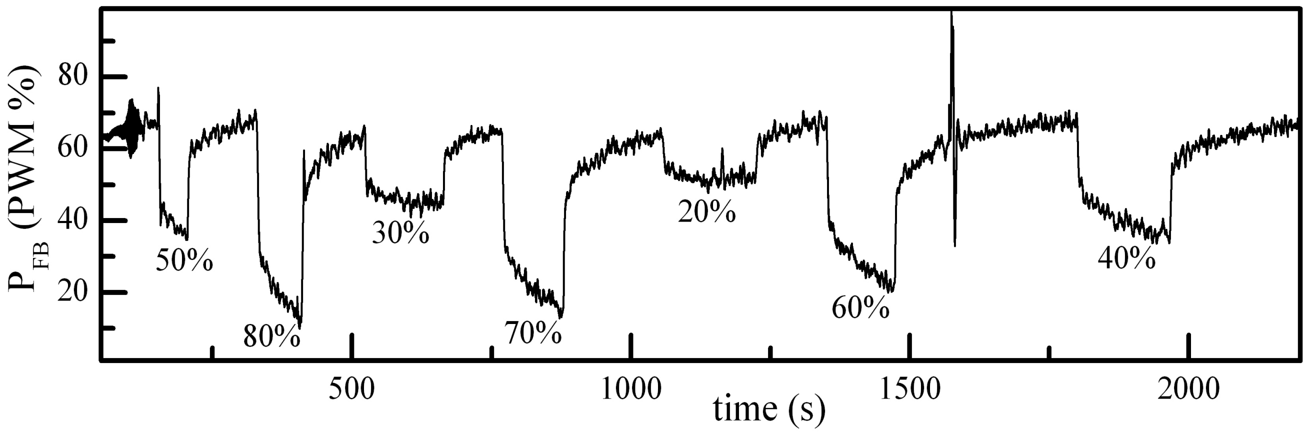

Figure 5: Feedback power delivered by the feedback controller while the bolometer is exposed to radiation power stimuli of various intensities. The intensity of the optical radiation power is defined by the cyclic ratio of the pulsed width modulation of the LED supply ; successively 50%, 80%, 30%...

	open-loop	closed-loop		
configuration		ES	analog CCES	digital CCES
95% rise time (s)	34,8	2,7	2,8	6

Tab 1: 95% rise time response depending on the configuration of the system.

Fig 5 illustrates the response of the system in closed-loop configuration to various optical power intensities. The decrease of the feedback power P_{FB} is higher when the optical power intensity is higher. Here again in closed-loop negative drifts when bolometer is lighted and positive drifts when not are observed. As previously, this can be explained by a direct heating of the epoxy ring that serves of intermediate thermal sink.

Fig 6 represents the treatment of the data illustrated in Fig 5. The variation of P_{FB} when the optical power is applied is a measure (P_{mes}) of the optical power absorbed by the bolometer. The figure represents the linear variations of the P_{FB} signal when the optical power is applied (down variation), when the optical power is shut off (up variation) and the mean value.

4. DISCUSSION

Similarly to conventional ES configuration, the CCES configuration allows an easy power reading and not a temperature reading as in open-loop bolometers. Besides performances comparable to ES configuration (response time reduction) the CCES does not require any extra power source onto the bolometer making it suitable for all kinds of existing resistive bolometers. CCES allows the independent setting of the electrical bias point with the DC bias current in the sensing resistor and of the thermal working point, i.e. V_{ref} for $V(T_B)$. The digital implementation of this configuration makes the interfacing easy and allows the linearization of the whole system.

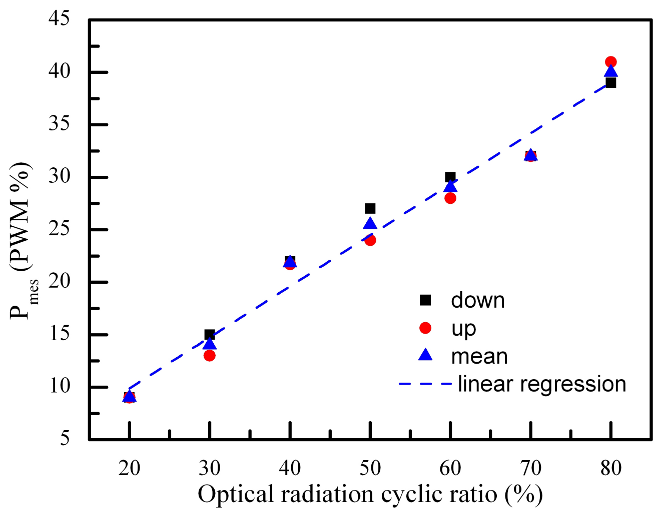

Figure 6: Measured power versus the cyclic ratio of the optical power radiation. Falling and rising jumps were extracted from the feedback power recording in Fig 5. The dashed line is a linear regression of the mean points.

5. CONCLUSION

In this paper, the new CCES configuration for resistive bolometer was presented. Similarly to every closed-loop configuration, this one allows time response reduction of the closed-loop system. In contrast with previous closed-loop configurations, the two main advantages of this configuration are that it can be applied to every resistive bolometers without sensor design changes and that it allows the setting of both the electrical bias point and thermal working point independently.

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