Instituto Superior Técnico

Instrumentação Suportada por Computadores Pessoais

Lab. 4 - Human body temperature measurement

Relatório

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Conteúdo

1 Introdução

Este trabalho tem como objetivo realizar a medição da temperatura corporal. Para a realização da medição da temperatura será utilizado um sensor de temperatura denominado por NTC *Negative Temperature Coefficient* e um microcontrolador baseado na plataforma Arduino, sendo este o *Arduino Uno*.

Na realização deste trabalho terão de ser cumpridos os seguintes objetivos:

- A gama total de medição de temperatura deve estar contida no intervalo [30°C; 45°C]. Sendo este o intervalo considerado normal para a temperatura do corpo humano;
- A resolução do valor de temperatura deve ser optimizado para obter valores de temperatura o mais próximo possível do valor real;
- Apresentação da gama total de medição de temperatura do sensor NTC utilizado.

2 Sensor NTC

Nesta secção será descrito o funcionamento do sensor bem como a implentação do mesmo no circuito com o microcontrolador baseado na plataforma arduino.

O sensor NTC consiste num sensor térmico na qual a variação de temeratura traduz-se num valor de resistência que por sua vez é inversamente proporcional à variação da temperatura, daí ser denominada por *Negative Temperature coefficient*. Este sensor é considerado um termístor.

Figura 2.1: Aspecto físico de um termístor NTC.

Este sensor possui uma variação de resistência, como mancionado anteriormente. Para a escolha do sensor tem de se verificar na folha de especificações a gama de medições de temperatura que o sensor possibilita e a tolerância do sensor. Em seguida, escolhe-se o valor da resistência para o valor de referência para 25°C consoante a tolerância do sensor.

Para a integração do sensor num circuito, elabora-se um circuito divisor resistivo com o sensor e a resistência que estabelece o valor de referência para 25°C, como representa a Figura 2.2

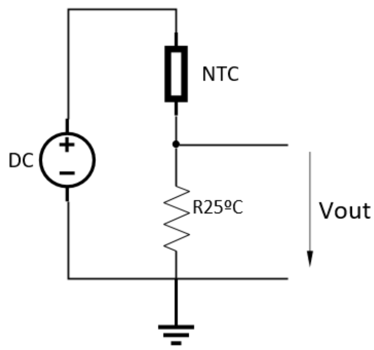


Figura 2.2: Divisor resistivo com o sensor e a resistência que estabelece o valor de referência para 25°C.

Para a obtenção de um valor de temperatura exacto é necessário obdecer a alguns parametros impostos pelo sensor, sendo estes as constantes A_1, B_1 $[k^{-1}]$, C_1 $[k^{-2}]$ e D_1 $[k^{-3}]$. Após se ter obtido o valor dos parametros mencionados recorre-se á equação 2.1 na qual serão utilizados os valores dos parametros.

$$T[^{\circ}C] = \frac{1}{A_1 + B_1 * \ln \frac{R}{R_{ref}} + C_1 * \ln^2 \frac{R}{R_{ref}} + D_1 * \ln^3 \frac{R}{R_{ref}}} - 273.15 \tag{2.1}$$

É de notar que é subtraído à equação 273.15 para a converção da temperatura de Kelvin para graus centígrados.

3 Circuito implementado

4 Anexos

ANEXOS

Código Implementado

```
#include <stdint.h>
#include <math.h>

#define R_REF 12129.0
#define A1 3.354016e-3
#define B1 2.569850e-4
#define C1 2.620131e-6
#define D1 6.383091e-8

#define AVERAGES 3000

void setup() {
  Serial.begin(9600);
}

void loop()
{
  double thermistor_r_sum = 0.0;

  for(uint16_t i=0; i<AVERAGES; i++) {
    uint16_t reading = analogRead(0);
    /* Small value readings are caused by erros */
    if (reading < 63 || reading == 1023) {
      i--;
      continue;
    }
    double thermistor_r = R_REF * (1023/(double)reading -1);
    thermistor_r_sum += thermistor_r;
  }

  double r_avg = thermistor_r_sum / AVERAGES;
  double log_calc = log(r_avg / R_REF);
  double temperature = 1 / (A1 + B1 * log_calc + C1 * pow(log_calc, 2) + D1 * pow(log_calc, 3)) - 275.15;

  Serial.println(temperature);
}
```

NTC Thermistors, Radial Leaded, Standard Precision

QUICK REFERENCE DATA		
PARAMETER	**VALUE**	**UNIT**
Resistance value at 25 °C	3.3 to 470K	Ω
Tolerance on R_{25}-value	± 2; ± 3; ± 5	%
$B_{25/85}$-value	2880 to 4570	K
Tolerance on $B_{25/85}$-value	± 0.5 to ± 3	%
Operating temperature range: At zero power dissipation; continuously At zero power dissipation; for short periods	 - 40 to + 125 ≤ 150	°C
Response time (in oil)	≈ 1.2	s
Thermal time constant τ (for information only)	15	s
Dissipation factor δ (for information only)	7 8.5 (for R_{25}-value ≤ 680 Ω)	mW/K
Maximum power dissipation at 55 °C	500	mW
Climatic category (LCT/UCT/days)	40/125/56	-
Weight	≈ 0.3	g

FEATURES

- Accuracy over a wide temperature range
- High stability over a long life
- Excellent price/performance ratio
- UL recognized, file E148885
- Material categorization: For definitions of compliance please see www.vishay.com/doc?99912

APPLICATIONS

- Temperature measurement, sensing and control, temperature compensation in industrial and consumer electronics

DESCRIPTION

These thermistors have a negative temperature coefficient. The device consists of a chip with two solid copper tin plated leads. It is grey lacquered and color coded, but not insulated.

PACKAGING

The thermistors are packed in bulk or tape on reel; see code numbers and relevant packaging quantities.

DESIGN-IN SUPPORT

For complete Curve Computation, visit: www.vishay.com/resistors-non-linear/curve-computation-list/

MARKING

The thermistors are marked with colored bands; see dimensions drawing and "Electrical data and ordering information".

MOUNTING

By soldering in any position.
Not intended for potted applications.

ELECTRICAL DATA AND ORDERING INFORMATION

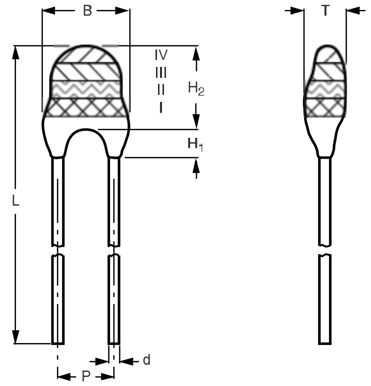
R_{25}	$B_{25/85}$-VALUE		UL APPROVED	SAP MATERIAL NUMBER	OLD 12NC CODE	COLOR CODE (3)		
(Ω)	(K)	(± %)	(Y/N)	NTCLE100E3....B0/T1/T2 (2)	2381 640 3/4/6.... (1)	I	II	III
3.3	2880	3	N	338*B0	*338	Orange	Orange	Gold
4.7	2880	3	N	478*B0	*478	Yellow	Violet	Gold
6.8	2880	3	N	688*B0	*688	Blue	Grey	Gold
10	2990	3	N	109*B0	*109	Brown	Black	Black
15	3041	3	N	159*B0	*159	Brown	Green	Black
22	3136	3	N	229*B0	*229	Red	Red	Black
33	3390	3	Y	339*B0	*339	Orange	Orange	Black
47	3390	3	Y	479*B0	*479	Yellow	Violet	Black
68	3390	3	Y	689*B0	*689	Blue	Grey	Black
100	3560	1.5	Y	101*B0	*101	Brown	Black	Brown
150	3560	1.5	Y	151*B0	*151	Brown	Green	Brown
220	3560	1.5	Y	221*B0	*221	Red	Red	Brown
330	3560	1.5	Y	331*B0	*331	Orange	Orange	Brown

ELECTRICAL DATA AND ORDERING INFORMATION								
R_{25}	$B_{25/85}$-VALUE		UL APPROVED	SAP MATERIAL NUMBER	OLD 12NC CODE	COLOR CODE [3]		
(Ω)	(K)	(± %)	(Y/N)	NTCLE100E3....B0/T1/T2 [2]	2381 640 3/4/6.... [1]	I	II	III
470	3560	1.5	Y	471*B0	*471	Yellow	Violet	Brown
680	3560	1.5	Y	681*B0	*681	Blue	Grey	Brown
1000	3528	0.5	Y	102*B0	*102	Brown	Black	Red
1500	3528	0.5	Y	152*B0	*152	Brown	Green	Red
2000	3528	0.5	Y	202*B0	*202	Red	Black	Red
2200	3977	0.75	Y	222*B0	*222	Red	Red	Red
2700	3977	0.75	Y	272*B0	*272	Red	violet	Red
3300	3977	0.75	Y	332*B0	*332	Orange	Orange	Red
4700	3977	0.75	Y	472*B0	*472	Yellow	Violet	Red
5000	3977	0.75	Y	502*B0	*502	Green	Black	Red
6800	3977	0.75	Y	682*B0	*682	Blue	Grey	Red
10 000	3977	0.75	Y	103*B0	*103	Brown	Black	Orange
12 000	3740	2	Y	123*B0	*123	Brown	Red	Orange
15 000	3740	2	Y	153*B0	*153	Brown	Green	Orange
22 000	3740	2	Y	223*B0	*223	Red	Red	Orange
33 000	4090	1.5	Y	333*B0	*333	Orange	Orange	Orange
47 000	4090	1.5	Y	473*B0	*473	Yellow	Violet	Orange
50 000	4190	1.5	Y	503*B0	*503	Green	Black	Orange
68 000	4190	1.5	Y	683*B0	*683	Blue	Grey	Orange
100 000	4190	1.5	Y	104*B0	*104	Brown	Black	Yellow
150 000	4370	2.5	Y	154*B0	*154	Brown	Green	Yellow
220 000	4370	2.5	Y	224*B0	*224	Red	Red	Yellow
330 000	4570	1.5	N	334*B0	*334	Orange	Orange	Yellow
470 000	4570	1.5	N	474*B0	*474	Yellow	Violet	Yellow

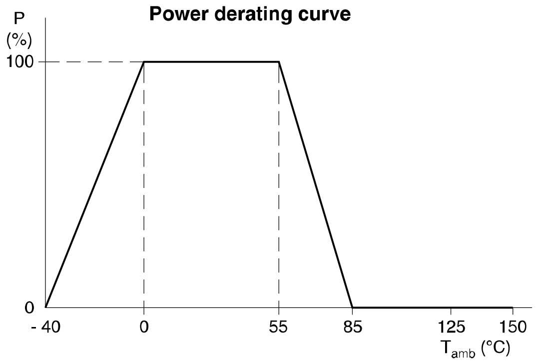
Notes

(1) Replace * in 12NC by 3 for 5 %, 6 for 3 %, 4 for 2 %
(2) Replace * in SAP by J for 5 %, H for 3 %, G for 2 %
(3) For R_{25} ± 2 % band IV is red, ± 3 % band IV is orange, ± 5 % band IV is gold

DIMENSIONS in millimeters



DERATING AND TEMPERATURE TOLERANCES



Note

- Zero power is considered as measuring power max. 1 % of max. power.

PHYSICAL DIMENSIONS FOR RELEVANT TYPE (all dimensions in millimeters)								
R_{25}-VALUE	$B_{MAX.}$	d	H_1		H_2 MAX.	L	P	$T_{MAX.}$
			MIN.	MAX.				
3.3 Ω to 220 Ω	5.0	0.6 ± 0.06	1.0	4.0	6.0	24 ± 1.5	2.54	4.0
330 Ω to 470 kΩ	3.3 ± 0.5	0.6 ± 0.06	1.0	3.0	6.0	24 ± 1.5	2.54	3.0

R_T VALUE AND TOLERANCE

These thermistors have a narrow tolerance on the B-value, the result of which provides a very small tolerance on the nominal resistance value over a wide temperature range. For this reason the usual graphs of $R = f(T)$ are replaced by Resistance Values at Intermediate Temperatures Tables, together with a formula to calculate the characteristics with a high precision.

FORMULAE TO DETERMINE NOMINAL RESISTANCE VALUES

The resistance values at intermediate temperatures, or the operating temperature values, can be calculated using the following interpolation laws (extended *"Steinhart and Hart"*):

$$R_{(T)} = R_{ref} \times e^{(A + B/T + C/T^2 + D/T^3)} \qquad (1)$$

$$T_{(R)} = \left(A_1 + B_1 \ln\frac{R}{R_{ref}} + C_1 \ln^2\frac{R}{R_{ref}} + D_1 \ln^3\frac{R}{R_{ref}}\right)^{-1} \qquad (2)$$

where:

A, B, C, D, A_1, B_1, C_1 and D_1 are constant values depending on the material concerned; see table below.

$R_{ref.}$ is the resistance value at a reference temperature (in this event 25 °C, $R_{ref.} = R_{25}$).

T is the temperature in K.

Formulae numbered and are interchangeable with an error of max. 0.005 °C in the range 25 °C to 125 °C and max. 0.015 °C in the range - 40 °C to + 25 °C.

DETERMINATION OF THE RESISTANCE/TEMPERATURE DEVIATION FROM NOMINAL VALUE

The total resistance deviation is obtained by combining the "R_{25}-tolerance" and the "resistance deviation due to B-tolerance".

When:

X = R_{25}-tolerance
Y = resistance deviation due to B-tolerance
Z = complete resistance deviation,

then: $Z = \left[\left(1 + \frac{X}{100}\right) \times \left(1 + \frac{Y}{100}\right) - 1\right] \times 100\ \%$ or $Z \approx X + Y$

When:

TCR = temperature coefficient
ΔT = temperature deviation,

then: $\Delta T = \frac{Z}{TCR}$

The temperature tolerances are plotted in the graphs on the previous page.

Example: at 0 °C, assume X = 5 %, Y = 0.89 % and TCR = 5.08 %/K (see table), then:

$$Z = \left\{\left[1 + \frac{5}{100}\right] \times \left[1 + \frac{0.89}{100}\right] - 1\right\} \times 100\%$$

$$= \{1.05 \times 1.0089 - 1\} \times 100\ \% = 5.9345\ \% (\approx 5.93\ \%)$$

$$\Delta T = \frac{Z}{TCR} = \frac{5.93}{5.08} = 1.167\ °C\ (\approx 1.17\ °C)$$

A NTC with a R_{25}-value of 10 kΩ has a value of 32.56 kΩ between - 1.17 °C and + 1.17 °C.

PARAMETER FOR DETERMINING NOMINAL RESISTANCE VALUES

NUMBER	$B_{25/85}$ (K)	NAME	TOL. B (%)	A	B (K)	C (K^2)	D (K^3)	A_1	B_1 (K^{-1})	C_1 (K^{-2})	D_1 (K^{-3})
1	2880	Mat O. with Bn = 2880K	3	- 9.094	2251.74	229098	- 2.744820E+07	3.354016E-03	3.495020E-04	2.095959E-06	4.260615E-07
2	2990	Mat P. with Bn = 3990K	3	- 10.2296	2887.62	132336	- 2.502510E+07	3.354016E-03	3.415560E-04	4.955455E-06	4.364236E-07
3	3041	Mat Q. with Bn = 3041K	3	- 11.1334	3658.73	- 102895	5.166520E+05	3.354016E-03	3.349290E-04	3.683843E-06	7.050455E-07
4	3136	Mat R. with Bn = 3136K	3	- 12.4493	4702.74	- 402687	3.196830E+07	3.354016E-03	3.243880E-04	2.658012E-06	- 2.701560E-07
5	3390	Mat S. with Bn = 3390K	3	- 12.6814	4391.97	- 232807	1.509643E+07	3.354016E-03	2.993410E-04	2.135133E-06	- 5.672000E-09
6	3528 (1)	Mat I. with Bn = 3528K	0.5	- 12.0596	3687.667	- 7617.13	- 5.914730E+06	3.354016E-03	2.909670E-04	1.632136E-06	7.192200E-08
	3528 (2)			- 21.0704	11903.95	- 2504699	2.470338E+08	3.354016E-03	2.933908E-04	3.494314E-06	- 7.712690E-07
7	3560	Mat H. with Bn = 3560K	1.5	- 13.0723	4190.574	- 47158.4	- 1.199256E+07	3.354016E-03	2.884193E-04	4.118032E-06	1.786790E-07
8	3740	Mat B. with Bn = 3740K	2	- 13.8973	4557.725	- 98275	- 7.522357E+06	3.354016E-03	2.744032E-04	3.666944E-06	1.375492E-07
9	3977	Mat A. with Bn =3977K	0.75	- 14.6337	4791.842	- 115334	- 3.730535E+06	3.354016E-03	2.569850E-04	2.620131E-06	6.383091E-08
10	4090	Mat C. with Bn = 4090K	1.5	- 15.5322	5229.973	- 160451	- 5.414091E+06	3.354016E-03	2.519107E-04	3.510939E-06	1.105179E-07
11	4190	Mat D. with Bn = 4190K	1.5	- 16.0349	5459.339	- 191141	- 3.328322E+06	3.354016E-03	2.460382E-04	3.405377E-06	1.034240E-07
12	4370	Mat E. with Bn = 4370K	2.5	- 16.8717	5759.15	- 194267	- 6.869149E+06	3.354016E-03	2.367720E-04	3.585140E-06	1.255349E-07
13	4570	Mat F. with Bn = 4570K	1.5	- 17.6439	6022.726	- 203157	- 7.183526E+06	3.354016E-03	2.264097E-04	3.278184E-06	1.097628E-07

Notes
(1) Temperature < 25 °C
(2) Temperature ≥ 25 °C