Thermopile IR Detectors and Their Uses

Overview

Thermopiles are used for non-contact temperature measurement in various applications. They are used in medical devices (ear and forehead thermometers, dialysis equipment), home appliances (microwave ovens, induction heaters, and other cooking equipment), automotive applications (HVAC controllers, occupancy detector), and electric vehicle “EV” applications (inverters, charging stations).

Radiated Infrared Energy

Object material emits infrared radiation and the radiation power increases as the target object surface temperature increases. The amount of heat radiation leaving an object depends on the shape, temperature, and surface material.

The warmer the source, the more energy it emits

$$W = \delta \varepsilon T^4$$

W = radiant flux emitted per unit area (W/cm^2)

δ = Stefan-Boltzmann constant

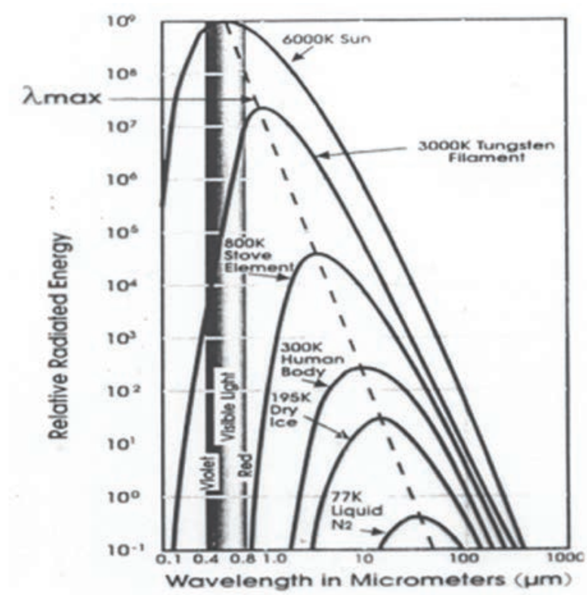
ε = Emissivity

T = Absolute temperature of object (K)

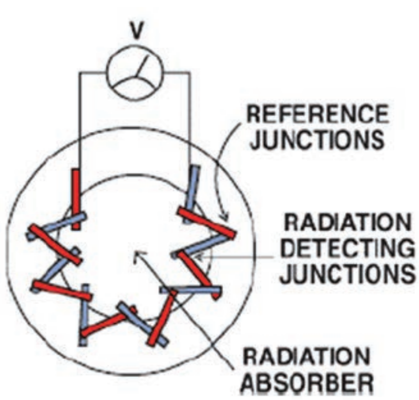
As the temperature of the source increases, the wavelength at which most of the energy is radiated decreases

$$\lambda_{max} = b/T$$

b = Wien’s displacement constant



Thermopile IR Sensor Function



- A thermopile radiation sensor develops a voltage output in response to incoming radiation.
- The device is a series connection of many thermocouple junctions arranged so that incoming radiation heats a group of detecting junctions while not heating a group of reference junctions.

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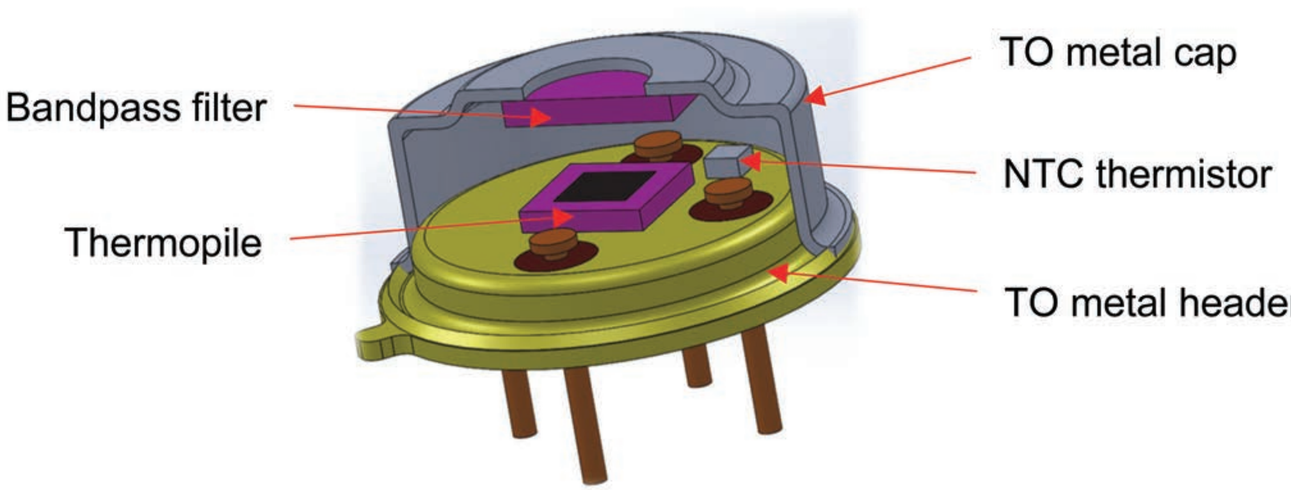


Figure 1 - CrossSection of Thermopile Metal Package

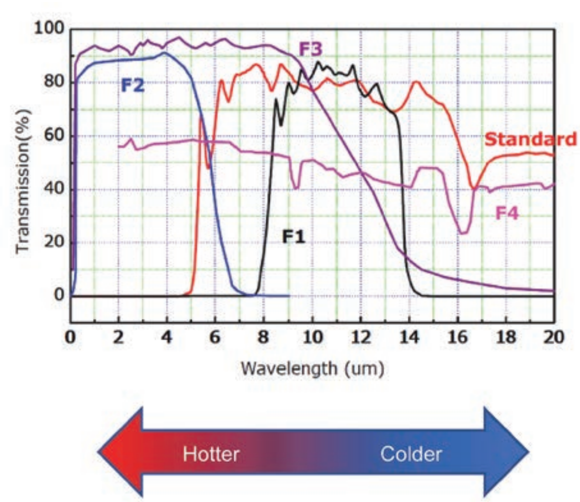
Item	Function	Remark
Thermopile	Object temperature sensing element	
Thermistor	Ambient temperature sensing element for ambient temperature compensation	10kΩ, 30kΩ, 100kΩ
Bandpass filter	IR wave transmit / cut-off device	5.5~14um, 8~14um
Header	Sensor body element	TO-39, TO-46
Cap		TO-39, TO-46

Example Filters

Thermopile IR detectors use various IR wavelength filters for different applications.

All packages listed below use different filter materials.

Filter	Material	Transmission Range	Application
Standard	Silicon	5.5~13um	Human body detection(Ear/forehead thermometer), Microwave oven, Automotive HVAC
F1	Silicon	8~14um	Occupancy detection, Intruder alarms
F2	Sapphire	2~5um	Flame detection, High temperature application, Analysis equipment
F3	CaF2	1~10um	
NDIR	Silicon	3.99±1%	Reference
		4.65±1%	CO gas detection
		4.26±1%	CO_2 gas detection



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Reference Circuit of Thermopile Application

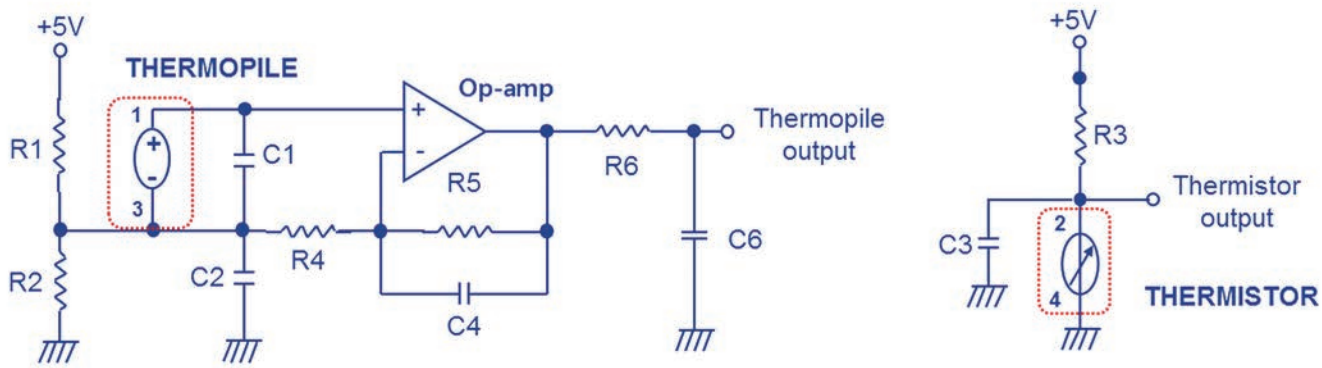

Figure 2 - IR Detector Application Circuit

The thermopile IR detector provides two different analog signals. One is for the thermopile and the other is for the thermistor (used for ambient temperature compensation).

This circuit can be used with different sensor packages, applications, and temperature ranges.

Thermopile IR Detector Calibration

The IR detector needs to be calibrated in order to provide an accurate temperature output. A blackbody source and shield case (water bath) are needed. The target and ambient temperatures must be precisely controlled.

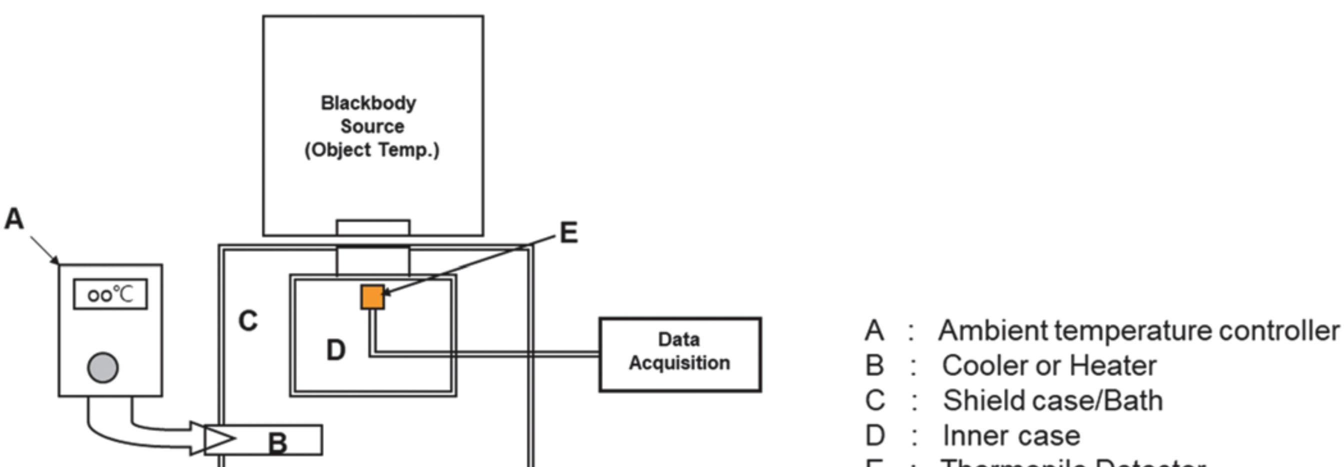

Figure 3 - Calibration Equipment Condition

(Test condition can change based on application condition)

TEST Procedure

1. Fix sensor at “E” position.
2. Set object temperature to measure (ex,55°C).
3. Get data under different ambient temperature using ambient controller.
4. Measure #2 and #3 under different Object temperature.
5. Create “Look-up table” based on the test result. (See Table 1)

Thermopile IR Detectors and Their Uses

Thermopile IR Detector Equation

The thermopile equation below relates temperature, emissivity, and the thermopile factor.

Table 1 is a thermopile characteristic table, which can be created using Figure 3 Calibration equipment setup.

$$Vtp = s^{*} \varepsilon * (To4\text{-}x - Ta4\text{-}x)$$

- Vtp : Thermopile output voltage
- Vth : Thermistor output voltage
- s : Thermopile factor
- ε : Emissivity parameter
- To : Object temperature
- Ta : Ambient temperature

Build Thermopile Characteristic Table *(object temp. 20 - 30)*

Object Temp.	20	21	22	23	24	25	26	27	28	29	30
Ambient Temp.	Output of IR (mV)										
20	0.000	0.148	0.297	0.448	0.600	0.754	0.909	1.066	1.225	1.385	1.546
21	-0.148	0.000	0.149	0.300	0.452	0.606	0.761	0.918	1.077	1.237	1.399
22	-0.297	-0.149	0.000	0.151	0.303	0.457	0.612	0.769	0.928	1.088	1.250
23	-0.448	-0.300	-0.151	0.000	0.152	0.306	0.461	0.618	0.777	0.937	1.099
24	-0.600	-0.452	-0.303	-0.152	0.000	0.154	0.309	0.466	0.625	0.785	0.947
25	-0.754	-0.606	-0.457	-0.306	-0.154	0.000	0.155	0.312	0.471	0.631	0.793
26	-0.909	-0.761	-0.612	-0.461	-0.309	-0.155	0.000	0.157	0.315	0.476	0.637
27	-1.066	-0.918	-0.769	-0.618	-0.466	-0.312	-0.157	0.000	0.159	0.319	0.480
28	-1.225	-1w.077	-0.928	-0.777	-0.625	-0.471	-0.315	-0.159	0.000	0.160	0.322
29	-1.385	-1.237	-1.088	-0.937	-0.785	-0.631	-0.476	-0.319	-0.160	0.000	0.162
30	-1.546	-1.399	-1.250	-1.099	-0.947	-0.793	-0.637	-0.480	-0.322	-0.162	0.000
31	-1.710	-1.562	-1.413	-1.262	-1.110	-0.956	-0.801	-0.644	-0.485	-0.325	-0.163
32	-1.875	-1.727	-1.578	-1.427	-1.275	-1.121	-0.966	-0.809	-0.650	-0.490	-0.328
33	-2.041	-1.894	-1.744	-1.594	-1.441	-1.288	-1.132	-0.975	-0.817	-0.657	-0.495
34	-2.209	-2.062	-1.913	-1.762	-1.610	-1.456	-1.300	-1.143	-0.985	-0.825	-0.633
35	-2.379	-2.232	-2.082	-1.932	-1.779	-1.626	-1.470	-1.313	-1.155	-0.995	-0.833
36	-2.551	-2.403	-2.254	-2.103	-1.951	-1.797	-1.642	-1.485	-1.326	-1.166	-1.004
37	-2.724	-2.576	-2.427	-2.276	-2.124	-1.970	-1.815	-1.658	-1.499	-1.339	-1.178
38	-2.899	-2.751	-2.602	-2.451	-2.299	-2.145	-1.990	-1.833	-1.674	-1.514	-1.352
39	-3.076	-2.928	-2.779	-2.628	-2.476	-2.322	-2.166	-2.009	-1.851	-1.691	-1.529
40	-3.254	-3.106	-2.957	-2.806	-2.654	-2.500	-2.345	-2.188	-2.029	-1.869	-1.707

Build Thermopile Characteristic Table *(object temp. 31 - 40)*

Object Temp.	31	32	33	34	35	36	37	38	39	40
Ambient Temp.	Output of IR (mV)									
20	1.710	1.875	2.041	2.209	2.379	2.551	2.724	2.899	3.076	3.254
21	1.562	1.727	1.894	2.062	2.232	2.403	2.576	2.751	2.928	3.106
22	1.413	1.578	1.744	1.913	2.082	2.254	2.427	2.602	2.779	2.957
23	1.262	1.427	1.594	1.762	1.932	2.103	2.276	2.451	2.628	2.806
24	1.110	1.275	1.441	1.610	1.779	1.951	2.124	2.299	2.476	2.654
25	0.956	1.121	1.288	1.456	1.626	1.797	1.970	2.145	2.322	2.500
26	0.801	0.966	1.132	1.300	1.470	1.642	1.815	1.990	2.166	2.345
27	0.644	0.809	0.975	1.143	1.313	1.485	1.658	1.833	2.009	2.188
28	0.485	0.650	0.817	0.985	1.155	1.326	1.499	1.674	1.851	2.029
29	0.325	0.490	0.657	0.825	0.995	1.166	1.339	1.514	1.691	1.869
30	0.163	0.328	0.495	0.663	0.833	1.004	1.178	1.352	1.529	1.707
31	0.000	0.165	0.332	0.500	0.670	0.841	1.014	1.189	1.366	1.544
32	-0.165	0.000	0.617	0.335	0.505	0.676	0.849	1.024	1.201	1.379
33	-0.332	-0.167	0.000	0.168	0.338	0.510	0.683	0.858	1.034	1.212
34	-0.500	-0.335	-0.168	0.000	0.170	0.341	0.515	0.689	0.866	1.044
35	-0.670	-0.505	-0.338	-0.170	0.000	0.172	0.345	0.520	0.696	0.874
36	-0.841	-0.676	-0.510	-0.341	-0.172	0.000	0.173	0.348	0.525	0.703
37	-1.014	-0.849	-0.683	-0.515	-0.345	-0.173	0.000	0.175	0.351	0.530
38	-1.189	-1.024	-0.858	-0.689	-0.520	-0.348	-0.175	0.000	0.177	0.355
39	-1.366	-1.201	-1.034	-0.866	-0.696	-0.525	-0.351	-0.177	0.000	0.178
40	-1.544	-1.379	-1.212	-1.044	-0.874	-0.703	-0.530	-0.355	-0.178	0.000

Rth(kΩ)	Vth(V)	Temp. In °C
124.92	2.78	20
122.15	2.75	20.5
119.46	2.72	21
116.83	2.69	21.5
114.28	2.67	22
111.79	2.64	22.5
109.36	2.61	23
106.99	2.58	23.5
104.69	2.56	24
102.45	2.53	24.5
100.27	2.5	25
98.14	2.48	25.5
96.08	2.45	26
94.07	2.42	26.5
92.12	2.4	27
90.22	2.37	27.5
88.37	2.35	28
86.59	2.32	28.5
84.85	2.3	29
83.17	2.27	29.5
81.54	2.25	30
79.96	2.22	30.5
78.44	2.2	31
76.97	2.17	31.5
75.55	2.15	32
74.18	2.13	32.5
72.87	2.11	33
71.62	2.09	33.5
70.41	2.07	34
69.26	2.05	34.5
68.17	2.03	35
67.14	2.01	35.5
66.16	1.99	36
65.24	1.97	36.5
64.39	1.96	37
63.59	1.94	37.5
62.86	1.93	38
62.19	1.92	38.5
61.59	1.91	39
61.06	1.9	39.5
60.61	1.89	40

Table 1 - Thermistor Output

Temp. In °C	Temp. In K	(T,Tref)
25	298.15	0.000
25.5	298.65	0.077
26	299.15	0.155
26.5	299.65	0.234
27	300.15	0.312
27.5	300.65	0.391
28	301.15	0.471
28.5	301.65	0.551
29	302.15	0.631
29.5	302.65	0.712
30	303.15	0.793
30.5	303.65	0.874
31	304.15	0.956
31.5	304.65	10.380
32	305.15	1.120
32.5	305.65	1.204
33	306.15	1.287
33.5	306.65	1.371
34	307.15	1.456
34.5	307.65	1.540
35	308.15	1.626
35.5	308.65	1.711
36	309.15	1.797
36.5	309.65	1.883
37	310.15	1.970
37.5	310.65	2.057
38	311.15	2.145
38.5	311.65	2.233
39	312.15	2.322
39.5	312.65	2.411
40	313.15	2.500
40.5	313.65	2.590
41	314.15	2.680
41.5	314.65	2.771
42	315.15	2.862
42.5	315.65	2.953
43	316.15	3.045
43.5	316.65	3.137
44	317.15	3.230
44.5	317.65	3.324
45	318.15	3.417

Table 2 - Thermopile Reference V-T

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Sensor Compensation and Calibration

1. Thermopile Output Equation

- The output of the thermopile is shown by the mathematical function of To (Object temperature) and Ta (Ambient temperature) in equation #1 below.

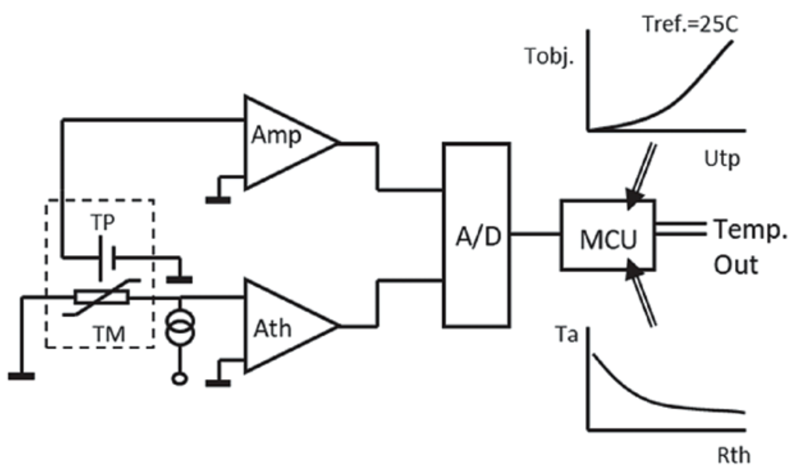
$$Vtp = \varepsilon * s * f(To, Ta) \qquad : \text{Equation \#1}$$

- Equation #1 convert to equation #2. based on the reference temperature (Tref)

$$Vtp = \varepsilon * s * f(To, Tref) - \quad * s * f(Ta, Tref). \qquad : \text{Equation \#2}$$

- Object temperature is achieved with equation #3

$$f(To, Tref) = Vtp / \varepsilon * s + f(Ta, Tref) \qquad : \text{Equation \#3}$$



Need to set a reference temp (Tref) and make the factor f (T, Tref) table (Table 2. Thermopile reference V-T table). This equation is used for finding f (Ta, Tref) and f (To, Tref) in the measurement procedure below, the temperature compensation procedure.

2. Calibration Procedure

2.1 Find the thermopile factor (S) of each sensor.

a) Make f (T, Tref) look-up table (Refer Table 2)

b) For calibration, fix the ambient temperature (Ta) then check the output voltage of 2 different temperatures (T1 and T2) using a blackbody source

$$Vtp1 = s*(f(T1, Tref) - (Ta, Tref)) \qquad : \text{Equation \#4}$$

$$Vtp2 = s*(f(T2, Tref) - (Ta, Tref)) \qquad : \text{Equation \#5}$$

c) Find the “s” value by tracking Vtp1 and Vtp2.

$$s = (Vtp1 - Vtp2) / (f(T1, Tref) - f(T2, Tref)) \qquad : \text{Equation \#6}$$

- Object temperature is achieved through equation #3
- Emissivity parameter (Target object material) should be the same value when solving for Vtp1 and Vtp2

Set a reference temp (Tref) to make the factor f (T, Tref) table (Table 1. Thermopile characteristic table)

This equation is used for finding f (Ta, Tref) and f (To, Tref) in the measurement procedure section

3. Measurement Procedure

3.1 Check ambient temperature (measured value)

a) Find the thermistor resistance (Rth) through the thermistor's voltage (Vth)

b) Convert Vth to ambient temperature (Ta) using the Thermistor R-T look-up table (Table 1)

3.2 Determine "f(Ta, Tref)" value using Ta (Refer to 3.1)

a) Find the factor f(Ta, Tref) value using Ta

b) Find the temperature compensation factor f(Ta, Tref) using Table 2

3.3 Find the target temperature

a) Object temperature f(To, Tref) can be solved with f(Ta, Tref)

3.4 Verify under different target object(blackbody) conditions

4. Example

1. Calculating the 'S' Value

• Vtp1 measurement condition and value - Object temperature : 30.0°C - Ambient temperature : 25.0°C Vtp1 = s*(f (T1, Tref) - (Ta, Tref)) = 0.785	• Vtp2 measurement condition and value - Object temperature : 45.0°C - Ambient temperature : 25.0°C Vtp2 =s*(f (T2, Tref) - (Ta, Tref)) = 3.388

1.1 Calculating "s" value using equation 6

- s = (Vtp1 – Vtp2) / (f(T1, Tref) – f(T2, Tref)) = 0.992 : Equation 6 refer to Table 2.

2. Calculating object temperature

2.1 After measuring the actual value below

- Tested Vtp = 1.688V and Vth = 2.412V =27.0°C Convert to temp by using Table 1.

2.2 Use equation 3 to calculate the ambient temperature compensated voltage.

- f(Tobj,Tref) =Vtp/ s + f(Ta,Tref) : Equation. 3 f(Ta,Tref) can get Table. 2.
  = 2.014

2.2 The actual object temp can be found from Table 2.

- Measured object temperature = 37.0°C

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