Composantes de la station (Instrumentation)

Caractéristiques des thermistances utilisées **YSI44033**

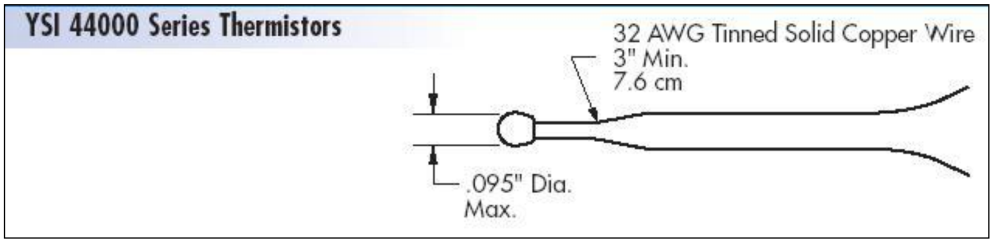
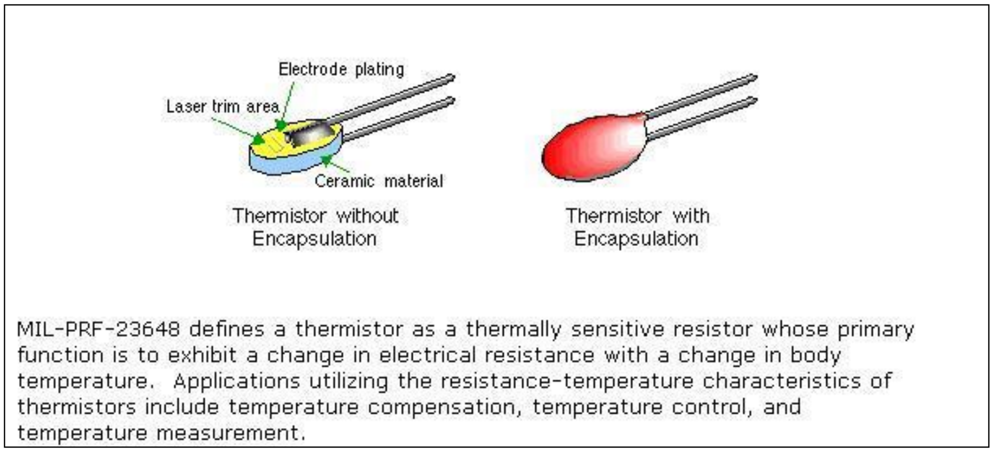
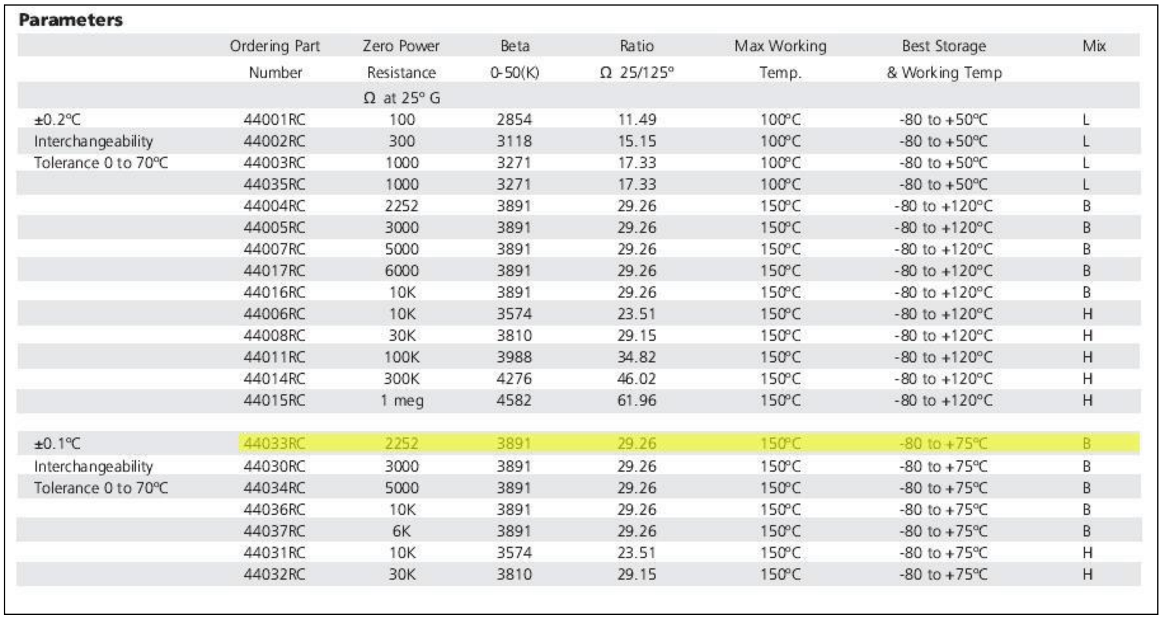


Figure 18 Schéma avec caractéristiques physiques d'une thermistance (source YSI)



MIL-PRF-23648 defines a thermistor as a thermally sensitive resistor whose primary function is to exhibit a change in electrical resistance with a change in body temperature. Applications utilizing the resistance-temperature characteristics of thermistors include temperature compensation, temperature control, and temperature measurement.

Figure 19 Description illustrée d'une thermistance (source YSI)



Parameters

	Ordering Part Number	Zero Power Resistance Ω at 25° G	Beta 0-50(K)	Ratio Ω 25/125°	Max Working Temp.	Best Storage & Working Temp	Mix
±0.2°C	44001RC	100	2854	11.49	100°C	-80 to +50°C	L
Interchangeability	44002RC	300	3118	15.15	100°C	-80 to +50°C	L
Tolerance 0 to 70°C	44003RC	1000	3271	17.33	100°C	-80 to +50°C	L
	44035RC	1000	3271	17.33	100°C	-80 to +50°C	L
	44004RC	2252	3891	29.26	150°C	-80 to +120°C	B
	44005RC	3000	3891	29.26	150°C	-80 to +120°C	B
	44007RC	5000	3891	29.26	150°C	-80 to +120°C	B
	44017RC	6000	3891	29.26	150°C	-80 to +120°C	B
	44016RC	10K	3891	29.26	150°C	-80 to +120°C	B
	44006RC	10K	3574	23.51	150°C	-80 to +120°C	H
	44008RC	30K	3810	29.15	150°C	-80 to +120°C	H
	44011RC	100K	3988	34.82	150°C	-80 to +120°C	H
	44014RC	300K	4276	46.02	150°C	-80 to +120°C	H
	44015RC	1 meg	4582	61.96	150°C	-80 to +120°C	H
±0.1°C	44033RC	2252	3891	29.26	150°C	-80 to +75°C	B
Interchangeability	44030RC	3000	3891	29.26	150°C	-80 to +75°C	B
Tolerance 0 to 70°C	44034RC	5000	3891	29.26	150°C	-80 to +75°C	B
	44036RC	10K	3891	29.26	150°C	-80 to +75°C	B
	44037RC	6K	3891	29.26	150°C	-80 to +75°C	B
	44031RC	10K	3574	23.51	150°C	-80 to +75°C	H
	44032RC	30K	3810	29.15	150°C	-80 to +75°C	H

Figure 20 Tableau avec paramètres des thermistances

“Interchangeability tolerance” is the value, in temperature, of how far a specific part may be from the nominal Resistance vs. Temperature curve. For example, a GSFC S311P18-08S7R6 thermistor is defined as having an interchangeability tolerance of ±0.1°C over the range from 0° to 70°C. This means at all points between 0° and 70°C, all S311P18-08S7R6 thermistors are within 0.1°C of the nominal resistance values for that particular thermistor curve (typically programmed into the instrumentation). This feature results in temperature measurements accurate to ±0.1°C no matter how many different S311P18-08S7R6 thermistors are substituted in the application.

The GSFC specification provides a range of resistance values from 2252 Ω to 30k Ω in either ±0.2° or ±0.1°C tolerances. YSI also offers a full line of precision probes and components featuring interchangeability tolerances of ±0.2°C, ±0.1° and ±0.05°C. These parts may be specified in a Source Control Drawing to meet applications requiring a wider range of resistance values or higher levels of long-term stability.

Thermistor stability may be defined as the ability of a thermistor to maintain the same resistance value over time when exposed to the same temperature. Failure to maintain the same resistance is described as thermistor “drift.”

“Thermometric drift” is a more specific type of drift in which the drift is the same amount of temperature at all temperatures of exposure. For example, a thermistor that exhibits a -0.02°C shift at 0°, 40° and 70°C (even though this is a different percentage change in resistance in each case) would be exhibiting thermometric drift. Thermometric drift: (1) occurs over time at varying rates, based on thermistor type and exposure temperature, and (2) as a general rule, increases as the exposure temperature increases. Most drift is thermometric.

Choosing the correct thermistor for the application is the key to providing accurate long-term measurements. YSI S-311-P-18 thermistors are recognized among the most stable parts in the industry exhibiting less than 0.01°C drift at room temperature exposure for many years. The comparison below shows typical drift for YSI thermistors after 10 month continuous exposure at 100° and 150°C:

Here are some common failure modes for thermistors:

Silver migration
This failure can occur when one of the following three conditions are present: constant direct current bias, high humidity, and electrolytes (disc contamination). Moisture finds its way into the thermistor and reacts with the contaminant. Silver (on the thermistor electrodes) turns to solution, and the direct current bias stimulates silver crystal growth across the thermistor element. The thermistor resistance decreases, eventually reaching zero Ω (short). Probably the most common failure mechanism, this failure can be eliminated by using the YSI 45000, 46000 or 55000 Series glass-coated thermistors in which the glass provides a hermetic seal around the thermistors.

Micro cracks
Thermistors can crack due to improper potting materials if a temperature change causes potting material to contract, crushing the thermistor. The result is a thermistor that has erratic resistance readings and is electrically “noisy.” Occurrence of this failure mechanism can be reduced by properly selecting potting materials with compatible rates of thermal expansion and contraction.

Aging out of resistive tolerance
If thermistors are exposed to high temperatures over time, sometimes referred to as “aging,” their resistivity can change. Generally the change is an upward change in resistivity, which results in a downward change in temperature. The occurrence of this failure can be minimized by selecting the proper thermistor for the temperature range being measured. Compare the following drift characteristics:

YSI 44000 Series (Used in S-311-P-18 parts)

- Epoxy-coated, high-density pressed disk.
- 0.20°C drift

Temperature cycling may be thought of as a form of aging. It is the cumulative exposure to high temperature that has the greatest influence on a thermistor component, not the actual temperature cycling. Temperature cycling can induce shifts if the component has been built into an assembly with epoxies or adhesives which do not match the temperature expansion characteristics of the thermistor.

The operating temperature was originally specified to minimize long term drift and provide long term survivability. The following chart defines a typical thermometric drift over time based on temperature.

Operating Temperature	Typical Thermometric Drift	
	10 Months	100 Months
0°C	<0.01°C	<0.01°C
25°C	<0.01°C	<0.02°C
100°C	0.20°C	0.32°C
150°C	1.5°C	not recommended

Operating the part above +70 or +90°C (up to 150°C) will not damage the part, but may cause the part to shift out of its original ±0.1° or ±0.2°C tolerance.

The operating temperature range is based upon continuous operating within the temperature range. Intermittent temperature incursions above and below the operating range will not effect long-term survivability. Encapsulant epoxy typically begins to break down at 150°C and the solder attaching leads to the thermistor body typically reflows at about 180°C. Either condition could result in failure of the thermistor.

YSI manufactures and tests thermistors based upon application specific requirements. We will test commercial parts to the GSFC Group A testing criteria, package and mark to customer specifications, assemble thermistors into customer specified housings then perform customer specified testing, and

Per MIL-DTL-39032E, Table 1, thermistors by definition are not ESD sensitive.

While specific testing on GSFC S-311-P-18 parts in radiation has not been performed, other YSI parts have been exposed to radiation with the following results:

44033 Thermistors
The YSI 44033 thermistor is a 2252 Ω @ 25°C (±0.1°C from 0 to 70°C), B-mix part (used in GSFC S311P18-01 and -02). Three 44033 thermistors were used for testing, with one thermistor used as a control and not irradiated. All thermistors were measured in a constant temperature oil bath before and after irradiation. The irradiated thermistors were connected in series with each other through a 1 MΩ resistor to a 4.3V supply during exposure to 2.3 x 105 roentgens. The thermistors were packed in dry ice continuously from the time irradiation began until they were again measured in the oil bath. Thermistor resistance measurements during irradiation indicated they were at approximately -55°C during this period.

These tests were run in air using a 12 kilocurie Co60 spatially extended source. Radiation received directly from the source was probably pure gamma rays since the covering on the Co60 blocks beta particles. Approximately 50% of the gamma rays had an energy of 1.17 Mev and approximately 50% had a 1.33 Mev energy level. The dose rate was approximately 2.3 x 105 roentgens. The only measured changes could be attributed to the bath temperature tolerance of ±0.05°C.

Lead Insulation
Use of Tefzel (Type “A” lead insulation in the GSFC S-311-P-18) is recommended for its superior resistance to atomic oxygen over Teflon (Type “T” insulation material).

There is no limit to the resolution of a thermistor. The limitations are in the electronics needed to measure to a specified resolution. Limitations also exist in determining the accuracy of the measurement at a specified resolution. For example, a typical YSI thermistor changes four percent of resistance for a one degree Celsius change at 25°C. A 10,000 Ω thermistor (S311P18-07) will change:

400 Ω / 1.0°C
40 Ω / 0.1°C
4 Ω / 0.01°C
0.4 Ω / 0.001°C
0.04 Ω / 0.0001°C
0.004 Ω / 0.00001°C
0.0004 Ω / 0.000001°C

Based on the example above, in order to define 1 µK (Kelvin), or 1 x 10-6 °C, instrumentation must be able to detect a change of 0.4 milliΩ. While this resolution is possible, self-heat and environmental conditions are critical considerations when trying to resolve such a small change in resistance. Defining absolute temperature to 1 µK is another matter; it is not possible with today's temperature measurement technology. Many of the fixed points used in temperature only state precision to 100 µK or 1 x 10-4 °C.

Thermistors are advanced ceramics where the repeatable electrical characteristics of the molecular structure (spinel) allow them to be used as solid-state, resistive temperature sensors. This molecular structure is obtained by mixing metal oxides together in varying proportions to create a material with the proper resistivity. YSI uses three general types of mixes in formulating thermistors of various values:

B Mix: The **B**asic or standard mix material, which utilizes two metal oxides to form the thermistor spinel. This mix is used in parts ranging in value from 2000 Ω to 10,000 Ω @ 25°C.

L Mix: A **L**ow resistance mix uses an additional metal oxide to lower the base resistivity of the thermistor material. This mix is used in making 100 Ω, 300 Ω, and 1000 Ω @ 25°C parts. L Mix parts exhibit greater shift in resistance over time and temperature than the other mixes. This makes L Mix parts less suitable for higher temperature applications.

H Mix: A **H**igh resistance mix uses an additional metal oxide to raise the base resistivity of the thermistor material. This mix is used in making 10k Ω, 30k Ω, 100k Ω, 300k Ω, and 1M Ω @ 25°C parts.

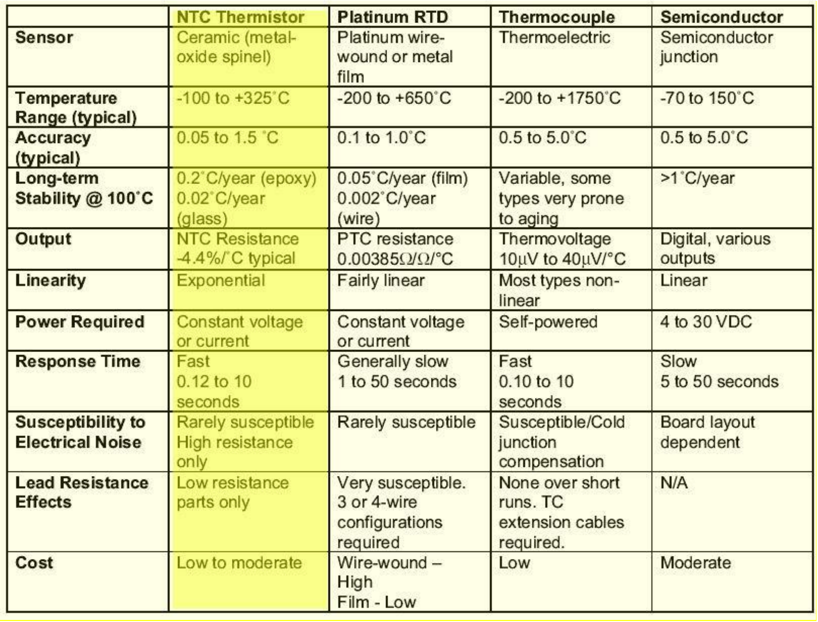
Parts for the GSFC S-311-P-18 specification use "B" and "H" mixes to produce the ceramic sensors. "B" mix is used to formulate -01 through -06 parts of 2252 to 5000 Ω @ 25°C, "H" mixes are used to formulate the -07 and -08 10k Ω and -09 and -10 30k Ω parts. Note the 10k Ω parts available per the GSFC S-311-P-18 specification are "H" mix. 10k Ω parts made from "B" mix are not currently available to the GSFC S-311-P-18 specification.

The Steinhart & Hart equation is a three-term polynomial curve-fit of a thermistor's Resistance vs. Temperature response - it is not specific to YSI thermistors. There are other polynomial expressions which can be used as well (i.e., four-term and five-term expressions). YSI has a great deal of experience with the Steinhart & Hart equation, having used it to generate catalog Resistance vs. Temperature charts (all YSI parts are tested to resistance values reflected on these charts). There will be some error in applying the Steinhart & Hart equation, but these errors are typically less than 0.02°C.

The Resistance vs. Temperature data listed in the YSI catalog was calculated using the Steinhart & Hart equation and temperature/resistance values 10°C apart. The calculated values for these 30°C regions were then "strung together" and tabulated. This method yields the best curve fit and the error for these values is 0.001°C to 0.002°C.

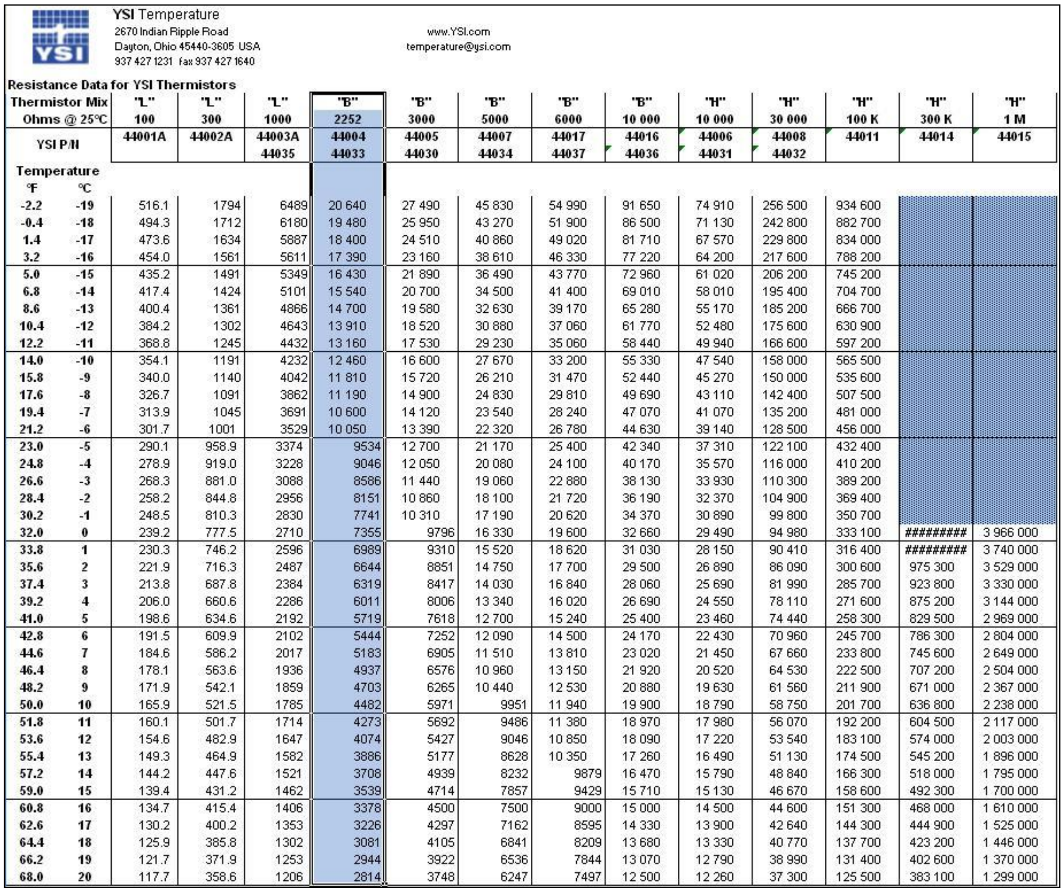
Regarding the RoHS directive, our 55000, 45000, 46000 series and standard bead glass encapsulated thermistors with bare leads are compliant with the directive. Our epoxy encapsulated thermistors, 44000 and 44900 series do not currently meet the lead free requirements of the RoHS directive. We are currently investigating the use of lead free solders for our manufacturing processes for our industrial thermistors and probe assemblies. We expect to be in full lead free production for the industrial products by the end of the first quarter 2006.

Current tin plated wire, terminal components and solder contain no more than 97% tin. The epoxy used to encapsulate our 44000 and 44900 series thermistors is approved by NASA as a low outgas epoxy. A copy of the NASA certification letter is available upon request.



	NTC Thermistor	**Platinum RTD**	**Thermocouple**	**Semiconductor**
Sensor	Ceramic (metal-oxide spinel)	Platinum wire-wound or metal film	Thermoelectric	Semiconductor junction
Temperature Range (typical)	-100 to +325°C	-200 to +650°C	-200 to +1750°C	-70 to 150°C
Accuracy (typical)	0.05 to 1.5 °C	0.1 to 1.0°C	0.5 to 5.0°C	0.5 to 5.0°C
Long-term Stability @ 100°C	0.2°C/year (epoxy) 0.02°C/year (glass)	0.05°C/year (film) 0.002°C/year (wire)	Variable, some types very prone to aging	>1°C/year
Output	NTC Resistance -4.4%/°C typical	PTC resistance 0.00385Ω/Ω/°C	Thermovoltage 10µV to 40µV/°C	Digital, various outputs
Linearity	Exponential	Fairly linear	Most types non-linear	Linear
Power Required	Constant voltage or current	Constant voltage or current	Self-powered	4 to 30 VDC
Response Time	Fast 0.12 to 10 seconds	Generally slow 1 to 50 seconds	Fast 0.10 to 10 seconds	Slow 5 to 50 seconds
Susceptibility to Electrical Noise	Rarely susceptible High resistance only	Rarely susceptible	Susceptible/Cold junction compensation	Board layout dependent
Lead Resistance Effects	Low resistance parts only	Very susceptible. 3 or 4-wire configurations required	None over short runs. TC extension cables required.	N/A
Cost	Low to moderate	Wire-wound – High Film - Low	Low	Moderate

Figure 21 Caractéristiques des différents types de senseurs (source YSI)



YSI Temperature
2670 Indian Ripple Road
Dayton, Ohio 45440-3605 USA
937 427 1231 fax 937 427 1640

www.YSI.com
temperature@ysi.com

Resistance Data for YSI Thermistors

Thermistor Mix		**"L"**	**"L"**	**"L"**	**"B"**	**"B"**	**"B"**	**"B"**	**"B"**	**"H"**	**"H"**	**"H"**	**"H"**	**"H"**
Ohms @ 25°C		**100**	**300**	**1000**	**2252**	**3000**	**5000**	**6000**	**10 000**	**10 000**	**30 000**	**100 K**	**300 K**	**1 M**
YSI P/N		**44001A**	**44002A**	**44003A 44035**	**44004 44033**	**44005 44030**	**44007 44034**	**44017 44037**	**44016 44036**	**44006 44031**	**44008 44032**	**44011**	**44014**	**44015**
Temperature														
°F	**°C**													
-2.2	**-19**	516.1	1794	6489	20 640	27 490	45 830	54 990	91 650	74 910	256 500	934 600		
-0.4	**-18**	494.3	1712	6180	19 480	25 950	43 270	51 900	86 500	71 130	242 800	882 700		
1.4	**-17**	473.6	1634	5887	18 400	24 510	40 860	49 020	81 710	67 570	229 800	834 000		
3.2	**-16**	454.0	1561	5611	17 390	23 160	38 610	46 330	77 220	64 200	217 600	788 200		
5.0	**-15**	435.2	1491	5349	16 430	21 890	36 490	43 770	72 960	61 020	206 200	745 200		
6.8	**-14**	417.4	1424	5101	15 540	20 700	34 500	41 400	69 010	58 010	195 400	704 700		
8.6	**-13**	400.4	1361	4866	14 700	19 580	32 630	39 170	65 280	55 170	185 200	666 700		
10.4	**-12**	384.2	1302	4643	13 910	18 520	30 880	37 060	61 770	52 480	175 600	630 900		
12.2	**-11**	368.8	1245	4432	13 160	17 530	29 230	35 060	58 440	49 940	166 600	597 200		
14.0	**-10**	354.1	1191	4232	12 460	16 600	27 670	33 200	55 330	47 540	158 000	565 500		
15.8	**-9**	340.0	1140	4042	11 810	15 720	26 210	31 470	52 440	45 270	150 000	535 600		
17.6	**-8**	326.7	1091	3862	11 190	14 900	24 830	29 810	49 690	43 110	142 400	507 500		
19.4	**-7**	313.9	1045	3691	10 600	14 120	23 540	28 240	47 070	41 070	135 200	481 000		
21.2	**-6**	301.7	1001	3529	10 050	13 390	22 320	26 780	44 630	39 140	128 500	456 000		
23.0	**-5**	290.1	958.9	3374	9534	12 700	21 170	25 400	42 340	37 310	122 100	432 400		
24.8	**-4**	278.9	919.0	3228	9046	12 050	20 080	24 100	40 170	35 570	116 000	410 200		
26.6	**-3**	268.3	881.0	3088	8586	11 440	19 060	22 880	38 130	33 930	110 300	389 200		
28.4	**-2**	258.2	844.8	2956	8151	10 860	18 100	21 720	36 190	32 370	104 900	369 400		
30.2	**-1**	248.5	810.3	2830	7741	10 310	17 190	20 620	34 370	30 890	99 800	350 700		
32.0	**0**	239.2	777.5	2710	7355	9796	16 330	19 600	32 660	29 490	94 980	333 100	#########	3 966 000
33.8	**1**	230.3	746.2	2596	6989	9310	15 520	18 620	31 030	28 150	90 410	316 400	#########	3 740 000
35.6	**2**	221.9	716.3	2487	6644	8851	14 750	17 700	29 500	26 890	86 090	300 600	975 300	3 529 000
37.4	**3**	213.8	687.8	2384	6319	8417	14 030	16 840	28 060	25 690	81 990	285 700	923 800	3 330 000
39.2	**4**	206.0	660.6	2286	6011	8006	13 340	16 020	26 690	24 550	78 110	271 600	875 200	3 144 000
41.0	**5**	198.6	634.6	2192	5719	7618	12 700	15 240	25 400	23 460	74 440	258 300	829 500	2 969 000
42.8	**6**	191.5	609.9	2102	5444	7252	12 090	14 500	24 170	22 430	70 960	245 700	786 300	2 804 000
44.6	**7**	184.6	586.2	2017	5183	6905	11 510	13 810	23 020	21 450	67 660	233 800	745 600	2 649 000
46.4	**8**	178.1	563.6	1936	4937	6576	10 960	13 150	21 920	20 520	64 530	222 500	707 200	2 504 000
48.2	**9**	171.9	542.1	1859	4703	6265	10 440	12 530	20 880	19 630	61 560	211 900	671 000	2 367 000
50.0	**10**	165.9	521.5	1785	4482	5971	9951	11 940	19 900	18 790	58 750	201 700	636 800	2 238 000
51.8	**11**	160.1	501.7	1714	4273	5692	9486	11 380	18 970	17 980	56 070	192 200	604 500	2 117 000
53.6	**12**	154.6	482.9	1647	4074	5427	9046	10 850	18 090	17 220	53 540	183 100	574 000	2 003 000
55.4	**13**	149.3	464.9	1582	3886	5177	8628	10 350	17 260	16 490	51 130	174 500	545 200	1 896 000
57.2	**14**	144.2	447.6	1521	3708	4939	8232	9879	16 470	15 790	48 840	166 300	518 000	1 795 000
59.0	**15**	139.4	431.2	1462	3539	4714	7857	9429	15 710	15 130	46 670	158 600	492 300	1 700 000
60.8	**16**	134.7	415.4	1406	3378	4500	7500	9000	15 000	14 500	44 600	151 300	468 000	1 610 000
62.6	**17**	130.2	400.2	1353	3226	4297	7162	8595	14 330	13 900	42 640	144 300	444 900	1 525 000
64.4	**18**	125.9	385.8	1302	3081	4105	6841	8209	13 680	13 330	40 770	137 700	423 200	1 446 000
66.2	**19**	121.7	371.9	1253	2944	3922	6536	7844	13 070	12 790	38 990	131 400	402 600	1 370 000
68.0	**20**	117.7	358.6	1206	2814	3748	6247	7497	12 500	12 260	37 300	125 500	383 100	1 299 000

Figure 22 Valeur des résistances en fonction de la température (source YSI)

Annexe 6

Composantes de la station (Instrumentation)

Belden 88761
22 AWG Stranded Conductors
Tinned copper
Twisted pair
Overall 100% Bed foil Shield
22 AWG Stranded TC Drain Wire
Red FEP Jacket (Teflon)
NEC CMP
FEP Insulation

Metal film resistors
PR1/10, TC5, 7.5K, 0.1%
Shunt resistors

Thermistor Calibration and the Steinhart-Hart Equation

Thermistors provide an inexpensive and accurate temperature monitor for use with laser diodes. The nonlinear resistance-temperature characteristics of a Negative-Temperature Coefficient (NTC) thermistor may be modeled to a high degree of accuracy using the Steinhart-Hart equation, LaGrange polynomials, or other modeling techniques. Figure 1 shows a common R-T relation curve for a 10kΩ NTC thermistor.

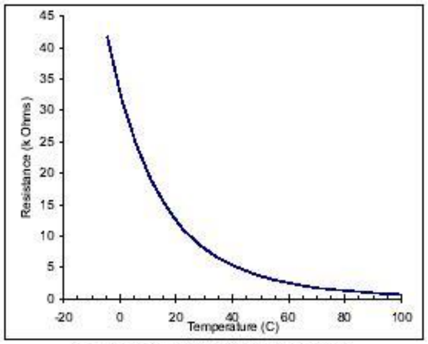


Figure 1. NTC R-T response curve.

In 1968, Steinhart and Hart developed a model for thermistor R-T characteristics in order to make accurate temperature measurements for oceanic studies. Today, the most popular model for R-T characterization is the Steinhart-Hart equation.

This publication describes two methods for calibrating thermistors using the Steinhart-Hart equation; the first method may be used with the ILX Lightwave Model LDT-5948 and LDT-5980[1] Temperature Controllers, or any other temperature controller which uses the Steinhart-Hart equation. The second form of the equation is simpler, and is used with the ILX Lightwave Model LDT-5525 Temperature Controller.

The Steinhart-Hart Equation

The three-term Steinhart-Hart equation (Equation 1) is the most popular model used for thermistor R-T modeling.

$$(1) \quad 1/T = C_1 + C_2 * \ln(R) + C_3 * \ln(R)^3$$

Where T is the absolute temperature in Kelvin and R is the thermistor resistance in ohms. The terms C_1, C_2, and C_3 are the Steinhart-Hart constants for the thermistor.

The simpler, two-term form of the Steinhart-Hart equation (Equation 2) may be used in some cases .

$$(2) \quad 1/T = C_1' + C_2' * \ln(R)$$

Note that $C_1' \neq C_1$ and $C_2' \neq C_2$.

Three Methods to Calculate the Steinhart-Hart Constants

Three methods for calculating the constants of the Steinhart-Hart equation are summarized in Table 1. Computer programs are available electronically, free of charge, from your ILX Lightwave representative, or from the ILX Lightwave, Temperature

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[1] Three-Term Steinhart-Hart equation is also used in ILX Lightwave Model 39xx and 37xx Laser Diode Controllers.

Control Center on the website. The Excel version of STEIN1.EXE is printed in the Appendix.

Table 1
Three Methods of Calculating Constants C_1, C_2, C_3

	Method 1	Method 2	Method 3
Model	Eq. (1)	Eq. (1)	Eq. (2)
Program	STEIN1 Or Excel	STEIN2	STEIN3
Accuracy^1	0.05 C^3	0.01 C^2	0.3 C^3
Calculation Method	Three-point	Least-squares fit	Least-squares fit

Table 1 Notes:

1 Accuracy over 0°C to 50°C range; assuming temperature and resistance readings are accurate to four places.

2 Using 10kΩ thermistor and ILX Lightwave model LDT-5910B temperature controller.

3 Using 10kΩ thermistor and ILX Lightwave model LDT-5525 temperature controller.

Discussion Regarding Temperature Accuracy

The method of thermistor calibration will depend on the accuracy requirements for the particular application. Table 1 shows the expected accuracies using the three different methods.

Thermistor Ratings

Manufacturers specify thermistor tolerances in several ways, usually with the resistance tolerance (R_{tol}) or temperature tolerance (T_{tol}), and the temperature coefficient of resistance (α). The rated R_{tol} and T_{tol} are typically given for 25°C with additional deviation factors for other temperatures. The temperature coefficient of resistance (α) is the percentage change of resistance for a 1°C change in temperature, and may be specified with one of the other two tolerances. The three factors are related as shown in Equation 3.

$$(3) \quad T_{tol} = R_{tol} \;/\; \alpha$$

When a thermistor is calibrated with the Steinhart-Hart model, its temperature tolerance over that range is improved to the tolerance of the model. Therefore, an inexpensive thermistor calibrated to ±0.02°C will be just as accurate as an expensive (i.e. tight tolerance) thermistor that is also calibrated to ±0.02°C over the same temperature range.

Net Accuracy

An LDT-5948 or 5980 or other ILX Temperature Controller may be used to independantly measure the temperature when calibrating a thermistor. However, to guarantee accuracy, the instrument's resistance measurement must be accurately calibrated and a previously calibrated thermistor (with the Steinhart-Hart coefficients entered) must be used to measure the temperature. Also, accuracy will be reduced by the temperature resolution of the instrument, unless the temperature is queried via GPIB.

Stability vs. Accuracy

Temperature accuracy, which is the *variance from true temperature*, depends primarily on the thermistor calibration. Temperature stability, which is the *invariance from the set temperature*, depends on the controller design and the environment of the thermistor and TE module.

If an LDT-5948 or 5980 is used, short-term temperature stability of ±0.001°C or better can be achieved.

thermistor. When a high temperature tolerance is required, it is recommended that these R-T values be discarded and new values be measured as described below.

For some applications the nominal R-T data is adequate and the Steinhart-Hart constants can be calculated using "Faster Method 2," described below.

ILX Lightwave Model 520 uncalibrated thermistors are shipped with three-term nominal constant values as follows:

C1 = 1.125
C2 = 2.347
C3 = 0.855

The two-term nominal constants, for use with the LDT-5525, are:

C1' = 0.99
C2' = 2.57

Procedure for Calculating Steinhart-Hart Constants

To calculate the constants for a new thermistor, the temperature and resistance of that thermistor will need to be measured at several different temperatures covering the expected range of operation.

The following procedure requires some method to set and control a nominal temperature and a calibrated precision thermistor to reference the temperature.

For all methods, it is worth noting that the ultimate accuracy of the constants is dependent upon the accuracy of the temperature and resistance measurements.

The control temperature tolerance will decrease rapidly if the thermistor is used outside of the temperature range in which it was calibrated. Temperature and resistance values should be made at evenly spaced increments over a range greater than the intended range-of-operation for the thermistor.

1. Set a nominal temperature and allow it to stabilize.
2. Using a precision DMM (accuracy to a minimum of four places) read the resistance of the reference thermistor and the uncalibrated thermistor.
3. Read the resistances three times before changing to a new nominal temperature. The three readings can be averaged if using Method 1, or all readings can be used if using Method 2 or Method 3.
4. If using Method 1, repeat steps 1-3 for a total of three temperature settings. For either Method 2 or Method 3, repeat the measurement as many times as practical; these two methods use least-squares fit to determine the constants, and will be more accurate with a greater number of measurements.
5. The "true" temperature in degrees Celsius can be determined using the constants for the precision thermistor and using the inverse of Equation 1, shown below as Equation 4.

   $$(4)\ T = (C_1 + C_2 * ln(R) + C_3 * ln(R)^3)^{-1} - 273.15$$

   If using Method 3, the approximated Steinhart-Hart equation, disregard the term using the constant C3 by using Equation 5.

   $$(5)\ T = (C_1 + C_2 * ln(R))^{-1} - 273.15$$

6. Compile the data into a table with two columns: "true" temperature calculated using Equation 4, and resistance measured from the uncalibrated thermistor.

This data will be used with one of the three methods listed in Table 1 to determine the three Steinhart-Hart constants for the new thermistor.

Three Methods of Steinhart-Hart Constant Calculation

Method 1, STEIN1.EXE

STEIN1.EXE can be run directly from the Windows environment, or the Excel spreadsheet can be used (see Appendix for program listing). The three temperature and resistance values are entered and the constant values are returned. If any of the constant values are negative there is an error and the data should be checked or re-measured.

The constants are output in the form used by an ILX temperature controller by scaling each as shown below.

$$(6)\ C1 = C_1 * 10^3$$

$$(7)\ C2 = C_2 * 10^4$$

$$(8)\ C3 = C_3 * 10^7$$

The program or spreadsheet performs this scaling so the output values can be entered directly into the temperature controller.

Method 2, STEIN2.EXE

STEIN2.EXE uses least-squares-fit error reduction, so requires a greater number of temperature/resistance readings to be taken to adjust the R-T curve for a good fit. Data should be entered into an ASCII data file in the format shown in Figure 2.

```
 (T)     (R)
-0.01   32444
14.99   15534
 ...     ...
 ...     ...
25.01   9864
36.95   5936
50.10   3560
  0      -1
```

Figure 2. Data format for STEIN2.EXE.

Note that the temperature and resistance readings must be separated by one space, and the file terminated with a resistance reading of '-1.'

The data file can be created in Excel and saved as a ".PRN" file to ensure the data is space delimited (the program will not function properly if the data is tab delimited). The constants will be output in the form required by the ILX Lightwave temperature controller.

Alternatively, the program called EasySTEIN2.EXE can be used. This program will prompt for the data to be input directly, rather than using a separate data file. As with STEIN2.EXE, the constants are output in a form that is entered directly into the temperature controller. The constant uncertainties are also calculated and displayed.

Both programs use the method described by Philip R Bevington in "Data Reduction and Error Analysis for the Physical Sciences," McGraw-Hill, New York, 1969. Matrix inversion is used to solve N simultaneous equations, where N is the number of data pairs in the data file (excluding the marker). Coefficients C_1, C_2, and C_3 are determined by mini mizing χ^2, the measure of the fit of the curve to the data.

Faster Method 2

As discussed previously, some manufacturers provide nominal R-T values with the thermistor. "Nominal" Steinhart-Hart constant values can be calculated from the manufacturer's R-T values with Method 2 if high temperature control tolerances are not required for a particular application.

Temperature error can be calculated using Equation (4) with the "nominal" constant values and the worst-case resistance values from the tolerance rating. Results of this exercise are shown in Figure 3 for a 1% and 5% tolerance thermistor. The error is the uncertainty in the temperature based on the resistance tolerance when deriving C_1, C_2, and C_3; it does not include any additional error based on the uncertainty in the resistance measurement.

As shown in Figure 3, below 50°C this error is less than about ±1.5°C for the 5% tolerance 10kΩ thermistor. The error for a typical 1% tolerance 10kΩ thermistor is better than ±0.6°C at 50°C.

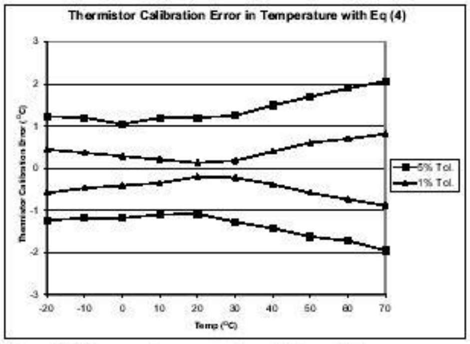


Figure 3. Temperature error due to thermistor calibration error.

Method 3, STEIN3.EXE

Similar to Method 2, the third method uses least-squares-fit error reduction to adjust the R-T curve for a good fit. This method is intended for use when only the first two Steinhart-Hart constants are used, as with the LDT-5525.

The R-T data is collected and formatted the same as described for Method 2, but the program titled STEIN3.EXE is used.

As with Method 2, a faster method using Method 3 can be performed by entering the nominal R-T values supplied by the thermistor manufacturer and running STEIN3.EXE. The resulting "nominal" Steinhart-Hart constant values can then be entered into the LDT-5525. Temperature error can be calculated using Equation 5 with the "nominal" constant values and the worst-case resistance values from the tolerance rating.

As shown in Figure 4, below 50°C this error is less than about ±2°C for the 5% tolerance 10kΩ thermistor. The error for a typical 1% tolerance 10kΩ thermistor is better than ±0.8°C at 50°C.

Figure 4 also shows the error associated with the calibration for a Model 510 (10kΩ) thermistor, used with the Model LDT-5525 Temperature Controller when using Equation 5. Again, this does not include any error in the resistance measurement.

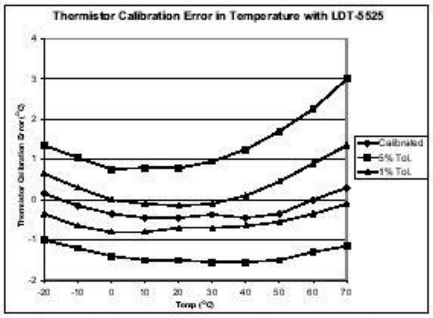


Figure 4. Temperature error due to thermistor calibration error.

In Conclusion

Thermistor calibration, though not difficult, can be time-consuming. Therefore, it is best to first determine the requirements of the application, then pick an appropriate calibration method. The methods discusses in this publication are summarized in Table 2. Thermistor accuracy is primarily a function of the thermistor calibration and resistance measurement accuracy, whereas temperature stability depends on the controller and control environment.

For more information on thermistor selection, see ILX Lightwave Application Note #2, *Selecting and Using Thermistors for Temperature Control.*

Copies of the programs may be obtained from ILX Lightwave free of charge through our Temperature Control Center at ILXlightwave.com

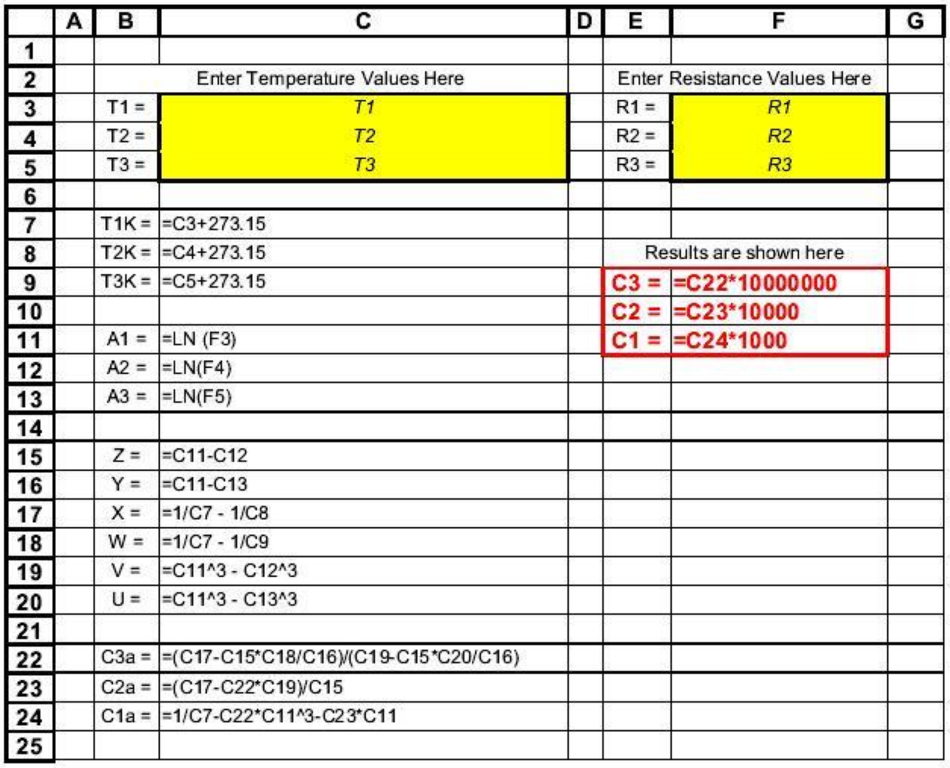
Table 2
Summary of Calibration Methods

*Also used in ILX Lightwave Model 37xx and 39xx Laser Diode Controllers.

	Method 1	**Method 2**	**Method 3**	**Method 2**	**Method 3**
Data Points	3	>3	>3	R-T provided by mfg	R-T provided by mfg
Method	Three-point fit	Least-Squares fit	Least-Squares fit	"Nominal" calculation	"Nominal" calculation
Model	Equation (1)	Equation (1)	Equation (2)	Equation (1) Equation (4)	Equation (2) Equation (5)
Program	STEIN1.EXE or Excel	STEIN2.EXE	STEIN3.EXE	STEIN2.EXE	STEIN3.EXE
Accuracy	±0.05 °C	±0.01 °C	±0.3 °C	±0.01 °C	±0.01 °C
Instrument	LDT-5948/80*	LDT-5948/80*	LDT-5525	LDT-5948/80*	LDT-5525

APPENDIX - Method 1 Excel Spreadsheet

Type in the equations as shown. Temperature readings are entered in Cells C3-C5; Resistance readings are entered in Cells F3-F5. The results are shown in Cells F9-F11, and are scaled so they may be entered into the LDT-5910B directly.



	A	B	C	D	E	F	G
1							
2		Enter Temperature Values Here			Enter Resistance Values Here		
3		T1 =	*T1*		R1 =	*R1*	
4		T2 =	*T2*		R2 =	*R2*	
5		T3 =	*T3*		R3 =	*R3*	
6							
7		T1K =	=C3+273.15				
8		T2K =	=C4+273.15		Results are shown here		
9		T3K =	=C5+273.15		**C3 =**	**=C22*10000000**	
10					**C2 =**	**=C23*10000**	
11		A1 =	=LN (F3)		**C1 =**	**=C24*1000**	
12		A2 =	=LN(F4)				
13		A3 =	=LN(F5)				
14							
15		Z =	=C11-C12				
16		Y =	=C11-C13				
17		X =	=1/C7 - 1/C8				
18		W =	=1/C7 - 1/C9				
19		V =	=C11^3 - C12^3				
20		U =	=C11^3 - C13^3				
21							
22		C3a =	=(C17-C15*C18/C16)/(C19-C15*C20/C16)				
23		C2a =	=(C17-C22*C19)/C15				
24		C1a =	=1/C7-C22*C11^3-C23*C11				
25							