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# A new method for detection of continuous infrared radiation by pyroelectric detectors

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ABSTRACT

A novel method for detection of continuous infrared (IR) radiation by pyroelectric detectors was presented. In this method, instead of conventional modulation of IR radiation by mechanical parts, which are complicated and unreliable, the temperature of the detector is modulated by thermoelectric cooler to activate it. With this new method, the main inherent limitation for application of these detectors is expected to be eliminated. An equivalent electrical circuit was proposed to simulate the thermal and electrical behavior of the detector. A prototype sensor was fabricated and its transient responses to different level of IR radiations were recorded. The model-based calculations were fitted to the measured data, and the fitting parameters were considered as model parameters. Good agreement between experimental data and analytical calculations confirmed the validity of the model. It was also demonstrated that, the application of this method increases the detection speed of the sensor. Improved speed is more than three orders of magnitude better than the other type of thermal detectors.

## 1. Introduction

Sensing and detection of infrared (IR) radiations are of prime technical importance [1]. The IR detectors have been used for many industrial [2,3] and medical [4] applications such as data transmission, monitoring and imaging systems [5,6]. In recent years, these detectors are considered as sensing element in space technologies [7,8]. Among these applications are imaging systems of remote sensing satellites [9,10] and attitude determination sensors [11,12].

The IR detectors may be classified as thermal and quantum (ore photonic) devices [13]. Quantum detectors directly convert optical radiations to electrical signal and offer higher detection performance and faster response speed, but their photo sensitivity depends on wavelength and operation temperature as well. So, the quantum detectors must be cooled for accurate measurement, except for detectors used in the near-infrared region [14].

In contrast, in thermal detectors, the absorption of the incident radiation raises the temperature of the device, and this in turn causes the change in some temperature-dependence parameters to generate an electrical output. As a consequence, the output of thermal detectors is proportional to the amount of energy absorbed per unit time. Thermal effects are generally wavelength independent, and the sensitivity of relevant detectors does not depend on the photonic nature of radiation. This means that, these detectors have a wide spectral response. On the other hand, the detection sensitivity of thermal devices is independent of operation temperature. So, they do not need to be cooled, and can be operated with good performance in any operating temperature. Because of such behavior, the applications of these detectors are more preferred at room temperature [15]. Despite the advantages mentioned above, thermal devices suffer from low sensitivity and the slow response [14].

Among various kinds of the thermal devices, pyroelectric detectors [16–18] are faster and more robust [19,20]. They have also fixed response in a broad spectral range. This feature has caused them to be considered in some specific systems [21] such as Earth Horizon Sensors (EHSs) [22], which are the main references in Attitude Determination and Control Subsystem (ADCS) of satellites.

The major weakness of pyroelectric detectors is that they are not sensitive to constant irradiance. In other words, they only respond to variation of IR flux. So, for detection of continuous radiations by these devices, several systems were developed to convert continuous radiation to alternative one. Among these systems, optical choppers [22–24], scanning mirror [25] and rotation of sensing element for scanning across the target surface [26] are more common. All of above mentioned systems require mechanical parts, which makes them bulky, heavy, expensive, and inconvenient to use in space applications. On the other hand, moving parts reduce the

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reliability and lifetime of systems and cause them prone to the failure. This is the main hindrance for application of pyroelectric detectors in space systems.

To overcome this restriction, we have proposed a new innovative method by which the continuous radiations can be detected using a pyroelectric sensing element without any need to mechanical parts. This method is based on alternative cooling and heating of the detector. The application of local temperature variation on the detector is performed by using a peltier cooling system. A peltier cooler transfers heat from one side to the other side, when direct current passes through it. The variation of temperature causes the pyroelectric detector to be activated and create the output electric signal (see below). We have shown that the amplitude of the output signal depends on the flux of continuous radiation coming toward the device. So, if the intensity of incoming IR radiation is changed due to target temperature variation, the detector signal will be changed accordingly. However, as will be reported later, the dependence of sensor output to radiation intensity is not linear.

## 2. Theory

The pyroelectricity results from the temperature dependence of spontaneous polarization of polar materials, and a pyroelectric detector converts the incident thermal radiation into an electrical signal [27]. This conversion takes place in three steps; (1) the absorption of radiation changes the temperature of the detector; (2) the variation of temperature polarizes the detector and creates the electric charge on its terminals; (3) the charge density appeared on the electrodes creates a current on the external circuit. The generated current at the device terminal can be calculated by [28]:

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

where, $i_p$ is pyroelectric current, $p$ ($\mathrm{C\,cm^{-2}\,K^{-1}}$) is the pyroelectric coefficient, $A_s$ is the effective surface area of sensing element and $T$ and $t$ are temperature and time, respectively. In practice, the commercial pyroelectric sensors (such as what we employed in this research) are packaged with a built-in FET amplifier, in source follower connection, to have low output impedance. This circuits convert the pyroelectric current to output voltage as $U_{out} = Z\cdot i_p$, where $Z$ is the transresistance of the electronic circuit and depends on its characteristics.

Due to the nature of pyroelectric effect, the incident IR radiation energy must be alternative to have a significant output signal in the device terminals. At the continuous radiations, the sensor goes to a steady-state condition (after transient time), and the output signal will be eliminated at the device relaxation. To solve this problem, we have proposed a new operating method for detection of continuous radiation by these sensors. Using this method, the continuous IR radiations can be detected without any need to modulation by mechanical parts. In this method, the periodic thermal pulses are applied to the sensor to activate it against continuous IR signal. The schematic of the proposed device is illustrated in Fig. 1. It comprises of a pyroelectric sensor (PES), and a peltier thermoelectric cooler for application of thermal cycles.

A peltier cooler (or thermoelectric heat pump) is a solid-state active heat pump which transfers heat from one side of the device to the other side by application of electric current. The hat transformation rate is proportional to current density and can be calculated by [29]:

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

where $dQ/dt$ is the heat transferred per unit time, $\pi$ is a constant known as peltier coefficient and $I$ is the electric current. The direction of heat transfer depends on direction of current and can be against to the temperature gradient (from cold to hot). It is clear that, the amplitude of thermal pulses can be controlled by amplitude of current as well.

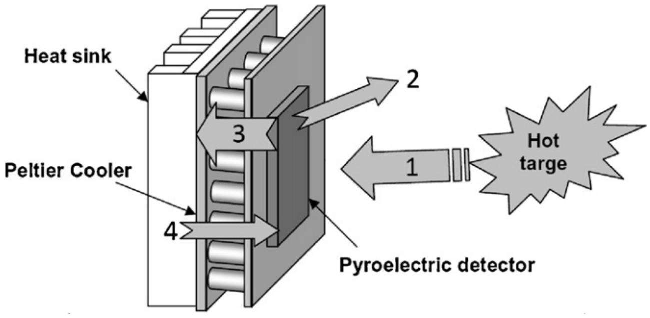

**Fig. 1.** The schematic of proposed application of the device.

The cold and hot surfaces of the cooler are mounted to PES and heat sink, respectively. The application of thermal pulses to the sensor is performed by connection of alternative rectangular current to the cooler. The pulses have amplitude from 0 to $I$; however, to have higher temperature variation speed it can be from $-I$ to $+I$. By application of thermal cycles, periodic electric pulses (dependent on the intensity of incident IR radiation) expected to be generated on the sensor.

Since, the output electric signal directly relates to thermal behavior of the device, the following model is proposed to simulate the variation of device temperature. In this model, IR radiation with flux of $\phi$ is supposed to be radiating toward the detector. So, the main mechanisms governing the conversion of radiated energy to electrical signal in a small time interval, $dt$, can be considered as follows:

(1) The instantaneous heat generated due to absorption of IR radiation at the device surface ($A_s$), $\Delta Q_1 = A_s\alpha\phi_1\Delta t$, where $\alpha$ is surface absorptance.
(2) Heat emission from the system to the surrounding due to thermal radiation ($\Delta Q_2$).
(3) Heat transmitted away by peltier cooler ($\Delta Q_3$).
(4) Thermal conduction from heat sink to sensor ($\Delta Q_4$).
(5) The net heat available to rise the temperature of device $\Delta Q = H\cdot\Delta T$, where $H$ is the heat capacity of the device.
(6) Conversion of temperature variation to electrical signal by sensing element and peripheral electronic circuit, $U_{\mathrm{out}} = K\cdot dT/dt$, where $K$ is the coefficient of proportionality, which includes all constant values in the equation as well as the signal conditioning circuit.
(7) Acquisition of electrical signal by external recording system.

The amount of heat available to raise the temperature of the device can be calculated by the summation of all above factors as:

$$\Delta Q = \Delta Q_1(t) - \Delta Q_2(t) - \Delta Q_3(t) + \Delta Q_4(t) = H\Delta T \tag{3}$$

where, $H$ is the heat capacity of device, including the detector and cold surface, which should be estimated experimentally. $\Delta Q_1 = A_s\alpha\phi_1 dt$ is the incoming energy due to absorbed IR radiation. $\Delta Q_2 = A_s\varepsilon\sigma T^4 dt$ is the outgoing energy due to thermal radiation. Where $\varepsilon$ is the surface emissivity and $\sigma = 5.67\times10^{-8}\,\mathrm{W\,m^{-2}\,K^{-4}}$ is the Stefan–Boltzmann constant. $\Delta Q_3 = \pi I\times dt$ is the outgoing energy to the heat sink by the peltier cooler connected to the external current source of $I$. Finally, $\Delta Q_4 = G(T - T_0)\times dt$ is the incoming energy due to thermal conductance ($G$) from the device surrounding as well as the heat sink. $T$ and $T_0$ are temperature of cold surface (device) and hot surface of the cooler (heat sink), respectively. By