Pyroelectrics vs. Thermopile IR Detectors

Phenomenology (How they Operate)

Thermopiles

Thermopiles are an "array" of thermocouples made from dissimilar materials with differing Seebeck coefficients. Each "couple" produces a voltage proportional to its temperature and the differences in the Seebeck coefficient of the couple materials. N and P type polysilicon are used as the couples in low-end thermopiles while Antimony and Bismuth are used in higher performing parts but at a higher cost, other materials such as Iron-Nickel are used as well. Half of the "couples" are blackened and called "actives" the remainder are made reflective and positioned out of the FOV and called "compensators". The signal polarity of the "compensator" couples is the opposite of the active couples which cancels the voltage from the local ambient temperature. They are usually connected electrically in series to raise the total resistance which improves the signal to noise. These devices are truly differential sensors in that the output signal is proportional to the temperature difference between the active and the comp. This cancels changes in the temperature of the micro atmosphere inside the detector capsule. Although these are usually very slow effects the thermopiles would respond to these as they are DC devices so the differential connection mitigates this problem.

The temperature rise in the active junction is a function of the IR energy received and the thermal inertia of the couple. Thermopiles are limited by the fact that the thermal mass of the sensor prevents it from changing temperature very quickly. This is governed by its thermal constant. The materials used, the substrate, the method of preparation and the gas sealed in the detector capsule all affect the thermal time constant. Typical thermal time constants for thermopiles range from 10 to 100 milliseconds and govern the rate of heat arriving and leaving the couples. Reducing the time constant will only reduce the output as it reduces the temperature rise and fall in the element. Because of this fact thermopiles have excellent DC response (constant temperature) but this falls off very quickly so that at frequencies above the thermal time constant the output is reduced. The main noise mechanism in thermopiles is the Johnson noise from its total resistance.

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Pyroelectrics

The Pyroelectric effect is manifested in dielectric materials which have a crystalline asymmetry such that its polarization is changed when its temperature is changed. This change is "spontaneous polarization" produces charge which can be measured on electrodes applied to its surfaces. However they only produce this charge (C/W) while their temperature is changing. Pyroelectrics are usually modeled as current sources (A/W) in parallel with its native capacitance. The current response (A/W) is the first derivative (dq/dt) of the change in charge (q). Thus current is only produced while the temperature of the element is changing. This means that pyroelectrics have no DC response (as opposed to thermopiles). As the temperature of the element changes as a function of time (frequency) the current output rises to a maximum value where the A/W is constant. This point is called the thermal time constant and is adjusted to suit the application.

There are many materials which have this property however there are only three commonly used to make IR detectors. These are Deuterated Lanthanum-Alanine doped Triglycine Sulphate (DLATGS), Lithium Tantalate (LTO), Lead Zirconate Titanate (PZT and its isomorphs). All have their specific and basically different applications. LTO is more commonly used in applications requiring good performance with a high degree of temperature stability such as Non Dispersive Infrared Spectroscopy (NDIR).

As dielectrics they have very high impedances and must be coupled to some form of impedance transforming preamplifier to be of practical usage. This is accomplished with JFETs in the voltage mode (VM) or with opamps in the current mode (CM). As dielectrics they do not exhibit any Johnson noise (but they do produce dielectric loss noise which is only important at higher frequencies. In practice most of the noise is generated by the preamplifier used.

Because pyroelectrics do have some low frequency response and are piezoelectric they are often configured with a compensation element which cancels the signal from fluctuations in temperature of the microclimate in the detector capsule. This may not be required as the chopping frequency is increased.

Similarities (Things in Common)

Both are thermal detectors whose spectral response is independent of wavelength but usually determined by the window or filter supplied. They are indirect sensors in that the temperature change caused by the change in IR is causes a property of the device to change. As opposed to photon sensor such as Lead Selenide (PbSe) whose output is a direct effect of the photons absorbed in the material.

Neither requires a bias voltage (as opposed to photoconductors) although both are commonly used with some sort of preamplifier which does require some operating voltage and current but with today's technology this is very minimal.

Compensated pyroelectrics and thermopiles do minimize the issue of the microclimate fluctuations.

Differences

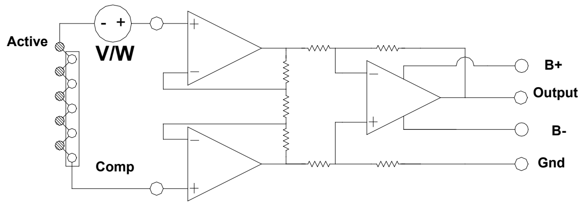
Pyroelectrics have no DC response as opposed to thermopiles. The pyroelectric signal (A/W) signal rises from "Zero" at DC to a maxim value determined by its thermal time constant. However it's noise falls as 1/f. The thermopiles output signal (V/W) is constant from DC until it reaches its thermal time constant (-3 db) where its signal falls as the frequency increases but its noise is constant with frequency.

The output signal (V/W) of a pyroelectric is substantially higher than the thermopile once the operating point is moved away from DC to a typical "chopping" frequency of 2 to 10 Hz. The Signal to Noise (NEP and D*) of the pyroelectric is also better at these higher frequencies.

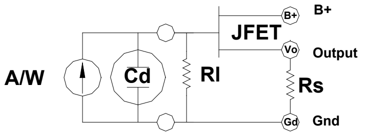
Following are Responsivity (V/W) and Dstar (Jones) plots for 1.2 mm x 1.2 mm MWA pyroelectrics from the MWA performance model and Heimann thermopiles from the Heimann data sheet (see attached) The Heimann Tpile 10 msec thermal TC as advertised was used in the calculation. The MWA pyro is uncompensated but this should not be an issue at the 8Hz or higher chopping frequencies. (Compensated devices are also available but have a slightly lower Dstar).

You can notice the significant increase in both V/W and Dstar from the Tpile to the pyro. The voltage responsivity is increased by a factor of 40 and the Dstar by a factor of 3.2. It can be seen that the voltage response begins to fall ll as the frequency is increased this is due to the impedance of the combination of the detector element's capacitance and the input impedance of the VM preamplifier in the CM the 3dB point is much higher as the capacitance of the detector does not add to the impedance.

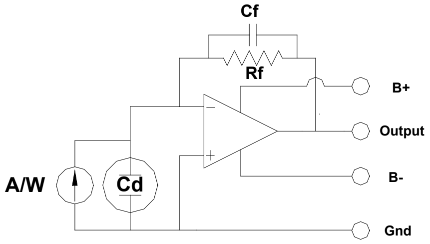
Thermopile with Typical Circuit

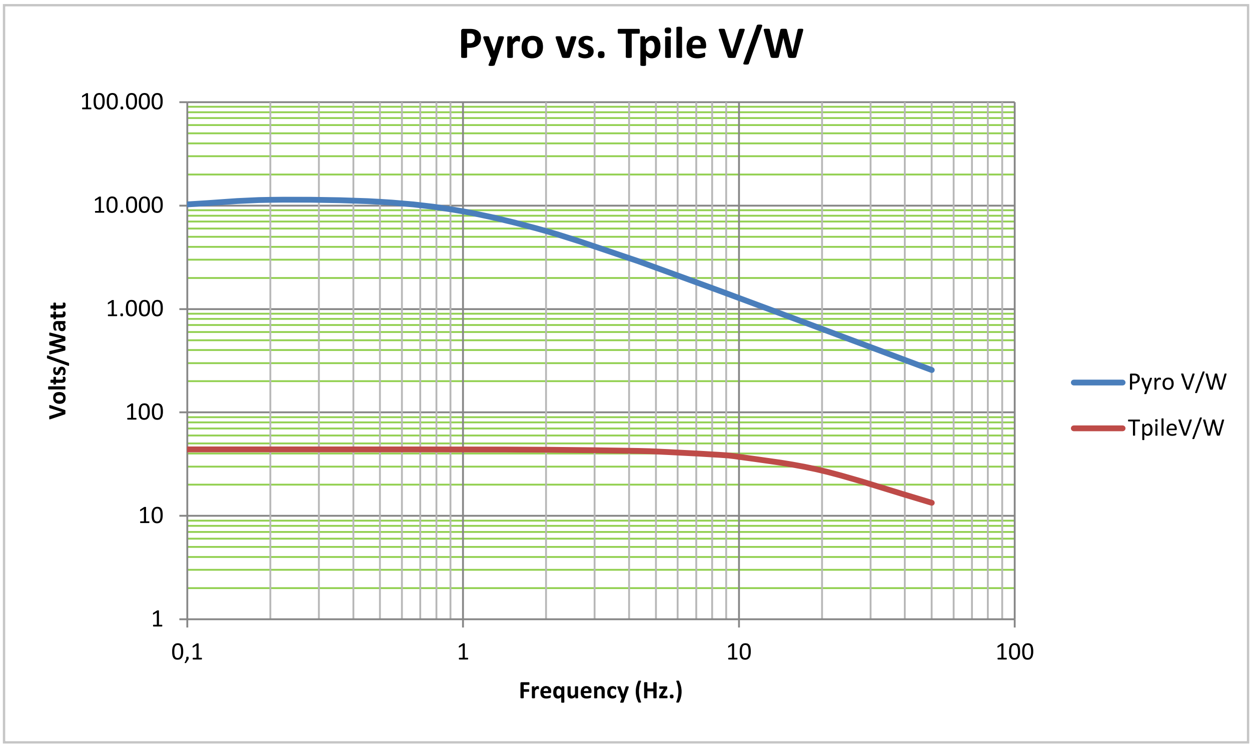


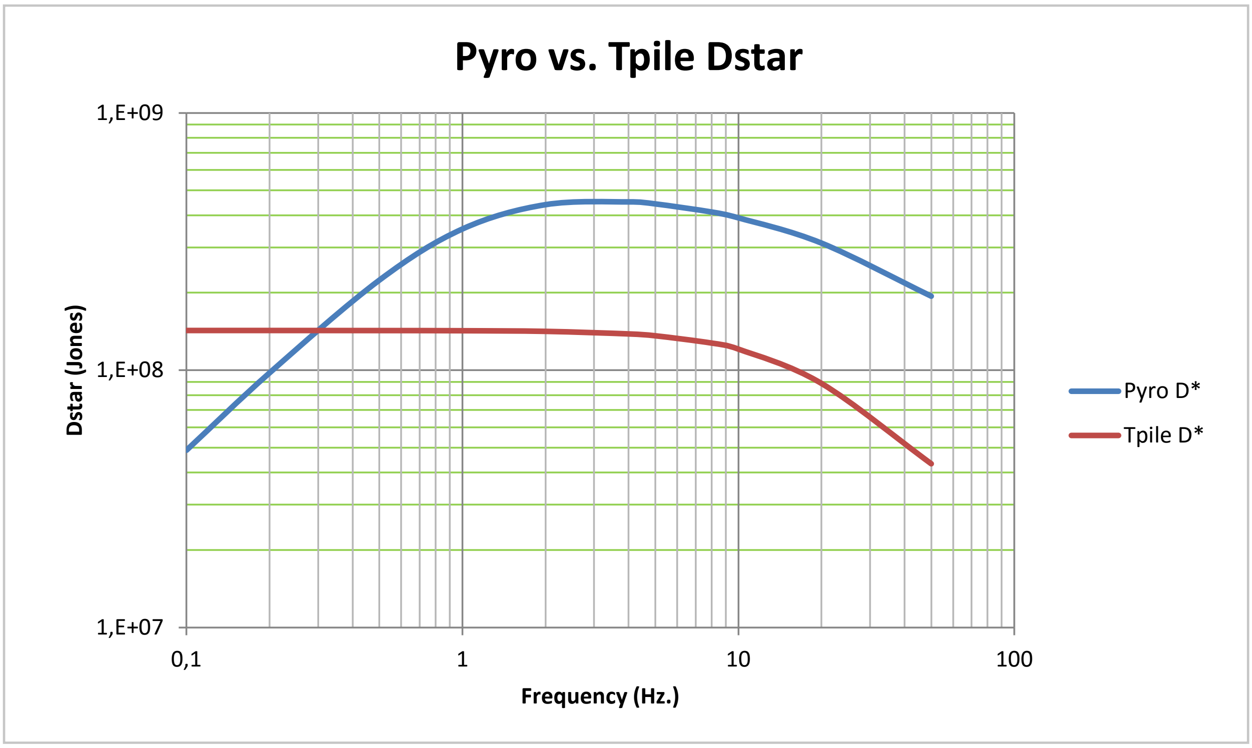
Pyroelectric VM



Pyroelectric CM




Pyro vs. Tpile V/W
Volts/Watt
100.000
10.000
1.000
100
10
1
0,1
1
10
100
Frequency (Hz.)
Pyro V/W
TpileV/W


Pyro vs. Tpile Dstar
Dstar (Jones)
1,E+09
1,E+08
1,E+07
0,1
1
10
100
Frequency (Hz.)
Pyro D*
Tpile D*