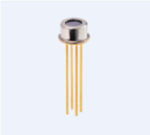
Thermopile Sensor
OTP-638D2

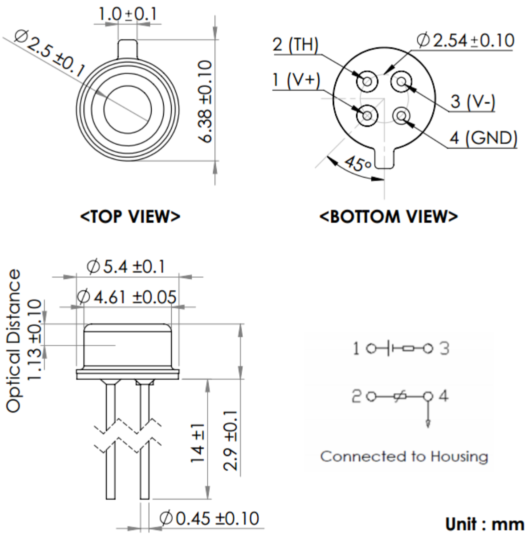
Revision Date: 2016/12/16 (Rev.00)

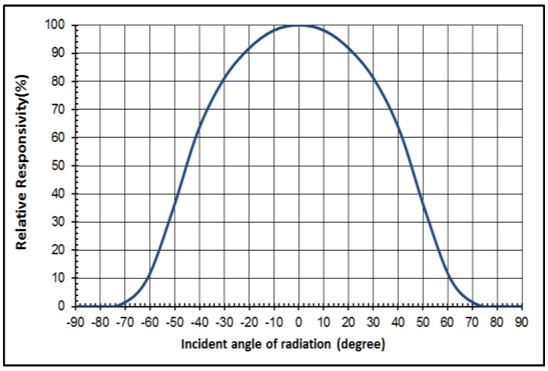


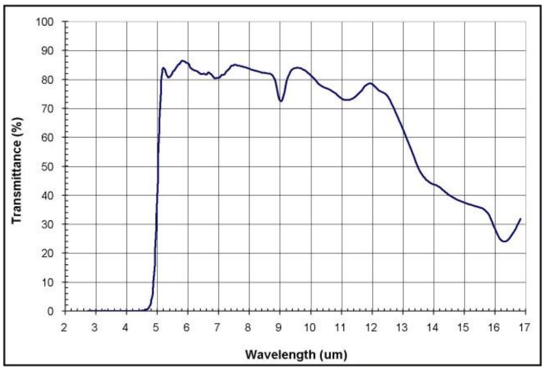
The OTP-638D2 is a thermopile sensor in classic TO-46 housing. The sensor is composed of 116 elements of thermocouple in series on a floating micro-membrane having an active area of diameter 545 μm. The thermopile sensor provides nearly Johnson-noise-limited performance, which can be calculated by its ohmic series resistance. A thermistor with a lead connected to ground is also provided inside the TO package for ambient temperature reference.

- TO-46 metal housing
- Thermistor temperature reference included
- Low temperature coefficient of sensitivity
- Ideally suited for ear thermometers, miniature pyrometer.

Parameter	Typ	Unit	Conditions
Sensitivity	128	V/W	323K, 5-14μm
TC of sensitivity	0.14±0.05	%/K	25℃
Thermopile Voltage	2.4±0.7	mV	Tb:50℃, Ta:25℃ 5-14μm
Active area in diameter	545	μm	
Resistance of thermopile	115±35	KΩ	25℃
TC of resistance	0.1±0.05	%/K	25℃
Time constant	17	ms	
Noise voltage	42.9	$nV/Hz^{1/2}$	r.m.s 300K
NEP	0.34	$nW/Hz^{1/2}$	323K, 5-14μm
Normalized detectivity (D*)	$1.43*10^{8}$	$cm*Hz^{1/2}/W$	323K, 5-14μm
Thermistor resistance	100±5%	KΩ	25℃
β value	3964±0.5%	K	25℃/100℃
Field of view	90	o	@50% target signal
Cut on wavelength	5±0.3	μm	@25℃, 50% transmittance





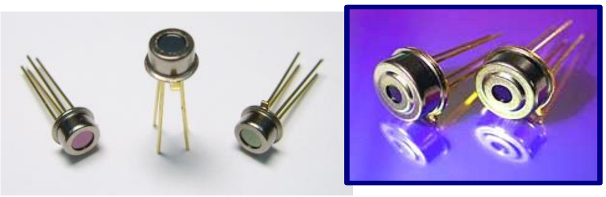


Application Note of Thermopile

1. Introduction

Thermopile is widely used in non-contact temperature measurement applications and temperature monitoring systems. Thermopiles detect the temperature of an object by absorbing the infrared (IR) radiation that emits from the object’s surface. Most of the device's detectors are equipped with a black body surface for effectively absorbing the IR radiation. A thermopile consists of an array of thermocouples connected together in series in order to increase the voltage output to more easily measured levels. The thermocouples that make up a thermopile consist of two strips of different metals welded at one end. Each thermocouple produces a voltage that is proportional to the temperature difference between the "hot" and "cold" ends, which is known as the Seebeck effect.

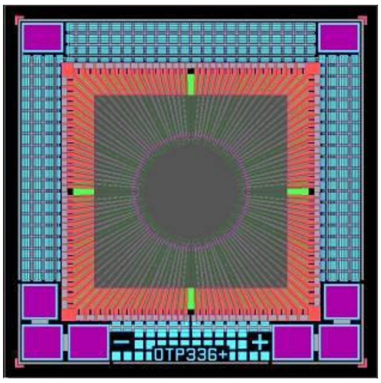
2. Thermopile Features

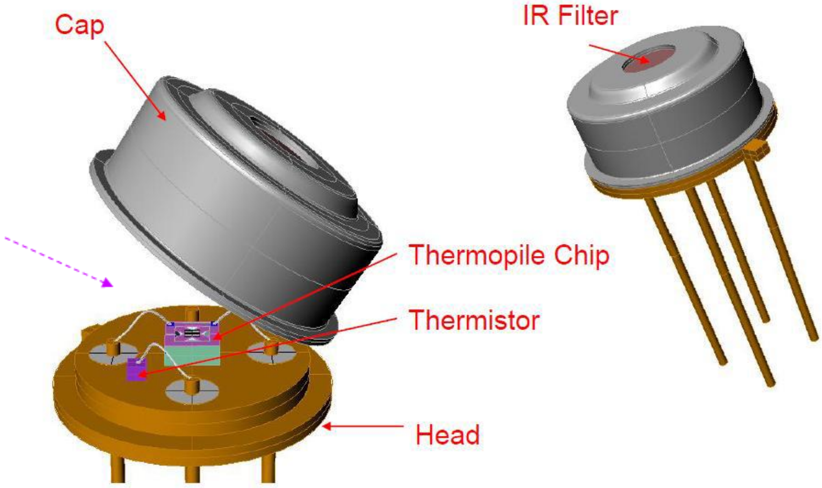


- TO metal housing with IR absorber coating inside
- Thermistor temperature reference included
- Low temperature coefficient of sensitivity
- Ideally suited for ear thermometers, miniature pyrometer

3. Structure of Thermopile IR Sensor

Our thermopile detector is packaged with silicon filter(5-14µm or 8-14µm) and thermistor as shown below. We are supplying two types of package (TO-5 and TO-46), but on request, other package types are also available.

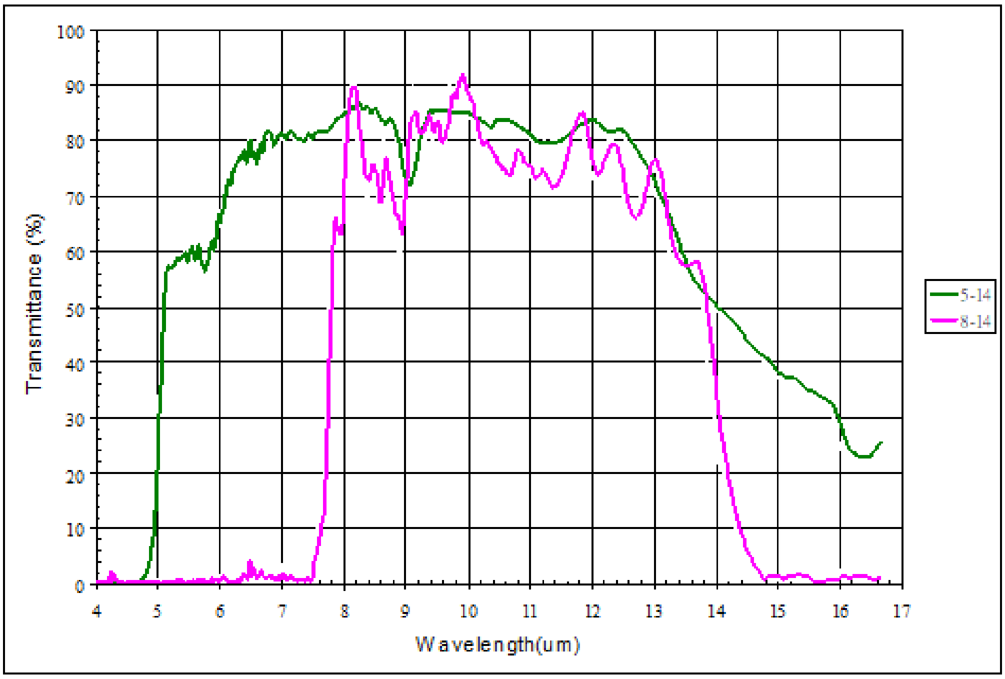




3-1.Thermistor

The variation of an environment temperature cause the output of thermopile detector will be changed. Therefore, it needs to compensate this temperature performance of thermopile detector. The thermopile detectors are using a thermistor for the compensation of an environment temperature, and we also have different types of thermistor for customization.

3-2.IR filter



Transmission Range	Filter Material	Applications
5 -14 µm	Silicon	Ear thermometer, Automotive (Air conditioning), Human body detection, HVAC, Occupancy detection, Industry (Object detection), Medical (Skin temperature), Monitoring Systems, Home appliances (Microwave oven), Security (Presence detection)
8-14 µm	Silicon	

4. Glossary of Parameters

4-1.Sensitivity :
The sensitivity(S) is the thermopile output per unit of input power. S definition is (V_{out} / P_{rad}), where V_{out} : the output of a thermopile; P_{rad}. : the absorbed radiation power. The units of sensitivity is volts/watt(V/W). It should be as high as possible. Typical sensitivity values of thermopiles are several 10 to about 100 V/W dependent on the area of the absorber and the number and type of thermocouples.

4-2. TC(temperature coefficient) of sensitivity:
The temperature coefficient is the relative change of a physical property when the temperature is changed by 1 Kelvin.

4-3. Time constant:
The time constant of thermopile is decided by the time required 63% of its output voltage at the same ambient temperature.

4-4. Noise voltage:
Johnson-Nyquist noise (thermal noise, Johnson noise, or Nyquist noise) is the electronic noise generated by the thermal agitation of the charge carriers (usually the electrons) inside an electrical conductor at equilibrium, which happens regardless of any applied voltage.

$Vn=(4KTR\triangle f)^{1/2}$: the thermal noise voltage is normalized by △f and therefore given in $V/Hz^{1/2}$
K: Boltzmann's constant
T: the resistor's absolute temperature
R: the resistor value
△f: the bandwidth in hertz over which the noise is measured

4-5. Noise equivalent power (NEP):
It is defined as the signal power which gives a signal to noise ratio of 1 for an integration time of half a second, or more technically the radiant power that produces a signal to noise ratio of unity at the output of a given optical detector at a given data-signaling rate or modulation frequency, and effective noise bandwidth. Therefore, it is desirable to have as low an NEP as possible, since a small NEP means a high signal to noise ratio (SNR).

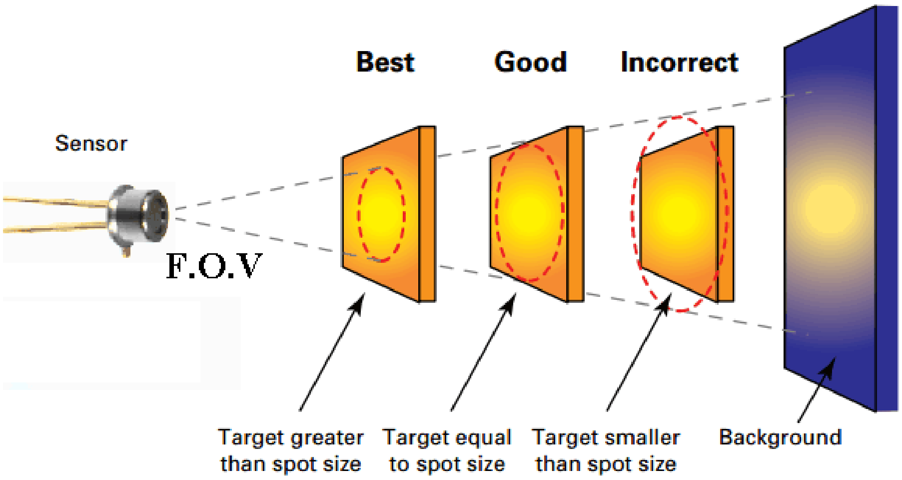
4-6. Normalized detectivity (D*):
For a thermopile, a figure of merit used to characterize performance, equal to the reciprocal of noise equivalent power (NEP), normalized to unit area and unit bandwidth.
Note: Specific detectivity, D*, is given by:

$$D^* = \frac{\sqrt{A\Delta f}}{NEP}$$

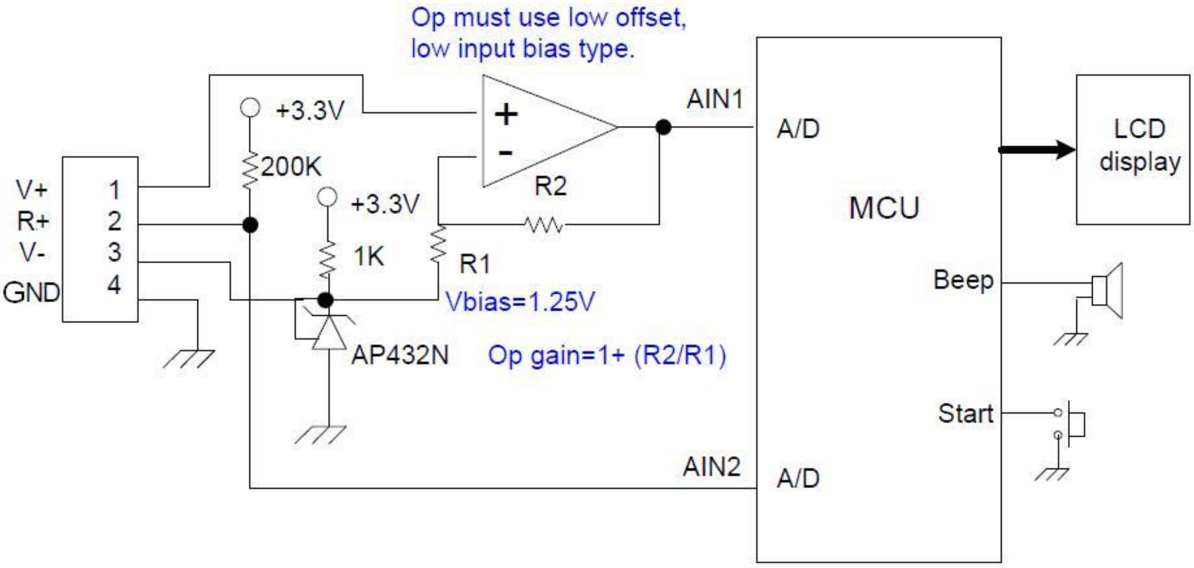
where A is the area of the sensitive region of the thermopile and △f is the effective noise bandwidth. Higher detectivity is more sensitive thermopile.

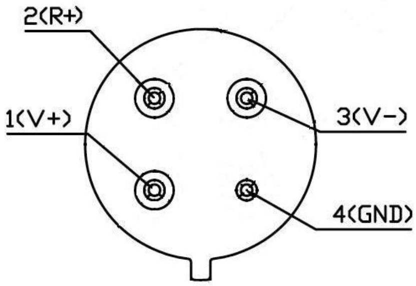
4-7.Field of view(F.O.V):

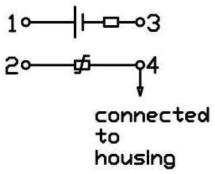
The solid angles through which the thermopile can see given object.



5. Circuit







6. Temperature Calculation

A thermopile sensor has four pins, two of them give the voltage across the series of thermocouples and the other two pins are used to measure thermistor resistance. The thermopile sensor generates a voltage, which is proportional to the incident IR radiation power. You can deduct the object's temperature from the thermopile signal because every object emits IR radiation with a power, which is a strict function of its temperature. The total radiation power P_{obj} emitted by an object of temperature T_{obj} can be expressed as:

$P_{obj} = \sigma \cdot \varepsilon \, . \, T_{obj}$ – Equation 1

with σ being the Stefan-Boltzmann constant and ε the so called emission factor (or emissivity) of the object. In an ideal case ε has the values '1' and '0'. For most substances, the emission factor lies in the range 0.85 to 0.95. Equation 1 is called the Stefan-Boltzmann law.

The heat-balance equation relates the net power P_{rad} received by the thermopile to two temperatures: T_{obj} and T_a. In most cases the thermopile's temperature equals (or is near to) the temperature of the ambient T_a. Therefore, refer to this value as T_a, the ambient temperature. The total heat power P_{rad} received from the object at temperature T_{obj} is given to:

$P_{rad} = k(\varepsilon_{obj} \cdot T_{obj}^{n} - \varepsilon_a \cdot T_a^{n})$ – Equation 2

Where ε_{obj} is the emission factor of object and ε_a is the emission factor of thermopile. The k contains of cause the constant σ in some form, but it mainly includes the view angle or field-of-view (FOV) of the thermopile. The theoretical value of symbol "n" is "4". But in the some applications, the value of symbol "n" will be mostly in the range of 3 .. 4.

Thermopile generates a voltage V_{TP} which is proportional to the incident radiation. The V_{TP} (ε_{obj} is equal to ε_a)is given to:

$V_{TP} = S \cdot k \cdot \varepsilon(T_{obj}^4 - T_a^4) = K(T_{obj}^4 - T_a^4)$ – Equation 3

Where S is sensitivity and K is calibration constant.

Usually, sensitivity of the thermopile is in the range of millivolts if the ambient temperature is fixed. An empirical relation between V_{TP} and T_{obj} or a look up table gives the object temperature. From Equation 2 and Equation 3, they are evident that V_{TP} changes according to changes in ambient temperature. This ambient temperature needs to be compensated to get the correct object temperature by using a thermistor.

R-T Table (Ta -20°C – 50°C)

TEMP	RESISTANCE		
	(Ω)		
(℃)	MIN.	CENTER.	MAX.
-20	898320	926920	956040
-19	849360	876150	903420
-18	803340	828450	854000
-17	760080	783620	807560
-16	719390	741470	763910
-15	681120	701820	722860
-14	645090	664520	684260
-13	611170	629410	647930
-12	579230	596350	613740
-11	549140	565220	581540
-10	520780	535880	551210
-9	494040	508240	522630
-8	468820	482170	495700
-7	445040	457580	470300
-6	422590	434390	446340
-5	401390	412500	423740
-4	381380	391830	402410
-3	362480	372320	382270
-2	344620	353880	363250
-1	327730	336460	345280
0	311770	319990	328290
1	296690	304430	312250
2	282420	289720	297090
3	268910	275790	282740
4	256120	262610	269160
5	244010	250140	256310
6	232540	238320	244140
7	221670	227130	232620
8	211370	216520	221700
9	201600	206460	211360
10	192340	196930	201550
11	183550	187890	192250
12	175210	179310	183430
13	167290	171170	175060
14	159780	163440	167120
15	152640	156100	159580

16	145860	149130	152420
17	139410	142510	145620
18	133290	136220	139150
19	127460	130230	133010
20	121920	124550	127180
21	116650	119140	121630
22	111640	113990	116350
23	106870	109100	111330
24	102330	104440	106550
25	98000	100000	102000
26	93830	95770	97700
27	89860	91740	93610
28	86080	87890	89710
29	82480	84240	85990
30	79050	80750	82450
31	75780	77420	79070
32	72660	74250	75850
33	69680	71230	72770
34	66850	68340	69840
35	64140	65590	67040
36	61560	62960	64370
37	59090	60450	61810
38	56740	58050	59380
39	54490	55760	57050
40	52340	53580	54820
41	50290	51490	52690
42	48330	49490	50660
43	46450	47580	48710
44	44660	45750	46850
45	42950	44000	45070
46	41310	42330	43360
47	39740	40730	41730
48	38240	39200	40170
49	36800	37740	38680
50	35430	36330	37250

V-T Table (Ta 0°C - 50°C / Tb 0°C – 25°C)

Thermopile Output Voltage [mV]	Typical Output Voltage Data (638D2)																									V 3.2
	Thermistor Temperature [°C]																									
Object Temperature [°C]	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
0	0.000	-0.073	-0.146	-0.220	-0.294	-0.369	-0.445	-0.521	-0.598	-0.675	-0.753	-0.832	-0.911	-0.991	-1.071	-1.152	-1.234	-1.316	-1.399	-1.482	-1.567	-1.651	-1.737	-1.823	-1.910	-1.997
1	0.073	0.000	-0.073	-0.147	-0.221	-0.296	-0.372	-0.448	-0.525	-0.602	-0.680	-0.759	-0.838	-0.918	-0.998	-1.079	-1.161	-1.243	-1.326	-1.410	-1.494	-1.579	-1.664	-1.750	-1.837	-1.924
2	0.146	0.073	0.000	-0.074	-0.148	-0.223	-0.299	-0.375	-0.452	-0.529	-0.607	-0.686	-0.765	-0.845	-0.925	-1.006	-1.088	-1.170	-1.253	-1.337	-1.421	-1.506	-1.591	-1.677	-1.764	-1.851
3	0.220	0.147	0.074	0.000	-0.074	-0.149	-0.225	-0.301	-0.378	-0.455	-0.533	-0.612	-0.691	-0.771	-0.851	-0.932	-1.014	-1.096	-1.179	-1.263	-1.347	-1.432	-1.517	-1.603	-1.690	-1.777
4	0.294	0.221	0.148	0.074	0.000	-0.075	-0.151	-0.227	-0.304	-0.381	-0.459	-0.537	-0.617	-0.697	-0.777	-0.858	-0.940	-1.022	-1.105	-1.188	-1.273	-1.357	-1.443	-1.529	-1.616	-1.703
5	0.369	0.296	0.223	0.149	0.075	0.000	-0.076	-0.152	-0.229	-0.306	-0.384	-0.463	-0.542	-0.622	-0.702	-0.783	-0.865	-0.947	-1.030	-1.113	-1.198	-1.282	-1.368	-1.454	-1.541	-1.628
6	0.445	0.372	0.299	0.225	0.151	0.076	0.000	-0.076	-0.153	-0.230	-0.308	-0.387	-0.466	-0.546	-0.626	-0.707	-0.789	-0.871	-0.954	-1.038	-1.122	-1.207	-1.292	-1.378	-1.465	-1.552
7	0.521	0.448	0.375	0.301	0.227	0.152	0.076	0.000	-0.077	-0.154	-0.232	-0.311	-0.390	-0.470	-0.550	-0.631	-0.713	-0.795	-0.878	-0.962	-1.046	-1.131	-1.216	-1.302	-1.389	-1.476
8	0.598	0.525	0.452	0.378	0.304	0.229	0.153	0.077	0.000	-0.077	-0.155	-0.234	-0.313	-0.393	-0.473	-0.554	-0.636	-0.718	-0.801	-0.885	-0.969	-1.054	-1.139	-1.225	-1.312	-1.399
9	0.675	0.602	0.529	0.455	0.381	0.306	0.230	0.154	0.077	0.000	-0.078	-0.157	-0.236	-0.316	-0.396	-0.477	-0.559	-0.641	-0.724	-0.807	-0.892	-0.976	-1.062	-1.148	-1.235	-1.322
10	0.753	0.680	0.607	0.533	0.459	0.384	0.308	0.232	0.155	0.078	0.000	-0.079	-0.158	-0.238	-0.318	-0.399	-0.481	-0.563	-0.646	-0.729	-0.814	-0.898	-0.984	-1.070	-1.157	-1.244
11	0.832	0.759	0.686	0.612	0.537	0.463	0.387	0.311	0.234	0.157	0.079	0.000	-0.079	-0.159	-0.239	-0.320	-0.402	-0.484	-0.567	-0.651	-0.735	-0.820	-0.905	-0.991	-1.078	-1.165
12	0.911	0.838	0.765	0.691	0.617	0.542	0.466	0.390	0.313	0.236	0.158	0.079	0.000	-0.080	-0.160	-0.241	-0.323	-0.405	-0.488	-0.572	-0.656	-0.741	-0.826	-0.912	-0.999	-1.086
13	0.991	0.918	0.845	0.771	0.697	0.622	0.546	0.470	0.393	0.316	0.238	0.159	0.080	0.000	-0.080	-0.161	-0.243	-0.325	-0.408	-0.492	-0.576	-0.661	-0.746	-0.832	-0.919	-1.006
14	1.071	0.998	0.925	0.851	0.777	0.702	0.626	0.550	0.473	0.396	0.318	0.239	0.160	0.080	0.000	-0.081	-0.163	-0.245	-0.328	-0.411	-0.496	-0.580	-0.666	-0.752	-0.839	-0.926
15	1.152	1.079	1.006	0.932	0.858	0.783	0.707	0.631	0.554	0.477	0.399	0.320	0.241	0.161	0.081	0.000	-0.082	-0.164	-0.247	-0.330	-0.415	-0.499	-0.585	-0.671	-0.758	-0.845
16	1.234	1.161	1.088	1.014	0.940	0.865	0.789	0.713	0.636	0.559	0.481	0.402	0.323	0.243	0.163	0.082	0.000	-0.082	-0.165	-0.249	-0.333	-0.418	-0.503	-0.589	-0.676	-0.763
17	1.316	1.243	1.170	1.096	1.022	0.947	0.871	0.795	0.718	0.641	0.563	0.484	0.405	0.325	0.245	0.164	0.082	0.000	-0.083	-0.166	-0.251	-0.335	-0.421	-0.507	-0.594	-0.681
18	1.399	1.326	1.253	1.179	1.105	1.030	0.954	0.878	0.801	0.724	0.646	0.567	0.488	0.408	0.328	0.247	0.165	0.083	0.000	-0.084	-0.168	-0.252	-0.338	-0.424	-0.511	-0.598
19	1.482	1.410	1.337	1.263	1.188	1.113	1.038	0.962	0.885	0.807	0.729	0.651	0.572	0.492	0.411	0.330	0.249	0.166	0.084	0.000	-0.084	-0.169	-0.254	-0.340	-0.427	-0.515
20	1.567	1.494	1.421	1.347	1.273	1.198	1.122	1.046	0.969	0.892	0.814	0.735	0.656	0.576	0.496	0.415	0.333	0.251	0.168	0.084	0.000	-0.085	-0.170	-0.256	-0.343	-0.430
21	1.651	1.579	1.506	1.432	1.357	1.282	1.207	1.131	1.054	0.976	0.898	0.820	0.741	0.661	0.580	0.499	0.418	0.335	0.252	0.169	0.085	0.000	-0.085	-0.171	-0.258	-0.346
22	1.737	1.664	1.591	1.517	1.443	1.368	1.292	1.216	1.139	1.062	0.984	0.905	0.826	0.746	0.666	0.585	0.503	0.421	0.338	0.254	0.170	0.085	0.000	-0.086	-0.173	-0.260
23	1.823	1.750	1.677	1.603	1.529	1.454	1.378	1.302	1.225	1.148	1.070	0.991	0.912	0.832	0.752	0.671	0.589	0.507	0.424	0.340	0.256	0.171	0.086	0.000	-0.087	-0.174
24	1.910	1.837	1.764	1.690	1.616	1.541	1.465	1.389	1.312	1.235	1.157	1.078	0.999	0.919	0.839	0.758	0.676	0.594	0.511	0.427	0.343	0.258	0.173	0.087	0.000	-0.087
25	1.997	1.924	1.851	1.777	1.703	1.628	1.552	1.476	1.399	1.322	1.244	1.165	1.086	1.006	0.926	0.845	0.763	0.681	0.598	0.515	0.430	0.346	0.260	0.174	0.087	0.000
26	2.085	2.012	1.939	1.865	1.791	1.716	1.640	1.564	1.487	1.410	1.332	1.253	1.174	1.094	1.014	0.933	0.851	0.769	0.686	0.602	0.518	0.434	0.348	0.262	0.175	0.088
27	2.174	2.101	2.028	1.954	1.879	1.804	1.729	1.653	1.576	1.499	1.421	1.342	1.263	1.183	1.103	1.022	0.940	0.858	0.775	0.691	0.607	0.522	0.437	0.351	0.264	0.177
28	2.263	2.190	2.117	2.043	1.969	1.894	1.818	1.742	1.665	1.588	1.510	1.431	1.352	1.272	1.192	1.111	1.029	0.947	0.864	0.780	0.696	0.611	0.526	0.440	0.353	0.266
29	2.353	2.280	2.207	2.133	2.059	1.984	1.908	1.832	1.755	1.678	1.600	1.521	1.442	1.362	1.282	1.201	1.119	1.037	0.954	0.870	0.786	0.701	0.616	0.530	0.443	0.356
30	2.443	2.371	2.298	2.224	2.149	2.074	1.999	1.923	1.846	1.768	1.690	1.612	1.533	1.453	1.372	1.291	1.210	1.127	1.045	0.961	0.877	0.792	0.707	0.621	0.534	0.446
31	2.535	2.462	2.389	2.315	2.241	2.166	2.090	2.014	1.937	1.860	1.782	1.703	1.624	1.544	1.464	1.383	1.301	1.219	1.136	1.052	0.968	0.883	0.798	0.712	0.625	0.538
32	2.627	2.554	2.481	2.407	2.332	2.258	2.182	2.106	2.029	1.952	1.874	1.795	1.716	1.636	1.556	1.475	1.393	1.311	1.228	1.144	1.060	0.975	0.890	0.804	0.717	0.630
33	2.719	2.647	2.573	2.499	2.425	2.350	2.274	2.198	2.122	2.044	1.966	1.888	1.808	1.729	1.648	1.567	1.485	1.403	1.320	1.237	1.153	1.068	0.982	0.896	0.810	0.722
34	2.812	2.740	2.667	2.593	2.518	2.443	2.368	2.292	2.215	2.137	2.059	1.981	1.902	1.822	1.741	1.660	1.579	1.496	1.413	1.330	1.246	1.161	1.076	0.990	0.903	0.815
35	2.906	2.834	2.760	2.687	2.612	2.537	2.462	2.385	2.309	2.231	2.153	2.075	1.996	1.916	1.835	1.754	1.673	1.590	1.507	1.424	1.340	1.255	1.169	1.083	0.997	0.909
36	3.001	2.928	2.855	2.781	2.707	2.632	2.556	2.480	2.403	2.326	2.248	2.169	2.090	2.010	1.930	1.849	1.767	1.685	1.602	1.518	1.434	1.350	1.264	1.178	1.091	1.004
37	3.096	3.024	2.950	2.876	2.802	2.727	2.651	2.575	2.499	2.421	2.343	2.265	2.185	2.106	2.025	1.944	1.862	1.780	1.697	1.614	1.530	1.445	1.359	1.273	1.187	1.099
38	3.192	3.119	3.046	2.972	2.898	2.823	2.747	2.671	2.594	2.517	2.439	2.361	2.281	2.201	2.121	2.040	1.958	1.876	1.793	1.710	1.625	1.541	1.455	1.369	1.282	1.195
39	3.289	3.216	3.143	3.069	2.995	2.920	2.844	2.768	2.691	2.614	2.536	2.457	2.378	2.298	2.218	2.137	2.055	1.973	1.890	1.806	1.722	1.637	1.552	1.466	1.379	1.292
40	3.386	3.313	3.240	3.166	3.092	3.017	2.941	2.865	2.788	2.711	2.633	2.554	2.475	2.395	2.315	2.234	2.152	2.070	1.987	1.904	1.819	1.735	1.649	1.563	1.476	1.389
41	3.484	3.411	3.338	3.264	3.190	3.115	3.039	2.963	2.886	2.809	2.731	2.652	2.573	2.493	2.413	2.332	2.250	2.168	2.085	2.002	1.917	1.833	1.747	1.661	1.574	1.487
42	3.583	3.510	3.437	3.363	3.289	3.214	3.138	3.062	2.985	2.908	2.830	2.751	2.672	2.592	2.512	2.431	2.349	2.267	2.184	2.100	2.016	1.931	1.846	1.760	1.673	1.586
43	3.682	3.609	3.536	3.462	3.388	3.313	3.237	3.161	3.084	3.007	2.929	2.850	2.771	2.691	2.611	2.530	2.448	2.366	2.283	2.200	2.115	2.031	1.945	1.859	1.772	1.685
44	3.782	3.709	3.636	3.562	3.488	3.413	3.337	3.261	3.184	3.107	3.029	2.950	2.871	2.791	2.711	2.630	2.548	2.466	2.383	2.300	2.215	2.131	2.045	1.959	1.872	1.785
45	3.883	3.810	3.737	3.663	3.589	3.514	3.438	3.362	3.285	3.208	3.130	3.051	2.972	2.892	2.812	2.731	2.649	2.567	2.484	2.400	2.316	2.231	2.146	2.060	1.973	1.886
46	3.984	3.912	3.838	3.765	3.690	3.615	3.540	3.463	3.387	3.309	3.231	3.153	3.073	2.994	2.913	2.832	2.750	2.668	2.585	2.502	2.418	2.333	2.247	2.161	2.075	1.987
47	4.086	4.014	3.940	3.867	3.792	3.717	3.642	3.565	3.489	3.411	3.333	3.255	3.176	3.096	3.015	2.934	2.853	2.770	2.687	2.604	2.520	2.435	2.349	2.263	2.177	2.089
48	4.189	4.117	4.043	3.969	3.895	3.820	3.744	3.668	3.592	3.514	3.436	3.358	3.278	3.199	3.118	3.037	2.955	2.873	2.790	2.707	2.623	2.538	2.452	2.366	2.280	2.192
49	4.293	4.220	4.147	4.073	3.999	3.924	3.848	3.772	3.695	3.618	3.540	3.461	3.382	3.302	3.222	3.141	3.059	2.977	2.894	2.810	2.726	2.641	2.556	2.470	2.383	2.296
50	4.397	4.324	4.251	4.177	4.103	4.028	3.952	3.876	3.799	3.722	3.644	3.565	3.486	3.406	3.326	3.245	3.163	3.081	2.998	2.915	2.830	2.746	2.660	2.574	2.487	2.400

V-T Table (Ta 0°C - 50°C / Tb 26°C – 50°C)

V 3.0

Thermopile Output Voltage [mV]	Typical Output Voltage Data (638D2)																								
	Thermistor Temperature [°C]																								
Object Temperature [°C]	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
0	-2.085	-2.174	-2.263	-2.353	-2.443	-2.535	-2.627	-2.719	-2.812	-2.906	-3.001	-3.096	-3.192	-3.289	-3.386	-3.484	-3.583	-3.682	-3.782	-3.883	-3.984	-4.086	-4.189	-4.293	-4.397
1	-2.012	-2.101	-2.190	-2.280	-2.371	-2.462	-2.554	-2.647	-2.740	-2.834	-2.928	-3.024	-3.119	-3.216	-3.313	-3.411	-3.510	-3.609	-3.709	-3.810	-3.912	-4.014	-4.117	-4.220	-4.324
2	-1.939	-2.028	-2.117	-2.207	-2.298	-2.389	-2.481	-2.573	-2.667	-2.760	-2.855	-2.950	-3.046	-3.143	-3.240	-3.338	-3.437	-3.536	-3.636	-3.737	-3.838	-3.940	-4.043	-4.147	-4.251
3	-1.865	-1.954	-2.043	-2.133	-2.224	-2.315	-2.407	-2.499	-2.593	-2.687	-2.781	-2.876	-2.972	-3.069	-3.166	-3.264	-3.363	-3.462	-3.562	-3.663	-3.765	-3.867	-3.969	-4.073	-4.177
4	-1.791	-1.879	-1.969	-2.059	-2.149	-2.241	-2.332	-2.425	-2.518	-2.612	-2.707	-2.802	-2.898	-2.995	-3.092	-3.190	-3.289	-3.388	-3.488	-3.589	-3.690	-3.792	-3.895	-3.999	-4.103
5	-1.716	-1.804	-1.894	-1.984	-2.074	-2.166	-2.258	-2.350	-2.443	-2.537	-2.632	-2.727	-2.823	-2.920	-3.017	-3.115	-3.214	-3.313	-3.413	-3.514	-3.615	-3.717	-3.820	-3.924	-4.028
6	-1.640	-1.729	-1.818	-1.908	-1.999	-2.090	-2.182	-2.274	-2.368	-2.462	-2.556	-2.651	-2.747	-2.844	-2.941	-3.039	-3.138	-3.237	-3.337	-3.438	-3.540	-3.642	-3.744	-3.848	-3.952
7	-1.564	-1.653	-1.742	-1.832	-1.923	-2.014	-2.106	-2.198	-2.292	-2.385	-2.480	-2.575	-2.671	-2.768	-2.865	-2.963	-3.062	-3.161	-3.261	-3.362	-3.463	-3.565	-3.668	-3.772	-3.876
8	-1.487	-1.576	-1.665	-1.755	-1.846	-1.937	-2.029	-2.122	-2.215	-2.309	-2.403	-2.499	-2.594	-2.691	-2.788	-2.886	-2.985	-3.084	-3.184	-3.285	-3.387	-3.489	-3.592	-3.695	-3.799
9	-1.410	-1.499	-1.588	-1.678	-1.768	-1.860	-1.952	-2.044	-2.137	-2.231	-2.326	-2.421	-2.517	-2.614	-2.711	-2.809	-2.908	-3.007	-3.107	-3.208	-3.309	-3.411	-3.514	-3.618	-3.722
10	-1.332	-1.421	-1.510	-1.600	-1.690	-1.782	-1.874	-1.966	-2.059	-2.153	-2.248	-2.343	-2.439	-2.536	-2.633	-2.731	-2.830	-2.929	-3.029	-3.130	-3.231	-3.333	-3.436	-3.540	-3.644
11	-1.253	-1.342	-1.431	-1.521	-1.612	-1.703	-1.795	-1.888	-1.981	-2.075	-2.169	-2.265	-2.361	-2.457	-2.554	-2.652	-2.751	-2.850	-2.950	-3.051	-3.153	-3.255	-3.358	-3.461	-3.565
12	-1.174	-1.263	-1.352	-1.442	-1.533	-1.624	-1.716	-1.808	-1.902	-1.996	-2.090	-2.185	-2.281	-2.378	-2.475	-2.573	-2.672	-2.771	-2.871	-2.972	-3.073	-3.176	-3.278	-3.382	-3.486
13	-1.094	-1.183	-1.272	-1.362	-1.453	-1.544	-1.636	-1.729	-1.822	-1.916	-2.010	-2.106	-2.201	-2.298	-2.395	-2.493	-2.592	-2.691	-2.791	-2.892	-2.994	-3.096	-3.199	-3.302	-3.406
14	-1.014	-1.103	-1.192	-1.282	-1.372	-1.464	-1.556	-1.648	-1.741	-1.835	-1.930	-2.025	-2.121	-2.218	-2.315	-2.413	-2.512	-2.611	-2.711	-2.812	-2.913	-3.015	-3.118	-3.222	-3.326
15	-0.933	-1.022	-1.111	-1.201	-1.291	-1.383	-1.475	-1.567	-1.660	-1.754	-1.849	-1.944	-2.040	-2.137	-2.234	-2.332	-2.431	-2.530	-2.630	-2.731	-2.832	-2.934	-3.037	-3.141	-3.245
16	-0.851	-0.940	-1.029	-1.119	-1.210	-1.301	-1.393	-1.485	-1.579	-1.673	-1.767	-1.862	-1.958	-2.055	-2.152	-2.250	-2.349	-2.448	-2.548	-2.649	-2.750	-2.853	-2.955	-3.059	-3.163
17	-0.769	-0.858	-0.947	-1.037	-1.127	-1.219	-1.311	-1.403	-1.496	-1.590	-1.685	-1.780	-1.876	-1.973	-2.070	-2.168	-2.267	-2.366	-2.466	-2.567	-2.668	-2.770	-2.873	-2.977	-3.081
18	-0.686	-0.775	-0.864	-0.954	-1.045	-1.136	-1.228	-1.320	-1.413	-1.507	-1.602	-1.697	-1.793	-1.890	-1.987	-2.085	-2.184	-2.283	-2.383	-2.484	-2.585	-2.687	-2.790	-2.894	-2.998
19	-0.602	-0.691	-0.780	-0.870	-0.961	-1.052	-1.144	-1.237	-1.330	-1.424	-1.518	-1.614	-1.710	-1.806	-1.904	-2.002	-2.100	-2.200	-2.300	-2.400	-2.502	-2.604	-2.707	-2.810	-2.915
20	-0.518	-0.607	-0.696	-0.786	-0.877	-0.968	-1.060	-1.153	-1.246	-1.340	-1.434	-1.530	-1.625	-1.722	-1.819	-1.917	-2.016	-2.115	-2.215	-2.316	-2.418	-2.520	-2.623	-2.726	-2.830
21	-0.434	-0.522	-0.611	-0.701	-0.792	-0.883	-0.975	-1.068	-1.161	-1.255	-1.350	-1.445	-1.541	-1.637	-1.735	-1.833	-1.931	-2.031	-2.131	-2.231	-2.333	-2.435	-2.538	-2.641	-2.746
22	-0.348	-0.437	-0.526	-0.616	-0.707	-0.798	-0.890	-0.982	-1.076	-1.169	-1.264	-1.359	-1.455	-1.552	-1.649	-1.747	-1.846	-1.945	-2.045	-2.146	-2.247	-2.349	-2.452	-2.556	-2.660
23	-0.262	-0.351	-0.440	-0.530	-0.621	-0.712	-0.804	-0.896	-0.990	-1.083	-1.178	-1.273	-1.369	-1.466	-1.563	-1.661	-1.760	-1.859	-1.959	-2.060	-2.161	-2.263	-2.366	-2.470	-2.574
24	-0.175	-0.264	-0.353	-0.443	-0.534	-0.625	-0.717	-0.810	-0.903	-0.997	-1.091	-1.187	-1.282	-1.379	-1.476	-1.574	-1.673	-1.772	-1.872	-1.973	-2.075	-2.177	-2.280	-2.383	-2.487
25	-0.088	-0.177	-0.266	-0.356	-0.446	-0.538	-0.630	-0.722	-0.815	-0.909	-1.004	-1.099	-1.195	-1.292	-1.389	-1.487	-1.586	-1.685	-1.785	-1.886	-1.987	-2.089	-2.192	-2.296	-2.400
26	0.000	-0.089	-0.178	-0.268	-0.358	-0.450	-0.542	-0.634	-0.727	-0.821	-0.916	-1.011	-1.107	-1.204	-1.301	-1.399	-1.498	-1.597	-1.697	-1.798	-1.899	-2.001	-2.104	-2.208	-2.312
27	0.089	0.000	-0.089	-0.179	-0.270	-0.361	-0.453	-0.546	-0.639	-0.733	-0.827	-0.923	-1.019	-1.115	-1.212	-1.310	-1.409	-1.508	-1.608	-1.709	-1.811	-1.913	-2.016	-2.119	-2.223
28	0.178	0.089	0.000	-0.090	-0.181	-0.272	-0.364	-0.456	-0.550	-0.643	-0.738	-0.833	-0.929	-1.026	-1.123	-1.221	-1.320	-1.419	-1.519	-1.620	-1.721	-1.823	-1.926	-2.030	-2.134
29	0.268	0.179	0.090	0.000	-0.091	-0.182	-0.274	-0.366	-0.460	-0.554	-0.648	-0.743	-0.839	-0.936	-1.033	-1.131	-1.230	-1.329	-1.429	-1.530	-1.631	-1.734	-1.836	-1.940	-2.044
30	0.358	0.270	0.181	0.091	0.000	-0.091	-0.183	-0.276	-0.369	-0.463	-0.557	-0.653	-0.749	-0.845	-0.943	-1.041	-1.139	-1.239	-1.339	-1.439	-1.541	-1.643	-1.746	-1.849	-1.954
31	0.450	0.361	0.272	0.182	0.091	0.000	-0.092	-0.184	-0.278	-0.372	-0.466	-0.561	-0.657	-0.754	-0.851	-0.949	-1.048	-1.147	-1.247	-1.348	-1.450	-1.552	-1.654	-1.758	-1.862
32	0.542	0.453	0.364	0.274	0.183	0.092	0.000	-0.093	-0.186	-0.280	-0.374	-0.470	-0.566	-0.662	-0.759	-0.857	-0.956	-1.055	-1.155	-1.256	-1.358	-1.460	-1.563	-1.666	-1.770
33	0.634	0.546	0.456	0.366	0.276	0.184	0.093	0.000	-0.093	-0.187	-0.282	-0.377	-0.473	-0.570	-0.667	-0.765	-0.863	-0.963	-1.063	-1.164	-1.265	-1.367	-1.470	-1.574	-1.678
34	0.727	0.639	0.550	0.460	0.369	0.278	0.186	0.093	0.000	-0.094	-0.188	-0.284	-0.380	-0.476	-0.574	-0.672	-0.770	-0.870	-0.970	-1.070	-1.172	-1.274	-1.377	-1.480	-1.585
35	0.821	0.733	0.643	0.554	0.463	0.372	0.280	0.187	0.094	0.000	-0.095	-0.190	-0.286	-0.382	-0.480	-0.578	-0.676	-0.776	-0.876	-0.976	-1.078	-1.180	-1.283	-1.386	-1.491
36	0.916	0.827	0.738	0.648	0.557	0.466	0.374	0.282	0.188	0.095	0.000	-0.095	-0.191	-0.288	-0.385	-0.483	-0.582	-0.681	-0.781	-0.882	-0.983	-1.085	-1.188	-1.292	-1.396
37	1.011	0.923	0.833	0.743	0.653	0.561	0.470	0.377	0.284	0.190	0.095	0.000	-0.096	-0.193	-0.290	-0.388	-0.486	-0.586	-0.686	-0.787	-0.888	-0.990	-1.093	-1.197	-1.301
38	1.107	1.019	0.929	0.839	0.749	0.657	0.566	0.473	0.380	0.286	0.191	0.096	0.000	-0.097	-0.194	-0.292	-0.391	-0.490	-0.590	-0.691	-0.792	-0.894	-0.997	-1.101	-1.205
39	1.204	1.115	1.026	0.936	0.845	0.754	0.662	0.570	0.476	0.382	0.288	0.193	0.097	0.000	-0.097	-0.195	-0.294	-0.393	-0.493	-0.594	-0.695	-0.798	-0.900	-1.004	-1.108
40	1.301	1.212	1.123	1.033	0.943	0.851	0.759	0.667	0.574	0.480	0.385	0.290	0.194	0.097	0.000	-0.098	-0.197	-0.296	-0.396	-0.497	-0.598	-0.700	-0.803	-0.907	-1.011
41	1.399	1.310	1.221	1.131	1.041	0.949	0.857	0.765	0.672	0.578	0.483	0.388	0.292	0.195	0.098	0.000	-0.099	-0.198	-0.298	-0.399	-0.500	-0.602	-0.705	-0.809	-0.913
42	1.498	1.409	1.320	1.230	1.139	1.048	0.956	0.863	0.770	0.676	0.582	0.486	0.391	0.294	0.197	0.099	0.000	-0.099	-0.199	-0.300	-0.402	-0.504	-0.607	-0.710	-0.814
43	1.597	1.508	1.419	1.329	1.239	1.147	1.055	0.963	0.870	0.776	0.681	0.586	0.490	0.393	0.296	0.198	0.099	0.000	-0.100	-0.201	-0.302	-0.404	-0.507	-0.611	-0.715
44	1.697	1.608	1.519	1.429	1.339	1.247	1.155	1.063	0.970	0.876	0.781	0.686	0.590	0.493	0.396	0.298	0.199	0.100	0.000	-0.101	-0.202	-0.304	-0.407	-0.511	-0.615
45	1.798	1.709	1.620	1.530	1.439	1.348	1.256	1.164	1.070	0.976	0.882	0.787	0.691	0.594	0.497	0.399	0.300	0.201	0.101	0.000	-0.101	-0.204	-0.306	-0.410	-0.514
46	1.899	1.811	1.721	1.631	1.541	1.450	1.358	1.265	1.172	1.078	0.983	0.888	0.792	0.695	0.598	0.500	0.402	0.302	0.202	0.101	0.000	-0.102	-0.205	-0.309	-0.413
47	2.001	1.913	1.823	1.734	1.643	1.552	1.460	1.367	1.274	1.180	1.085	0.990	0.894	0.798	0.700	0.602	0.504	0.404	0.304	0.204	0.102	0.000	-0.103	-0.206	-0.311
48	2.104	2.016	1.926	1.836	1.746	1.654	1.563	1.470	1.377	1.283	1.188	1.093	0.997	0.900	0.803	0.705	0.607	0.507	0.407	0.306	0.205	0.103	0.000	-0.104	-0.208
49	2.208	2.119	2.030	1.940	1.849	1.758	1.666	1.574	1.480	1.386	1.292	1.197	1.101	1.004	0.907	0.809	0.710	0.611	0.511	0.410	0.309	0.206	0.104	0.000	-0.104
50	2.312	2.223	2.134	2.044	1.954	1.862	1.770	1.678	1.585	1.491	1.396	1.301	1.205	1.108	1.011	0.913	0.814	0.715	0.615	0.514	0.413	0.311	0.208	0.104	0.000