*Thermistor Calibration and
the Steinhart-Hart Equation*

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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.
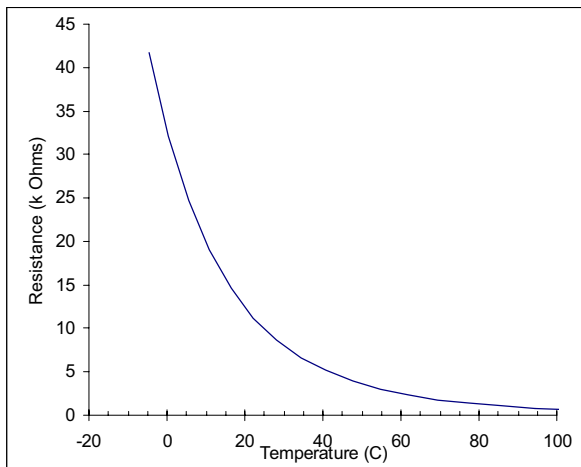

Figure 1. NTC R-T response curve.

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_2	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 tempera ture 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 toler-ance (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 Stein-hart-Hart model, its temperature tolerance over that range is improved to the tolerance of the model. Therefore, an inexpensive therm-istor 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 Tem-perature Controller may be used to indepen-dantly measure the temperature when cali-brating a thermistor. However, to guarantee accuracy, the instrument's resistance mea-surement must be accurately calibrated and a previously calibrated thermistor (with the Steinhart-Hart coefficients entered) must be used to measure the temperature. Also, accu-racy will be reduced by the temperature reso-lution of the instrument, unless the tempera-ture is queried via GPIB.

Stability vs. Accuracy

Temperature accuracy, which is the *variance from true temperature*, depends primarily on the thermistor calibration. Temperature stabil-ity, which is the *invariance from the set tem-perature*, 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 toler-ance 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 therm-istors 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 thermis-tor, 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 tempera-ture and a calibrated precision thermistor to reference the temperature.

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

The control temperature tolerance will

decrease rapidly if the thermistor is used out-side 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 mini-mum of four places) read the resistance of the reference thermistor and the uncali-brated 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 measure-ments.

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 Stein-hart-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
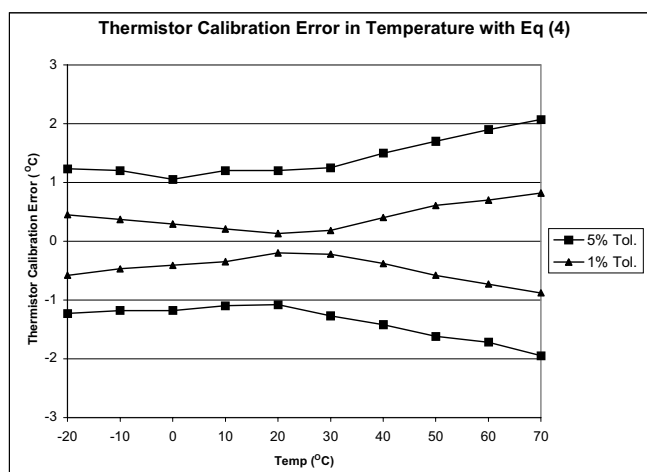

Figure 3. Temperature error due to thermistor calibration error.

10kΩ thermistor. The error for a typical 1% tolerance 10kΩ thermistor is better than ±0.6°C at 50°C.

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.
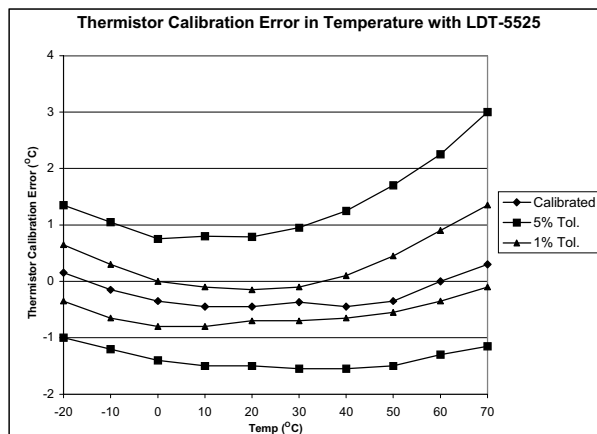
Figure 4. Temperature error due to thermistor calibration error.

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 publi-

cation 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 ℃	±0.01 ℃	±0.3 ℃	±0.01 ℃	±0.01 ℃
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							

The following publications are available for download on www.ilxlightwave.com.

White Papers

• A Standard for Measuring Transient Suppression of Laser Diode Drivers
• Degree of Polarization vs. Poincaré Sphere Coverage
• Improving Splice Loss Measurement Repeatability

Technical Notes

• Attenuation Accuracy in the 7900 Fiber Optic Test System
• Automatic Wavelength Compensation of Photodiode Power Measurements Using the OMM-6810B Optical Multimeter
• Bandwidth of OMM-6810B Optical Multimeter Analog Output
• Broadband Noise Measurements for Laser Diode Current Sources
• Clamping Limit of a LDX-3525 Precision Current Source
• Control Capability of the LDC-3916371 Fine Temperature Resolution Module
• Current Draw of the LDC-3926 16-Channel High Power Laser Diode Controller
• Determining the Polarization Dependent Response of the FPM-8210 Power Meter
• Four-Wire TEC Voltage Measurement with the LDT-5900 Series Temperature Controllers
• Guide to Selecting a Bias-T Laser Diode Mount
• High Power Linearity of the OMM-6810B and OMH-6780/6790/6795B Detector Heads
• Large-Signal Frequency Response of the 3916338 Current Source Module
• Laser Wavelength Measuring Using a Colored Glass Filter
• Long-Term Output Drift of a LDX-3620 Ultra Low-Noise Laser Diode Current Source
• Long-Term Output Stability of a LDX-3525 Precision Current Source
• Long-Term Stability of an MPS-8033/55 ASE Source
• LRS-9424 Heat Sink Temperature Stability When Chamber Door Opens
• Measurement of 4-Wire Voltage Sense on an LDC-3916 Laser Diode Controller
• Measuring the Power and Wavelength of Pulsed Sources Using the OMM-6810B Optical Mutlimeter
• Measuring the Sensitivity of the OMH-6709B Optical Measurement Head
• Measuring the Wavelength of Noisy Sources Using the OMM-6810B Optical Multimeter
• Output Current Accuracy of a LDX-3525 Precision Current Source
• Pin Assignment for CC-305 and CC-505 Cables
• Power and Wavelength Stability of the 79800 DFB Source Module
• Power and Wavelength Stability of the MPS-8000 Series Fiber Optic Sources
• Repeatability of Wavelength and Power Measurements Using the OMM-6810B Optical Multimeter
• Stability of the OMM-6810B Optical Multimeter and OMH-6727B InGaAs Power/Wavehead
• Switching Transient of the 79800D Optical Source Shutter
• Temperature Controlled Mini-DIL Mount
• Temperature Stability Using the LDT-5948
• Thermal Performance of an LDM-4616 Laser Diode Mount
• Triboelectric Effects in High Precision Temperature Measurements
• Tuning the LDP-3840 for Optimum Pulse Response
• Typical Long-Term Temperature Stability of a LDT-5412 Low-Cost TEC
• Typical Long-Term Temperature Stability of a LDT-5525 TEC

• Typical Output Drift of a LDX-3412 Loc-Cost Precision Current Source
• Typical Output Noise of a LDX-3412 Precision Current Source
• Typical Output Stability of the LDC-3724B
• Typical Output Stability of a LDX-3100 Board-Level Current Source
• Typical Pulse Overshoot of the LDP-3840/03 Precision Pulse Current Source
• Typical Temperature Stability of a LDT-5412 Low-Cost Temperature Controller
• Using Three-Wire RTDs with the LDT-5900 Series Temperature Controllers
• Voltage Drop Across High Current Laser Interconnect Cable
• Voltage Drop Across High Current TEC Interconnect Cable
• Voltage Limit Protection of an LDC-3916 Laser Diode Controller
• Wavelength Accuracy of the 79800 DFB Source Module

Application Notes

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• App Note 2: Selecting and Using Thermistors for Temperature Control

• App Note 3: Protecting Your Laser Diode

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ILX Lightwave Corporation was founded in 1986 as a privately held, venture financed manufacturer of photonic test and measurement instruments. Our commitment to you is to provide the highest quality instrumentation and technical support available.

For application assistance or additional information on our products or services you can contact us at:

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