

# Production Testing of Thermistors Using the Model 2400 SourceMeter® Instrument

## Introduction

Thermistors are devices that exhibit a change in resistance with a change in temperature. The resistance of an NTC (negative temperature coefficient) thermistor decreases with an increase in temperature, whereas the resistance of a PTC (positive temperature coefficient) thermistor increases with an increase in temperature. Thermistors have many applications, including their use as temperature sensors, resettable fuses, power indicators, and current limiters.

Due to the wide variety of applications for thermistors, the specific production tests performed on these devices often depend on the application. One common production test, regardless of the application, is resistance versus temperature. The range of resistance of a thermistor may vary from  $<1\Omega$  to as high as  $1M\Omega$ . In most cases, however, the resistance is in the kilo-ohm range. While digital multimeters are often used to measure the resistance, these instruments do not usually allow programming the magnitude and duration of the test current. To keep the test current low when using a DMM, the resistance measurement must often be made on a higher range, which decreases sensitivity. However, the Model 2400 SourceMeter instrument measures a wide range of resistance and has an adjustable test current. This instrument measures resistance directly by using a separate current source and voltmeter. Even though it combines both a source and measuring instrument in one unit, it is the same size as a half-rack DMM and is just as easy to use.

This application note describes how to configure a thermistor production test system using the Model 2400 SourceMeter instrument. A short program that's included configures the instrument to output a single short current pulse and measure the resistance. Another program provided measures the resistance of an external temperature device and then calculates the temperature. In some production applications, the temperature reference and the thermistors need to be switched to only one SourceMeter instrument. For these cases, a test configuration that includes programmable switching instruments is provided.

## Test Description

The DC resistance value of a thermistor is measured at one or more specific temperatures, typically  $25^{\circ}\text{C}$ . To get accurate measurements, the test method must ensure self-heating of the thermistor is minimized. This can be done by using the lowest possible DC or pulsed test current. Testing the thermistors in an oil bath also reduces heating effects and ensures temperature stability. In some cases, however, the thermistors may be tested in air, in which case, lower current or pulsed current is used. In either case, the oil or air temperatures are typically measured because measuring and compensating for the temperature is usually easier than trying to control it. A reference thermistor, which has a similar composition to the thermistors being tested, is often used to make the temperature compensation measurement. Once the temperature is known, the control software can correct for the actual resistance measurement of the thermistor. The resistance value is compared to a standard value, then the thermistor is either sorted with an automatic handling machine and placed in the proper bin or reground to tolerance.

## Test Procedures

### Using the Model 2400 to Measure the Resistance of a Thermistor

Depending on the magnitude of resistance being measured, either a two-wire or four-wire method is used. The 4-wire method prevents any lead resistance from being added into the measurement. For measurements in the kilo-ohm ranges, a two-wire approach is usually sufficient. **Figure 1** illustrates making a two-wire connection from the SourceMeter to a thermistor.

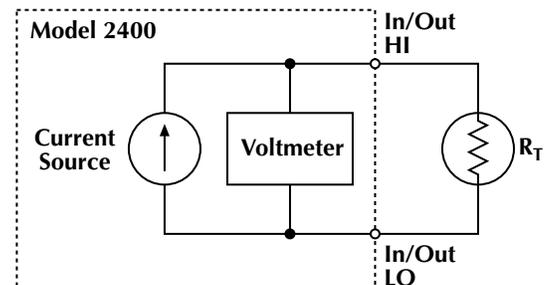


Figure 1. Using the Model 2400 to measure resistance of a thermistor

The lowest possible test current should be used to avoid thermistor self-heating. This is especially true for testing in air and for NTC thermistors, which are very sensitive to temperature changes. The SourceMeter instrument allows programming both the magnitude and duration of the test current. The magnitude of the test current can be programmed from  $\pm 50\mu\text{A}$  to  $\pm 1\text{A}$ . The instrument can generate pulses as short as  $\approx 2\text{ms}$ , while still ensuring an accurate measurement.

To meet the time limitation when outputting pulses in the millisecond range, the SourceMeter instrument must be pro-

grammed to run as fast as possible, which involves disabling features of the instrument that slow it down, such as autoranging, auto zeroing, the front panel display, and filters. The programmable trigger delay is set to 0 seconds. The source delay time controls the duration of the pulse.

The program listed below was developed to output  $10\mu\text{A}$  for 5ms into a thermistor with a resistance of  $10\text{k}\Omega$ . One resistance measurement is taken and displayed on the screen of the computer.

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```
' Program Name is 2400res.bas.
'$INCLUDE: 'ieeeqb.bi'
' This program uses Microsoft QuickBasic 4.5 and the KPC-488.2AT IEEE
' Interface Card

CALL initialize(21, 0)

CALL transmit("UNT UNL MTA LISTEN 24 SDC UNL UNT", gpib.status%)
CALL send(24, "*RST", gpib.status%)

DATA$ = SPACE$(800)

REM*****global paramters
CALL send(24, ":SYST:AZERO 0", gpib.status%)           'auto zero off
CALL send(24, ":SYST:RSEN 0", gpib.status%)           'local sense, 2-wire
CALL send(24, ":DISP:ENABLE OFF", gpib.status%)       'turn display off
CALL send(24, ":FORM:ELEM RES", gpib.status%)         'resistance reading only

REM*****set measure/compliance
CALL send(24, ":SENS:FUNC:OFF:ALL", gpib.status%)     'turn all functions off
CALL send(24, ":SENS:FUNC 'RES'", gpib.status%)       'turn on resistance function
CALL send(24, ":SENS:RES:MODE MAN", gpib.status%)     'manual resistance mode
CALL send(24, ":VOLT:RANG 2;NPLC 0.01", gpib.status%) '2 volt range
CALL send(24, ":VOLT:PROT 20", gpib.status%)          '20 volt compliance

REM*****set source
CALL send(24, ":SOURCE:FUNC:MODE CURR", gpib.status%) 'source current
CALL send(24, ":SOURCE:CLEAR:AUTO ON", gpib.status%) 'source clear auto
CALL send(24, ":SOURCE:CURR:RANG 100E-6", gpib.status%)
CALL send(24, ":SOURCE:CURR 10E-6", gpib.status%)
CALL send(24, ":SOURCE:CURR:MODE FIXED", gpib.status%)
CALL send(24, ":SOURCE:DELAY .004", gpib.status%)     '4ms delay time

REM*****set output to ZERO mode
CALL send(24, ":OUTPUT:SMODE ZERO", gpib.status%)

REM*****set trigger
CALL send(24, "ARM:COUNT 1", gpib.status%)
CALL send(24, "TRIG:COUN 1", gpib.status%)            'output 1 pulse
CALL send(24, "TRIG:SOURCE IMM", gpib.status%)
CALL send(24, "TRIG:DELAY 0", gpib.status%)          'no delay before pulse

REM*****take reading
CALL send(24, ":READ?", gpib.status%)
CALL enter(DATA$, length$, 24, gpib.status%)
PRINT DATA$

REM*****turn output OFF
CALL send(24, ":SOURCE:CLEAR:AUTO OFF", gpib.status%)
CALL send(24, ":OUTP OFF", gpib.status%)             'turn off source

END
```

The duration of the test current is controlled using the :SOURCE:DELAY command. In the program listing, note that the source delay was programmed for 4ms, even though the actual pulse is about 5ms in length. Depending on the setup of the 2400, there is roughly 1ms of overhead time when both sourcing a current and taking a voltage measurement. A discussion for calculating the source-delay-measure timing cycle can be found in the Model 2400 User's Manual.

## Using the Model 2400 to Measure Temperature

It's also necessary to measure the temperature of the air or oil in which the thermistors are tested. This temperature measurement is often made with a thermistor that has a similar composition to the thermistors being tested. This similarity is important in order to ensure that the reference thermistor and the thermistors under test will have the same temperature time constant. However, in some cases, a more accurate temperature sensor, such as an RTD, may be used. The Model 2400 has a dual-channel input

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```
'Program name is 2400temp.bas
'$INCLUDE: 'ieeeqb.bi'
'This program uses Microsoft Quickbasic 4.5 and the KPC-488.2AT IEEE Interface Card
CALL initialize(21, 0)

CALL transmit("UNT UNL MTA LISTEN 24 SDC UNL UNT", status%)
CALL send(24, "*RST", status%)

REM*****set function:
CALL send(24, ":SENS:FUNC 'RES'", status%)           'measure resistance
CALL send(24, ":RES:MODE MAN", status%)           'manual mode
CALL send(24, ":RES:RANG 10E3;NPLC 1.0", status%)

REM*****set source:
CALL send(24, ":SOURCE:FUNC:MODE CURR", status%)
CALL send(24, ":SOURCE:CURR:RANG 10E-6", status%)
CALL send(24, ":SOURCE:CURR 1E-6", status%)
CALL send(24, ":SOURCE:CURR:MODE FIXED", status%)
CALL send(24, ":SOURCE:DELAY 0", status%)

REM*****global paramters
CALL send(24, ":SYST:AZERO 0", status%)           'auto zero off
CALL send(24, ":SYST:RSEN 0", status%)           'remote sense off

REM*****set up math expression for temperature conversion
CALL send(24, ":CALC:MATH:DEL:ALL", status%)
CALL send(24, ":CALC:MATH:EXPR:NAME 'TEMP'", status%)
CALL send(24, ":CALC:MATH:EXPR ((res - 4593.39)/(-32.402))", status%)
CALL send(24, ":CALC:MATH:NAME 'TEMP'", status%)
CALL send(24, ":CALC:MATH:UNITS 'C'", status%)
CALL send(24, ":CALC:STATE ON", status%)

REM*****set trigger:
CALL send(24, "ARM:COUNT 1", status%)
CALL send(24, "TRIG:COUNT 1", status%)           'trigger once
CALL send(24, "TRIG:SOURCE IMM", status%)
CALL send(24, "TRIG:DELAY 0", status%)

CALL send(24, "OUTPUT ON", status%)           'turn output ON

REM*****get temperature reading:
CALL send(24, ":INIT", status%)
CALL send(24, ":CALC:DATA?", status%)
A$ = SPACE$(80)
CALL enter(A$, length%, 24, status%)
PRINT USING "##.##C"; VAL(LEFT$(A$, length%))

CALL send(24, ":OUTP OFF", status%)           'turn output OFF

END
```

(programmable front/rear switching), so the reference temperature can be measured at the rear terminals and the resistance of the unknown thermistor can be measured at the front terminals. In this way, it's possible to take a temperature compensation measurement automatically without the need for a second instrument. If timing is critical, keep in mind that the sum of both the switching and settling times can be in the tens of milliseconds.

When the 2400 is switched from one input to the other, the output is automatically turned off, ensuring cold switching. The relay used to switch between front and rear inputs (Keithley Part No. RL-163) has a mechanical life expectancy of  $10^8$  operations. If the contact life of the RL-163 relay is not long enough, then a separate scanner system can be used with the SourceMeter instrument to switch the input, either to the thermistor under test or the temperature sensing element. This is discussed further in the section titled, "Switching Multiple Thermistors."

To illustrate measuring temperature using the SourceMeter instrument, a thermi-linear component consisting of both a thermistor composite and a resistor set can be used as a temperature sensing element. This particular device linearly relates its resistance to a temperature over a specific temperature range. The program for the SourceMeter instrument on the previous page automatically converts the resistance of the device (as expressed in ohms) to a temperature measurement (in degrees Celsius) by using the instrument's built-in math capability.

## Example Programs

To obtain a digital file of either of the Example Programs listed, access Keithley's World Wide Web site.

## Switching Multiple Thermistors

Some applications require switching both the temperature sensor and the thermistors to a single SourceMeter instrument. **Figure 2** shows the input/output of the instrument being switched to either one reference thermistor or to any of the 39 thermistors of unknown value.

In this switching example, a two-wire technique is used. The scanning is accomplished using one Model 7001 Scanner Mainframe and one Model 7011 40-Channel Switch Card. To measure the reference thermistor, Channel 1 is closed and the resistance is measured. Open Channel 1, then close Channel 2 to measure the resistance of the first thermistor,  $R_T \#1$ . This process is repeated for all the thermistors.

**Figure 3** shows a scanner system using a four-wire technique. For scanning thermistors with lower resistances ( $<100\Omega$ ), a four-wire technique is used to prevent the lead resistance from being added into the measurement. Note that two 2-pole relays are used to connect each thermistor to the instrument.

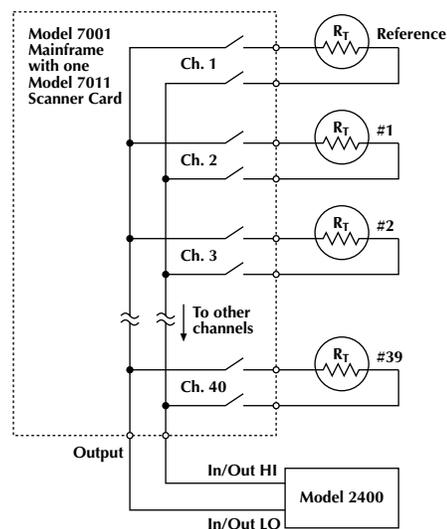


Figure 2. Switching multiple thermistors to Model 2400 using 2-wire method

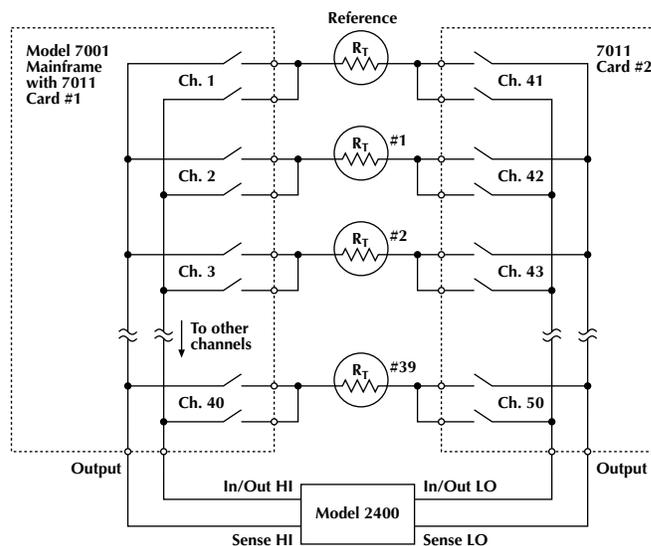


Figure 3. Switching multiple thermistors to Model 2400 using 4-wire method

To measure the resistance of the reference thermistor, close Channels 1 and 41, apply the specified current, and measure the resistance. Open Channels 1 and 41, then close Channels 2 and 42 to begin testing the first thermistor,  $R_T \#1$ . Repeat this procedure for all the thermistors.

The actual number of thermistors may vary, depending on the system. Switching systems can be configured for any number of thermistors and for various electrical specifications. When used with the appropriate scanner cards, each Keithley Model 7002 Scanner Mainframe can switch up to 400 thermistors using a two-pole method or up to 200 thermistors using a four-pole method. Multiple mainframes may be used for larger systems.

# Test System Configuration

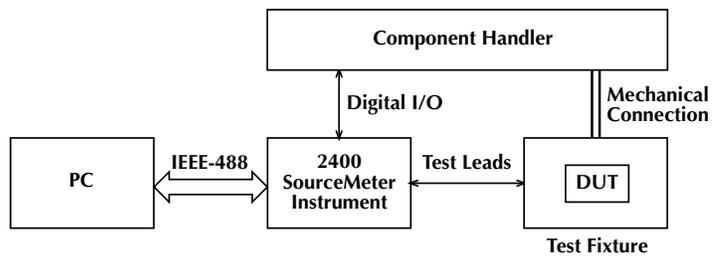


Figure 4. Thermistor production test system

A block diagram of a Model 2400-based production test system for thermistors is shown in **Figure 4**. The thermistor is placed in a temperature-controlled test fixture with connections to the instrument. When triggered, the instrument outputs a current and measures the voltage drop across the thermistor, then automatically calculates the resistance. The instrument compares this resistance measurement to a pre-specified limit, then sends a signal via the digital I/O port to the component handler, which assigns the thermistor to the appropriate bin.

As **Figure 4** illustrates, the Model 2400 has both an IEEE-488 output and a digital I/O port. The digital I/O port can send signals directly to and receive signals from an automatic handler machine. Up to five limit values (one compliance, two high and two low values) can be programmed into the instrument. The limit values will determine the Pass/Fail and High/Low status of subsequent measurements. Once a measurement is made and the tolerance is determined, the digital I/O port sends a TTL level signal to the automatic handling machine to route the thermistor to the appropriate bin. The SourceMeter instrument has four digital output lines that can be used to set up bit patterns to produce TTL level signals.

## Typical Sources of Error

### Lead Resistance

A common source of resistance measurement error is the series resistance of the test leads running from the SourceMeter instrument to the thermistor. This series resistance is added into the measurement when making a two-wire connection (See **Figure 5**). The effect of lead resistance is particularly detrimental when long connecting cables and high currents are used, because the voltage drop across the lead resistance becomes significant compared to the measured voltage.

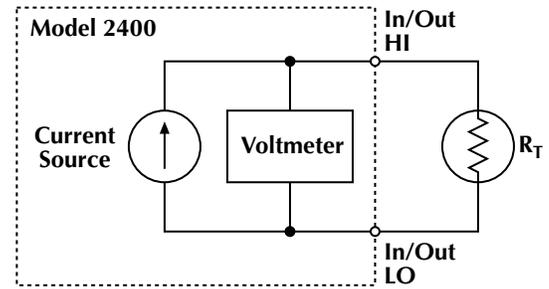


Figure 5. Two-wire technique

To eliminate this problem, use the four-wire remote sensing method rather than the two-wire technique. With the four-wire method (**Figure 6**), a current is forced through the thermistor using one pair of leads and the voltage across the thermistor is measured through a second set of leads. As a result, only the voltage drop across the thermistor is measured.

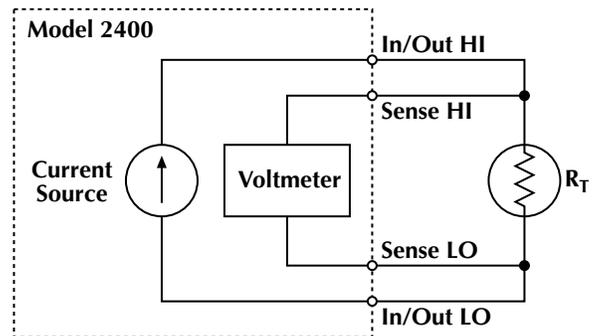


Figure 6. Four-wire technique

### Thermoelectric EMFs

Thermoelectric EMFs may cause measurement problems, especially when testing the thermistors in air. One way to avoid these thermally generated voltages is to use the instrument's offset compensated ohms mode. This mode works by first taking a measurement with the source current on, then taking another with the source current off. The second measurement is then subtracted from the first measurement, canceling out any voltage offsets. The corrected measurement is automatically determined by using the two point measurement method and is expressed mathematically as:

$$\text{Offset Compensated Ohms} = \frac{V_2 - V_1}{I_2 - I_1}$$

where:  $I_1$  is the source current set to a specified level.

$I_2$  is the source current set to zero (it could be set to any level).

$V_1$  is the voltage measured at  $I_1$ .

$V_2$  is the voltage measured at  $I_2$ .

This feature can be enabled from the front panel by first placing the instrument in the source current mode, then pressing CONFIG and then FCTN. Selecting OFF-COMP-OHMS will bring up the menu, making it possible to select the two desired source currents (one of which should be zero). If programming the instrument via the bus, the Offset Compensated Ohms function is configured using the CALC1 Subsystem.

## Alternative Solutions

If controlling the duration and magnitude of the test current is unimportant, then a DMM can be used to make these measurements. The Models 2001 and 2002 DMMs offer two high and two low limit values, which can be tied to the status of any of four digital outputs. When used with a component handler, this allows these DMMs to be used to sort or grade thermistors. When measuring thermistors with values less than 100Ω, the Model 2010 Low-Noise Multimeter may be used because it offers a low power measurement mode on the 10Ω and 100Ω ranges. All Keithley 2000 Series DMMs (2000, 2001, 2002 and 2010) offer two and four-wire ohms measurement functions and optional plug-in scanner cards for switching multiple thermistors.

If the thermistors are in the milliohm range, the Model 2750 Multimeter/Switch System provides resistance measurements with 10μΩ resolution and includes a built-in switch mainframe for multi-channel operation.

## Test System Safety

Many electrical test systems or instruments are capable of measuring or sourcing hazardous voltage and power levels. It is also possible, under single fault conditions (e.g., a programming error or an instrument failure), to output hazardous levels even when the system indicates no hazard is present.

These high voltage and power levels make it essential to protect operators from any of these hazards at all times. Protection methods include:

- Design test fixtures to prevent operator contact with any hazardous circuit.
- Make sure the device under test is fully enclosed to protect the operator from any flying debris.
- Double insulate all electrical connections that an operator could touch. Double insulation ensures the operator is still protected, even if one insulation layer fails.
- Use high reliability, fail-safe interlock switches to disconnect power sources when a test fixture cover is opened.
- Where possible, use automated handlers so operators do not require access to the inside of the test fixture or have a need to open guards.
- Provide proper training to all users of the system so they understand all potential hazards and know how to protect themselves from injury.

It is the responsibility of the test system designers, integrators, and installers to make sure operator and maintenance personnel protection is in place and effective.

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