Thermal energy capture by pyroelectric effect

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Abstract. Taking advantage of the physical nature of the pyroelectric materials, in this investigation a characteristic of these materials known as the pyroelectric effect was studied and corroborated, which allows this type of materials are sensitive to infrared electromagnetic radiation, and whose response can be seen in the form of electric potential difference. In this way, in this document the theoretical basis of operation of this effect is presented, and in turn, the results of experiments carried out in laboratories of the University of Santo Tomás Bogotá D.C. The experiments were performed using the “PIR325” sensor, which is composed of two thin films of pyroelectric material. In the first instance, the response of the sensor to thermal electromagnetic radiation produced by the human body is obtained, in the second instance, the same experiment is repeated, However, on this occasion, a Fresnel lens is used to ensure the highest infrared electromagnetic energy collection. Finally, the capture of the signals obtained in each experiment is performed and the results are contrasted, where the theoretical basis of the pyroelectric effect is demonstrated, and in turn, the importance of using a Fresnel lens in applications to carry out this type of sensors.

1. Introduction
Pyroelectricity, is a quality that some materials called pyroelectric have, it has been used by engineering to partly forge the current technological world. Pyroelectric materials have important physical characteristics for the industry, for example, they are used in the manufacture of electronic devices, sensor manufacturing, radiation measurement, infrared ray analyzers, automatic domotic systems, etc. The importance of these materials in the world is such that it has been decided to study their theoretical and experimental behavior, in order to characterize its principle of operation and physical properties of operation.

2. Pyroelectric effect
In terms of closed circuit with two electrodes, the current generated by a material pyroelectric is defined by equation (1), which expresses the relationship between the intensity of electric current $I$, and the variation of electric charge $Q$ with respect to time, In addition, this current represents the amount of electrical charge that crosses the section of the pyroelectric material on a time interval.

$$I = \frac{dQ}{dt} \ \ \ \ (1)$$
Taking into account the electric dipole moment, for pyroelectric materials, the equation (2) defines the relationship between the temperature change $\Delta T$ as a function of time, the charge generated $Q$, the pyroelectric current $I$, the surface area of material $A$ and the pyroelectric coefficient of the material $p$ under conditions of short circuit with electrodes that are oriented normal to the direction polar[1].

$$\frac{dQ}{dt} = pA \frac{dT}{dt}$$ \hspace{1cm} (2)

Taking into account that the pyroelectric coefficient and the surface area of the pyroelectric material are constant, then, integrating on both sides of the equation (2) is obtained:

$$\Delta Q = pA \Delta T$$ \hspace{1cm} (3)

Equation (3) expresses the directly proportional relationship between the electric charge and the temperature variation in a pyroelectric material, given that behaves like a dielectric material, the capacitance of the pyroelectric element is defined according to the equation (4), the above, taking into account a thin film of material as shown in figure (1), which behaves as a parallel plate capacitor, where the absolute electrical permittivity is expressed by equation (5), where $E_0$ is the electric permittivity under vacuum and $E_r$ the relative permittivity of the material. [1] [4] [5]

$$C = A \frac{E}{h}$$ \hspace{1cm} (4)

$$E = E_r E_0$$ \hspace{1cm} (5)

In open circuit conditions, the pyroelectric charge generates a potential difference between the faces of the material, the above based on the fact that the surface charge is proportional to the potential difference, therefore, the equation (6) expresses the relationship existing between capacitance $C$, the potential difference $V$ and the electric charge $Q$. Accordingly, equation (7) defines the potential difference $V$ in a pyroelectric material under open circuit conditions. [1]

$$Q = CV$$ \hspace{1cm} (6)

$$V = \frac{\rho}{E} h \Delta T$$ \hspace{1cm} (7)

3. Pyroelectric Infrared Sensor

Radiation is a component of the electromagnetic spectrum, but since the length of this radiation is greater than that of the visible region, it is not possible to observe it with the human eye, but it is feasible to
detect it. According to black body radiation a hot object emits electromagnetic waves from the infrared region, but in addition to hot objects animals and the human body also emit them, these have the strongest radiation emission present in a wavelength of 9.4 μm. [2]

A pyroelectric sensor is a device sensitive to temperature changes, these based their operation in thin films of pyroelectric materials, which in accordance with the relationship expressed in equation (7), generates a potential difference directly proportional to the temperature change, therefore, this type of devices behave as transducers, transforming a response thermal energy into electrical energy as can be seen in figure (2).

![Figure 2.](image)

**Figure 2.** The infrared light with which the sample is irradiated, changes the temperature of this, resulting in a variation in the electric field proportional to the electrical potential.

### 4. Experiment of capture of thermal energy

In order to obtain the response of a pyroelectric sensor to temperature variation, we used the pyroelectric sensor PIR325 shown in Figure (3a), which is made of a crystalline material that generates an electrical charge on the surface when exposed to heat in the form of infrared radiation. When the amount of radiation inciding the crystal changes, the amount of charge also changes and can be measured with an integrated FET device in the sensor. The sensor elements are sensitive to radiation over a wide range, so a filtered window is added to the TO5 package to limit incoming radiation in a range of 8μm to 14μm, being the wavelength range most sensitive to radiation of human body. [2]

![Figure 3.](image)

**Figure 3.** (a) Pyroelectric Sensor PIR 325, (b) PIR 325 pyroelectric sensor operation.[2]
The PIR sensor has two pyroelectric elements connected in a setting of voltage variation. This arrangement cancels the signals caused by vibrations, temperature changes and sunlight. A body that passes in front of the sensor will first activate one and then the other element as shown in figure (3b), while other sources will affect both elements simultaneously and be canceled. [2].

To obtain the sensor response signal, the circuit shown in figure (4) was implemented, where the signal coming from the sensor is passed through a stage of amplification and filtering, this way, the circuit is composed of a low pass filter active of the first order, this was designed to have an input-output gain of 10 [V/V], in turn, a cutoff frequency of 10 [Hz], taking into account that these types of sensors present their response in the frequency spectrum not exceeding 10[Hz].

![Figure 4. Circuit implemented for signal collection](image)

In order to obtain the response signal from the sensor to temperature variation, the sensor was exposed to the infrared electromagnetic radiation produced by the human body according to the operation shown in figure (3b), exciting the two elements of pyroelectric material present in the sensor, from the left and right positions respectively, the above to demonstrate the excitation of the two elements of pyroelectric material, thus achieving by passing the hand to excite first one pyroelectric element and then the other respectively. Therefore, the signals are obtained as shown in figures (5) and (6), in which the response signals of the sensor can be seen from the positions described above.

![Figure 5. Response obtained from the sensor to temperature variation by the human body from the Left position.](image)
Figure 6. Response obtained from the sensor to temperature variation by the human body from the Right position.

The signals shown in figures (5) and (6), show the electric potential is generated according to the relationship of equation (7) in response to the change in temperature caused by the radiation of the human body, in turn, it is possible to observe how the shape of the signal obtained changes when passing the hand from the left and right positions, remembering that the pyroelectric elements present in the sensor are in voltage variation configuration, the response signal depends on the pyroelectric material that is excited in the first instance, thus, when passing the hand from left to right, the response of the pyroelectric element located on the left side of the sensor is evidenced first and then that of the element located on the right side of the sensor, it works the same way if it is passed from the right position, activating first the right pyroelectric element and then the left. This can be observed in the signals obtained.

5. Thermal energy capture using Fresnel lens

In applications of pyroelectric effect, an optical system used to ensure the greatest amount of infrared electromagnetic energy collection is composed of a Fresnel lens, whose function is to focus the radiation on the area of pyroelectric material. Fresnel lenses have behaviors similar to convex lenses, however, the cost of manufacturing a Fresnel lens is much lower, which makes them effective in some of the low-cost applications, its operation is shown in figure (7b), in which it can be seen as an electromagnetic wave that hits the surface of the lens, diffracts and converges to the central point $P_o$ and at a focal length $d$, what causes that based on the principle of conservation of the energy, all the irradiated energy is concentrated in the angle of vision of the lens in the central point $P_o$.

Figure 7. (a). Fresnel lens used (b). Fresnel curve lens operation.
The lens shown in figure (7a) was used, which is made of plastic and has a low cost in the market. In addition, it is implemented on other various sensors passive infrared motion detectors, therefore, the experiment was performed from the left and right positions by adding the Fresnel lens, being so, the figures (8) and (9) show the signals captured, corresponding to the two positions raised previously.

Figures (8) and (9) show a considerable increase in electrical potential when the Fresnel lens is added, this is because all the energy irradiated on the lens converges to the point where the elements of pyroelectrical material are located, in such a way, the importance of this type of lens can be seen experimentally when wanting to capture as much infrared radiation as possible, in turn, in the same way as in figures (5) and (6) the excitation of the two pyroelectric elements located on the left and right side of the sensor, respectively, can be evidenced.
6. Conclusion
Performing the experiments presented above, the operation of the pyroelectric effect could be corroborated, thus managing to capture the electrical potential generated on the surface of each of the pyroelectric material elements present in the sensor, the above, when the infrared electromagnetic radiation coming from the human body affects the surface of these elements, leaving in evidence that the infrared light with which this type of materials is irradiated, produces a variation in its temperature, which, translates into a variation of electric field proportional to the electrical potential on the surface of the material.

Finally, when supporting the experiment using the Fresnel lens, it is found that the amount of electrical potential that is generated by irradiating the elements of pyroelectric material is considerably greater, mainly because the field of vision is increased to 120°, and all the energy radiated on the Fresnel lens converges to the location point of the pyroelectric material elements, this demonstrates the importance of using this type of optical systems in infrared thermal energy capture.

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