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

ILX Lightwave Corporation
31950 Frontage Road, Bozeman, MT 59715
Phone: 406-556-2481 • 800-459-9459 • Fax: 406-586-9405
Email: sales@ilxlightwave.com

To obtain contact information for our international distributors and product repair centers or for fast access to product information, technical support, LabVIEW® drivers, and our comprehensive library of technical and application information, visit our website at:

www.ilxlightwave.com
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.

**The Steinhart-Hart Equation**

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

\[
\frac{1}{T} = C_1 + C_2 \ln(R) + C_3 \ln(R)^3
\]

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.

\[
\frac{1}{T} = C_1' + C_2' \ln(R)
\]

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 and software are available electronically, free of charge, from your ILX Lightwave representative, or from the Downloads section of our website.

**Thermistor Calibration and the Steinhart-Hart Equation**

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The Excel version of STEIN1.EXE is printed in the Appendix.

### Table 1

<table>
<thead>
<tr>
<th>Method</th>
<th>Model</th>
<th>Eq. (1)</th>
<th>Eq. (1)</th>
<th>Eq. (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>STEIN1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>STEIN2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>STEIN3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Eq. (1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Eq. (1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Eq. (2)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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 (Rtol) or temperature tolerance (Ttol), and the temperature coefficient of resistance (α). The rated Rtol and Ttol 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.

\[ T_{tol} = \frac{R_{tol}}{\alpha} \]

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 independently 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.

### 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.

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Enter Temperature Values Here</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>T1</td>
<td>T1</td>
<td>R1</td>
<td>R7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>T2</td>
<td>T2</td>
<td>R2</td>
<td>R2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>T3</td>
<td>T3</td>
<td>R3</td>
<td>R3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>T1K = =C3+273.15</td>
<td>Results are shown here</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>T2K = =C4+273.15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>T3K = =C5+273.15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>A1 = =LN(F3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>A2 = =LN(F4)</td>
<td>C1 = =C24*10000000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>A3 = =LN(F5)</td>
<td>C2 = =C23*10000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>C1 = =C24*1000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Z = =C11+C12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Y = =C11+C13</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>X = =1/C7 - 1/C9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>V = =C11^3 - C12^3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>U = =C11^3 - C13^3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>C3a = =C17-C15(C18+C16)/(C19-C15*C20+C16)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>C2a = =C17-C22*C19+C15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>C1a = =1/C7-C22<em>C11^3-C23</em>C11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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 the Downloads section on www.ilxlightwave.com.

**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 discussed in this publication are summarized in Table 2.

![Graph](image1.png)  
Figure 4. Temperature error due to thermistor calibration error.

**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.

Often, the thermistor manufacturer will provide R-T values, but the accuracy of these values depends on the resistance tolerance of the 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.

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

- \( C_1 = 1.125 \)
- \( C_2 = 2.347 \)
- \( C_3 = 0.855 \)

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

- \( C_1' = 0.99 \)
- \( C_2' = 2.57 \)

**Table 2**  
Summary of Calibration Methods

<table>
<thead>
<tr>
<th>Method 1</th>
<th>Method 2</th>
<th>Method 3</th>
<th>Method 2</th>
<th>Method 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Points</td>
<td>3</td>
<td>&gt;3</td>
<td>&gt;3</td>
<td>R-T provided by mfg</td>
</tr>
<tr>
<td>Method</td>
<td>Three-point fit</td>
<td>Least-Squares fit</td>
<td>Least-Squares fit</td>
<td>“Nominal” calculation</td>
</tr>
<tr>
<td>Model</td>
<td>Equation (1)</td>
<td>Equation (1)</td>
<td>Equation (2)</td>
<td>Equation (1)</td>
</tr>
<tr>
<td>Program</td>
<td>STEIN1.EXE or Excel</td>
<td>STEIN2.EXE</td>
<td>STEIN3.EXE</td>
<td>STEIN2.EXE</td>
</tr>
<tr>
<td>Accuracy</td>
<td>±0.05 °C</td>
<td>±0.01 °C</td>
<td>±0.3 °C</td>
<td>±0.01 °C</td>
</tr>
<tr>
<td>Instrument</td>
<td>LDT-948/80*</td>
<td>LDT-948/80*</td>
<td>LDT-5525</td>
<td>LDT-948/80*</td>
</tr>
</tbody>
</table>

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

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**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.

\[
(4) T = \left( C_1 + C_2 \ln(R) + C_3 \ln(R)^3 \right)^{-1} - 273.15
\]

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

\[
(5) T = \left( C_1 + C_2 \ln(R) \right)^{-1} - 273.15
\]
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.

\[
\begin{align*}
(6) & \quad C_1 = C_1 \times 10^3 \\
(7) & \quad C_2 = C_2 \times 10^4 \\
(8) & \quad C_3 = C_3 \times 10^7
\end{align*}
\]

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 minimizing \( \chi^2 \), 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 \( \pm 1.5^\circ \text{C} \) for the 5% tolerance 10kΩ thermistor. The error for a typical 1% tolerance 10kΩ thermistor is better than \( \pm 0.8^\circ \text{C} \) 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.

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 \( \pm 2^\circ \text{C} \) for the 5% tolerance 10kΩ thermistor. The error for a typical 1% tolerance 10kΩ thermistor is better than \( \pm 0.8^\circ \text{C} \) 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.
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

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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.

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(8) \quad & C_3 = C_3 \times 10^7
\end{align*}
\]

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. 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.

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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.
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 discussed in this publication are summarized in Table 2.

### Table 2

<table>
<thead>
<tr>
<th>Method 1</th>
<th>Method 2</th>
<th>Method 3</th>
<th>Method 3</th>
<th>Method 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Points</td>
<td>&gt;3</td>
<td>&gt;3</td>
<td>R-T provided by nfg</td>
<td>R-T provided by nfg</td>
</tr>
<tr>
<td>Method</td>
<td>Three-point fit</td>
<td>Least-Squares fit</td>
<td>Least-Squares fit</td>
<td>&quot;Nominal&quot; calculation</td>
</tr>
<tr>
<td>Model</td>
<td>Equation (1)</td>
<td>Equation (2)</td>
<td>Equation (1)</td>
<td>Equation (4)</td>
</tr>
<tr>
<td>Program</td>
<td>STEIN1.EXE</td>
<td>STEIN2.EXE</td>
<td>STEIN3.EXE</td>
<td>STEIN2.EXE</td>
</tr>
<tr>
<td>Accuracy</td>
<td>±0.05 °C</td>
<td>±0.05 °C</td>
<td>±0.3 °C</td>
<td>±0.01 °C</td>
</tr>
<tr>
<td>Instrument</td>
<td>LDT-5948/80*</td>
<td>LDT-5948/80*</td>
<td>LDT-5525</td>
<td>LDT-5948/80*</td>
</tr>
</tbody>
</table>

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

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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.

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.

\[
T = \left( \frac{C_1 + C_2 \ln R + C_3 \ln^3 R}{C_1 + C_2 \ln R + C_3 \ln^3 R} \right) - 273.15
\]

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

\[
T = \left( \frac{C_1 + C_2 \ln R}{C_1 + C_2 \ln R} \right) - 273.15
\]
of the other two tolerances. The three factors are related as shown in Equation 3.

\[ T_{\text{tol}} = R_{\text{tol}} / \alpha \]

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 \( \pm 0.02^\circ C \) will be just as accurate as an expensive (i.e. tight tolerance) thermistor that is also calibrated to \( \pm 0.02^\circ C \) over the same temperature range.

### Net Accuracy

An LDT-5948 or 5980 or other ILX Temperature Controller may be used to independently 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 \( \pm 0.001^\circ C \) or better can be achieved.

---

**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.

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Enter Temperature Values Here</td>
<td>Enter Resistance Values Here</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>T1 =</td>
<td>T1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>T2 =</td>
<td>T2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>T3 =</td>
<td>T3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>T1K =</td>
<td>=C3+273.15</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>T2K =</td>
<td>=C4+273.15</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>T3K =</td>
<td>=C5+273.15</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>C3 =</td>
<td>=C22*10000000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>C2 =</td>
<td>=C23*1000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>A1 =</td>
<td>=LN(F3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>A2 =</td>
<td>=LN(F4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>A3 =</td>
<td>=LN(F5)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Z =</td>
<td>=C11-C12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Y =</td>
<td>=C11-C13</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>X =</td>
<td>=1/C7 - 1/C8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>W =</td>
<td>=1/C7 - 1/C9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>V =</td>
<td>=C11^3 - C12^3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>U =</td>
<td>=C11^3 - C13^3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>C3a =</td>
<td>=(C17-C15<em>C18/C16)/(C19-C15</em>C20/C16)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>C2a =</td>
<td>=(C17-C22*C19)/C15</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>C1a =</td>
<td>=1/C7-C22<em>C11^3-C23</em>C11</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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.

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.

The Steinhart-Hart Equation

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

\[
\frac{1}{T} = C_1 + C_2 \ln(R) + C_3 \ln(R)^3
\]

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.

\[
\frac{1}{T} = C_1' + C_2' \ln(R)
\]

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 Downloads section of our website.

App Note 1: Controlling Temperatures of Diode Lasers and Detectors Thermoelectrically

App Note 2: Selecting and Using Thermistors for Temperature Control

App Note 3: Protecting Your Laser Diode

App Note 4: Thermistor Calibration and the Steinhart-Hart Equation

App Note 5: An Overview of Laser Diode Characteristics

App Note 6: Choosing the Right Laser Diode Mount for Your Application

App Note 7: Mode Hopping in Semiconductor Lasers

App Note 8: Optimize Testing for Threshold Current Calculation Repeatability

App Note 9: Pulsing a Laser Diode

App Note 10: The Differences between Threshold Current Calculation Methods

App Note 11: Testing Bond Quality by Measuring Thermal Resistance of Laser Diodes

App Note 12: Optimizing TEC Drive Current

App Note 13: Ad590 and Lm335 Sensor Calibration

App Note 14: Basic Test Methods for Passive Fiber Optic Components

App Note 15: Typical Output Drift of a Ldx-3412 Loc-Cost Precision Current Source

App Note 16: Typical Output Noise of a Ldx-3412 Precision Current Source

App Note 17: Typical Output Stability of the Ldt-5948

App Note 18: Typical Pulse Overshoot of the Ldp-3840/03 Precision Pulse Current Source


App Note 20: PID Control Loops in Thermoelectric Temperature Controllers

App Note 21: High Performance Temperature Control in Laser Diode Test Applications

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.

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 Temperature Controllers, or any other temperature controller which uses the Steinhart-Hart equation. The second form of the equation is simpler, and is used when only the first two Steinhart-Hart constants are used.

The Steinhart-Hart Equation

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

\[
\frac{1}{T} = C_1 + C_2 \ln(R) + C_3 \ln(R)^3
\]

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.

\[
\frac{1}{T} = C_1' + C_2' \ln(R)
\]

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 Downloads section of our website.

1 Three-Term Steinhart-Hart equation is also used in ILX Lightwave Model 39xx and 37xx Laser Diode Controllers.
Thermistor Calibration and the Steinhart-Hart Equation

APPLICATION NOTE