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Using Pyroelectric Sensors to Detect Continuous Infrared Radiation

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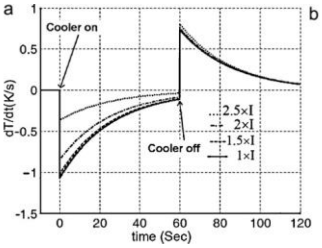
Graphical abstract



Abstract

This paper focuses on an optimized method for detecting continuous infrared rays make use of Pyroelectric devices. Now, Pyroelectric devices are usually very sensitive to changes in infrared radiation in the presence of an object when transfers or radiation is connected or disconnected. In this new approach, the thermo-electric cooler is employed to active temperature sensors instead of conventional modulation. They use mechanical parts, which are complex and un-reliable. The most of the sensor consists of a number of important restrictions, which are expected to be eliminated by a new method in this study. To simulate the thermal and electrical behavior of the detector, the equivalent electrical circuit is needed that will be proposed.The practical results of Pyroelectric sensor are sent to a computer by a digital oscilloscope, and then they are monitored and analyzed. After that, the model is simulated with MATLAB software. Finally, practical and theoretical results compared with each other and a good agreement of them is shown and confirms the validity of the model.

Keywords: Pyroelectric detectors; thermo-electric cooler; temperature changes; infrared radiation

Abstrak

Kajian ini memberi tumpuan kepada kaedah optimum bagi mengesan sinar inframerah gelombang terus untuk digunakan sebagai peranti pyro-elektrik. Terkini, peranti pyro-elektrik adalah amat sensitif dengan sebarang perubahan radiasi sinar inframerah terhadap objek apabila berlaku sesuatu pemindahan, atau radiasi yang dihubungkan atau dihalang. Dengan pendekatan terbaru, penyejuk therma-elektrik sebagai pengaktifan sensor suhu dipilih berbanding kaedah modulasi konvensional. Ini adalah kerana mereka menggunakan bahagian-bahagian mekanikal, yang lebih kompleks dan seterusnya. Kebanyakan sensor terdiri daripada beberapa sekatan penting, dan melalui kaedah baru dijangka akan dilupuskan dalam kajian ini. Untuk mensimulasikan ciri-ciri sensor haba dan elektrik, litar elektrik diperlukan dan perlawanan yang dicadangkan. Isyarat yang dihasilkan dari sensor pyro-elektrik itu dihantar ke komputer melalui osiloskop digital, dan kemudian ia dipantau dan dianalisis. Selepas itu, simulasi model dengan perisian MATLAB. Akhirnya, keputusan teori dan praktikal berbanding, dan mendapati ia untuk model yang tepat pada masanya dan ditubuhkan secara sah.

Kata kunci: Pengesan pyro-elektrik; termoelektrik sejuk; perubahan suhu; sinaran inframerah

■1.0 INTRODUCTION

Most industrial [1, 2] and medical applications for instance data transmission, monitoring and imaging systems [3, 4] use the infrared radiation (IR) detectors that these detectors, nowadays, are taken into account as sensing element in space technologies [5, 6]. Generally, IR detectors are divided into two groups, thermal and quantum devices. The optical radiations are directly transformed into an electrical signal by quantum detectors and also these detectors suggest higher detection routine and quicker answer rapidity, while their photo sensitivity depends on wavelength and operation temperature. Consequently, these detectors should be refrigerated for precise measurement, excluding for detectors used in the near infrared region [7].

In contrary, there are thermal detectors. In these detectors, the temperature of the device is increased by the absorption of the occurrence radiation and this in order leads to the changes in some temperature-dependence characteristics to produce an electrical output. As a result, the output of thermal detectors is relational to the volume of energy absorbed per unit time. These detectors have a broad spectral response because their impacts are usually wavelength independent and the sensitivity of thermal devices also does not depend on the photonic nature of radiation. In addition, it is independent of operation temperature. Therefore, they do not necessarily to be cooled; moreover, they can be operated with the appropriate act in any operating temperature. The applications of thermal detectors are more preferred at room temperature due to some behavior. In spite of the benefits of these detectors, they suffer low sensitivity and low reaction. Pyroelectric detectors [8-10] is a type of thermal devices that among different kind of them, those are faster and more vigorous [11, 12] and have also fixed reaction in a wide spectral range. This quality has led them to be taken into account in some particular systems [13] like Earth Horizon Sensors (EHS) [14].

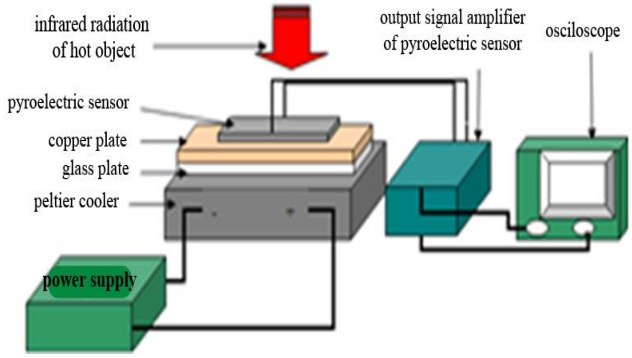


Figure 1 The structure of the Pyroelectric detector system

Pyroelectric detectors are not sensitive to constant radiance which is the main weakness of them. This means, they only answer to difference of IR flux. Consequently, to detect of continuous radiations by these detectors, so many systems were progressed to adapt continuous radiation to alternative one optical choppers [14-16], scanning mirror [17], and more mutual among these systems that all of them need mechanical parts which not only making them huge, weighty, expensive, and inconvenient to use in space applications, but also moving parts descend the dependability and life span of systems and lead them prone to the failure. This is the major interference for applications of Pyroelectric detectors in space systems.

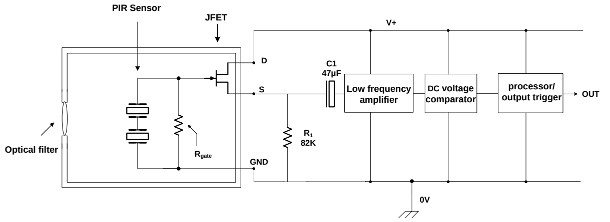


Figure 2 The structure of electrical circuit to amplify the signal of Pyroelectric sensors.

In this essay, a novel advanced technique is proposed to overcome the limitation. It is using the Pyroelectric sensors without any necessity to mechanical parts and just based on alternative cooling and heating of the detector. Using a Peltier cooling system, which transfers heat from one side to another side when direct current passes through hit; make the application of local temperature difference on the detector. The temperature difference leads the Pyroelectric detector to be attained and produced the electrical signal.

The amplitude of the output signal depends on the flux of continuous radiation coming to the device have shown in this paper. Thus, the detector signal will be altered because of target temperature difference. The structure of the Pyroelectric detector system is shown in Figure 1. In this structure, Peltier cooler has two sides, hot and cool. Hot side needs to be cool; therefore, it is installed on the heat sink and transfers heat to outside while cool side is connected to Pyroelectric sensor. This system requires a power supply to launch. Furthermore, the output signal amplitude of Pyroelectric sensor is very weak and needs an amplifier. Finally, the output signal is shown by digital oscilloscope. An electrical circuit requires amplifying the output signal of Pyroelectric sensors that is exposed in Figure 2.

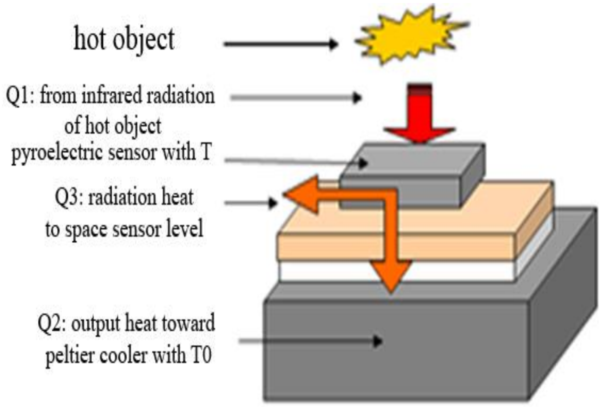


Figure 3 The schematic of Pyroelectric sensor structure

2.0 THEORY

There are three significant stages that Pyroelectric sensor can change the event thermal radiation into an electrical signal. First, the temperature of the detector is changed by the absorption of radiation. Secondly, the detector is polarized by the difference in temperature and the electric charge is created on its terminals. Finally, a current in the external circuit is shaped by the charge density seemed on the electrodes. Following equation calculate the produced current at the device terminal [15]:

$$i_p = pA_S\frac{dT}{dt} \tag{1}$$

Where i_p and p, are the Pyroelectric current and Pyroelectric coefficient respectively, A_s is the effective surface area of sensing element; in addition, T and t are temperature and time, correspondingly.

In fact, a built-in FET amplifier that has low output impedance in source follower connection pack commercial Pyroelectric sensors. The schematic of Pyroelectric sensor structure is illustrated in Figure 3. The Pyroelectric current is converted to output voltage as $U_{out} = Z.i_p$, which Z is the Trans resistance of the electronic circuit and depends on its parameters.

The event IR radiation energy must be alternative to have a crucial output signal in the device terminals because of the nature of Pyroelectric impact. The sensor goes to stable–state circumstance at the device relaxation. To eliminate this problem, a new operating method for detection of continuous radiation has proposed by Pyroelectric sensors. The schematic of the proposed device is illuminated in Figure 4. It includes a Pyroelectric sensor and a Peltier thermo-electric cooler for the application of thermal cycles.

A solid-state active heat pump is called a Peltier cooler that transfers heat from one side of the device to the other side by application of electric current. The following equation calculates the hat transformation rate that is proportional to the current density:

$$\frac{dQ}{dt}=\pi\cdot I \tag{2}$$

Where dQ/dt, π, and I, are the heat transferred per unit time, a constant known as Peltier coefficient, and the electric current, respectively. It is evident; the amplitude of thermal pulses can be managed by amplitude of current.

A schematic of the proposed device is shown in Figure 4 that a Pyroelectric sensor is installed on the cold surface; on the other hand, the hot surface is connected to a Peltier cooler and heat sink. The rectangular current is connected to the cooler that it causes the application of thermal pulses to the sensor. The amplitude of pulses is between 0 to I and it can be changed between –I to +I to reach higher temperature difference. Therefore, the output electrical signal directly depends on the thermal behavior of the device.

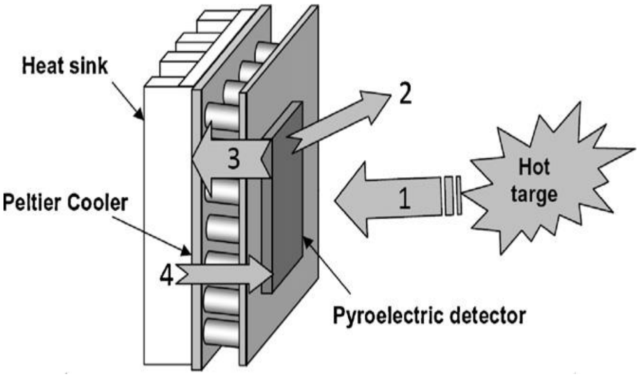


Figure 4 The schematic of proposed application of the device

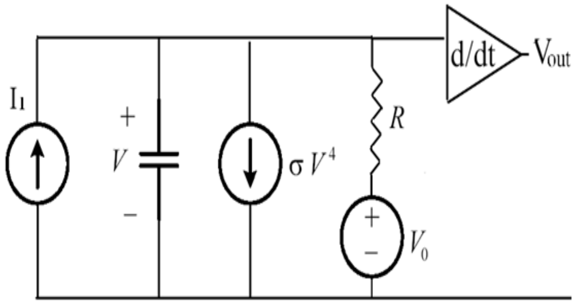


Figure 5 Electrical model of thermal system for pyroelectric detector

Figure 5 shows the structure of input and output energy of the system that leads to temperature changes. When the sensor is heated, the general equation of warming based on heat transfer relations is:

$$Q=C\Delta T \tag{3}$$

Where C is the heat capacity of the device and ΔT is the thermal changes.

In used system, this equation can be computed as follows:

$$\Delta Q=\Delta Q_1(t)-\Delta Q_2(t)-\Delta Q_3(t) \tag{4}$$

Where, $\Delta Q_1(t)$ is the transferred energy to the sensor of the infrared radiation and is depended on heat flux and time. $\Delta Q_2(t)$ is the outgoing energy to sensor due to thermal radiation and is equal to $\alpha\sigma T^4$ according to Stefan-Boltzmann relation. $\Delta Q_3(t)$ is the outgoing energy from sensor due to thermal conductivity between sensor and cool surface of Peltier cooler, and is proportional to their temperature difference.

$$\Delta Q_1=\varphi_1 dt \tag{5}$$

$$\Delta Q_2=\alpha\sigma T^4\,dt \tag{6}$$

Where α is the surface emissivity, and $\sigma=5.67\times10^{-8}\,Wm^{-2}k^{-4}$ is the Stefan-Boltzmann constant.

$$\Delta Q_3=G(T-T_0)dt \tag{7}$$

Where, G is the thermal conductance, T and T_0 are the temperature of cold surface and hot surface of the device, respectively.

With substituting (3) – (7):

$$\Delta Q=\varphi_1 dt-\alpha\sigma T^4 dt-G(T-T_0)dt=C\frac{dT}{dt} \tag{8}$$

The electrical model of this equation as an equivalent electronic circuit is shown in Figure 5. In addition, the output signal of Pyroelectric sensor is proportional to the temperature difference over time; hence:

$$V_{out}=K\frac{dT}{dt} \tag{9}$$

Where, K is the Pyroelectric constant. If the amount of heat stored in the sensor is considered as Q, according to mentioned equations and used system, Equation (8) can be modeled by an electronic circuit, as shown in Figure 5. Q and the heat capacity of the sensor are equivalent to capacity voltage and capacitance, C, of the electronic circuit, respectively. Moreover, incoming and outgoing energy of sensor can be replaced by a current source. Therefore, the electrical behavior of Pyroelectric detector is stated by:

$$\frac{dV}{dt}=I_1-\alpha\sigma V^4-G(V-V_0) \tag{10}$$

This model simulated by Matlab programming and its output signal have shown in Figure 6. The validity of this result can be verified by comparison of it with a typical experimentally Obtained output on oscilloscope screen is provided as Figure 7.

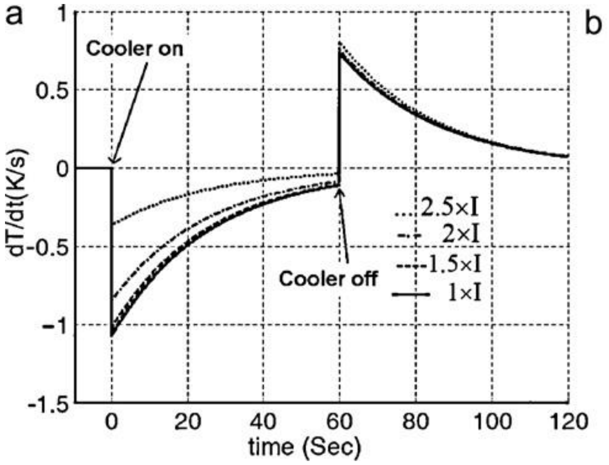
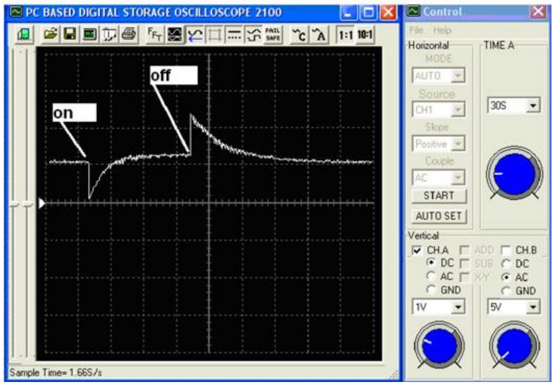


Figure 6 the simulated output signal by Matlab



PC BASED DIGITAL STORAGE OSCILLOSCOPE 2100

Control

Horizontal: MODE AUTO; Source CH1; Slope Positive; Couple AC

TIME A: 30S

Vertical: ☑ CH.A ● DC ○ AC ○ GND 1V; ☐ ADD ☐ SUB ☐ X/Y; ☐ CH.B ○ DC ● AC ○ GND 5V

Sample Time= 1.66S/s

Figure 7 the real output recorded at the oscilloscope screen

3.0 METHODOLOGY

The fabrication of a prototype device, is shown in Figure 8, inspect the experimental confirmation of the theoretical model. This device includes a commercially accessible Pyroelectric sensor (PIR 325, that is used to detect human-motion and its parameters are illustrated in Table 1) and a Peltier cooler devoted to an aluminum heat sink. The Pyroelectric sensor is installed at the cold surface of the cooler. In this model, the sensing element is preserved by a steel package covered by thermal insulator to avoid the light to pass from the surrounding environment. Its output signal requires an amplifier circuit because of lower output amplitude. These sensors describe the Earth's horizon by the 14-16.25 µm infrared emission of CO2 at 30-40 km altitude, which is the bigger of two stable infrared spectral bands in the atmosphere [18].

The Pyroelectric cooler is attached to a pulse generator by constant current pulses with restricted duty cycle. Moreover, the device output is attached to a digital oscilloscope to record of its transient response and digital oscilloscope also connected to a computer by USB cable to show the output signal. As be mentioned above, the output signal needs an electronic amplifier circuit with a total gain with about 1000.

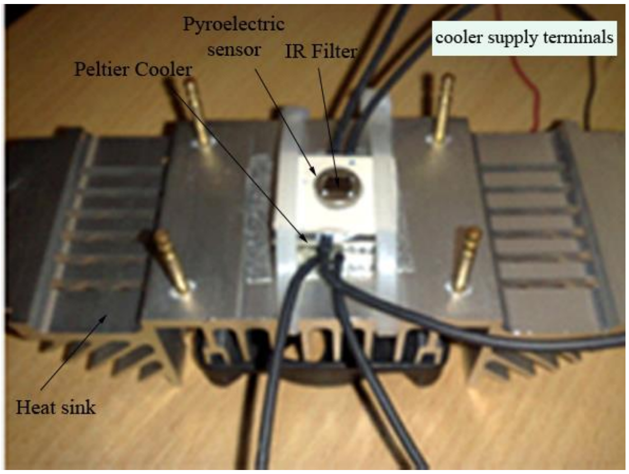


Figure 8 The photograph of fabricated device

The suitable distance between the sensor and hot surface was selected to create the geometric resemblance to test circumstances with the exact position of the sensor on the satellite locate at geosynchronous orbit. The sensitivity measurements were only achieved at the target temperatures from 25 to 200°C because of the instrumentation's restriction.

Table 1 Parameters of use sensors in this paper

PIR 325	
ELEMENT SIZE	2×1, 2 elements
Spectral response µm (1)	5~14
Noise µV_{P-P}	20
OUTPUT mV_{P-P}(2)	3900
Offset voltage volts(3)	1
supply voltage volts(4)	2.5~15
Operating temperature ˚c	-30~70
storage temperature ˚c	-40~80

This research was focused on the study of system thermal behavior due to the strong dependence between sensor response and its temperature changes during this test, a constant current, about 1.85 am, was applied to the cooler at t=0 and the device temperature started to decline, accordingly.

When the current at t=30 was turned off, the temperature started to ascend because of IR absorption and steadied after t=90s. The difference of device temperature was measured in distinct times. The practiced information about the device thermal behavior is used achieves of its model characteristics.

4.0 RESULTS AND DISCUSSION

The validity of the proposed model is confirmed by comparison of experimental data, offered as loops in Figure 5, with the analytical calculations. The parameters of used sensors in this paper are shown in Table 1, which curve fitting of experimentally measured data calculates these parameters. They are estimated by the optimization technique improved by Lagarias *et al.* [19] which renders the best fit to a set of practical information and it described the application of the method. Application of the approach defined on a set of experimental data can compute the parameters based on a certain element and sensor system that this fact increase the practical importance of Equation 10, which is used to forecast and plan goals.

Good agreement between theoretical and practical results, assured applying of the model for simulation of device reaction at any other level of infrared radiation. Figure 6 displays the calculated device response for different level of radiation that the results show the maximum level of sensor output appears the first steps of cooler transition time. Furthermore, if the target temperature ascends, the sensor output descends at cooler "on" and rises at cooler "off" transition. The significant specification of this proposed model is that waiting for sensor stabilization at the steady-state condition is not essential to approximate the level of incoming radiation because of managing the rate temperature change by cooler current.

■5.0 CONCLUSION

The present novel technique of Pyroelectric sensors is quite effective for detection of continuous infrared radiation. In addition, validation of Peltier cooler, which is used to create temperature differences, can reduce using of the mechanical parts. They were used in conventional modulation and were not appropriate because of their complex parts. The simple proposed model shows considerable capability of a Pyroelectric device to detect continuous infrared radiation. The thermal behavior is only discussed in the theoretical analysis and other mechanisms has profound influence on the thermal behavior of the device of various geometries. The practical and theoretical results recorded then they were at the compared with each other. The similarity between these results verify proposed model in this research.

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