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APPLICATION NOTE 817

Using Thermistors in Temperature Tracking Power Supplies

Abstract: This article provides a simple, intuitive tutorial on negative temperature coefficient (NTC) thermistors and how to make basic use of them in general, and specifically in power supply regulators. A good example application is their use to cancel temperature effects on LCD display contrast. Two simple NTC thermistor linearizing techniques are shown, and regulator design procedures and examples demonstrate their application. Each example includes a schematic and compares the measured output voltage versus temperature to the target.

Power supply regulators, by definition, are designed to provide an output voltage that is stable despite variations in line (input voltage), load, and temperature. While for most applications, a stable output is the goal, there are some applications where it is advantageous to provide a temperature-dependent output voltage. This article provides a tutorial, design procedure, and circuit examples utilizing negative temperature coefficient (NTC) thermistors in temperature tracking power supplies.

By far the most common application for temperature-dependent regulation is in LCD bias supplies, where the contrast of the display will vary with ambient temperature. By applying a temperature-dependent bias voltage, the LCD's temperature effects can be automatically canceled to maintain constant contrast over a wide temperature range. The examples in this article are targeted toward LCD bias solutions; however, the tutorial and design equations are simple and may be easily applied in a variety of circuits.

Why NTC Thermistor?

The NTC thermistor provides a near optimum solution for temperature-dependent regulation. It is low-cost, readily available through a variety of suppliers (Murata, Panasonic, etc.), and available in small surface-mount packaging from 0402 size through 1206 size. Furthermore, with only a basic understanding, the NTC thermistor is straightforward to apply to your circuit.

NTC Characteristic

As the name implies, the thermistor is just a temperature-dependent resistor. Unfortunately, the dependence is very non-linear (see **Figure 1**) and, by itself, would not be very helpful for most applications. Fortunately, there are two easy techniques to linearize a thermistor's behavior.

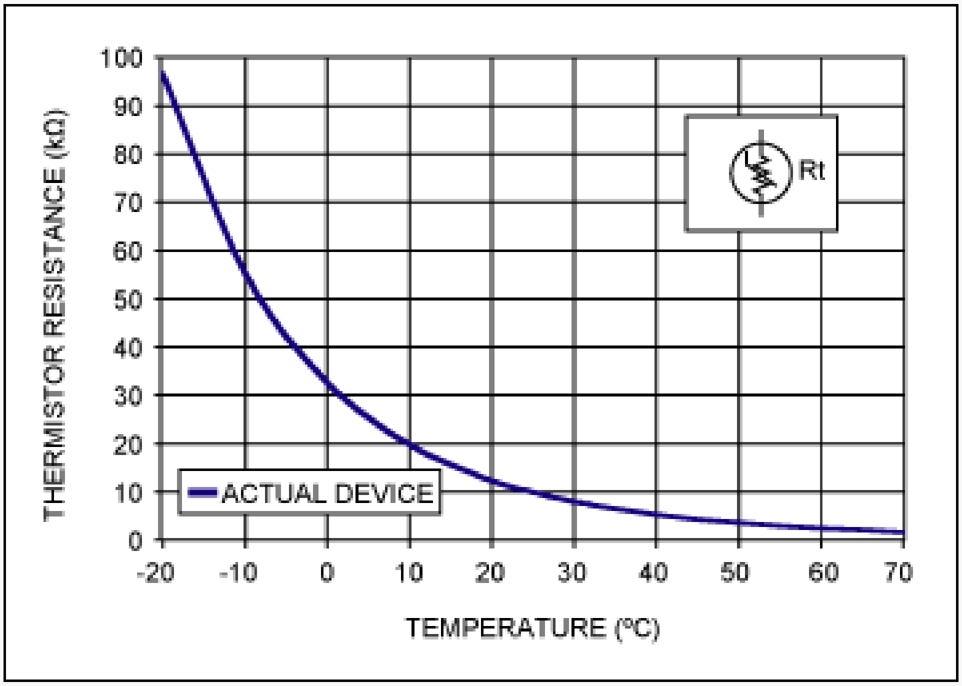

Figure 1. NTC thermistor resistance varies extremely non-linearly with temperature. This makes it difficult to utilize the thermistor without applying it in a linearizing network. (R_{25C} = 10kΩ, β = 3965K).

The standard formula for NTC thermistor resistance as a function of temperature is given by:

$$R_T = R_{25C} e^{\left\{\beta\left[\left(\frac{1}{T + 273}\right) - \left(\frac{1}{298}\right)\right]\right\}}$$

where R_{25C} is the thermistor's nominal resistance at room temperature, β (beta) is the thermistor's material constant in K, and T is the thermistor's actual temperature in Celsius.

This equation is a very close approximation of the actual temperature characteristic, as can be seen in **Figure 2**. Note the use of log-scale for the Y-axis.

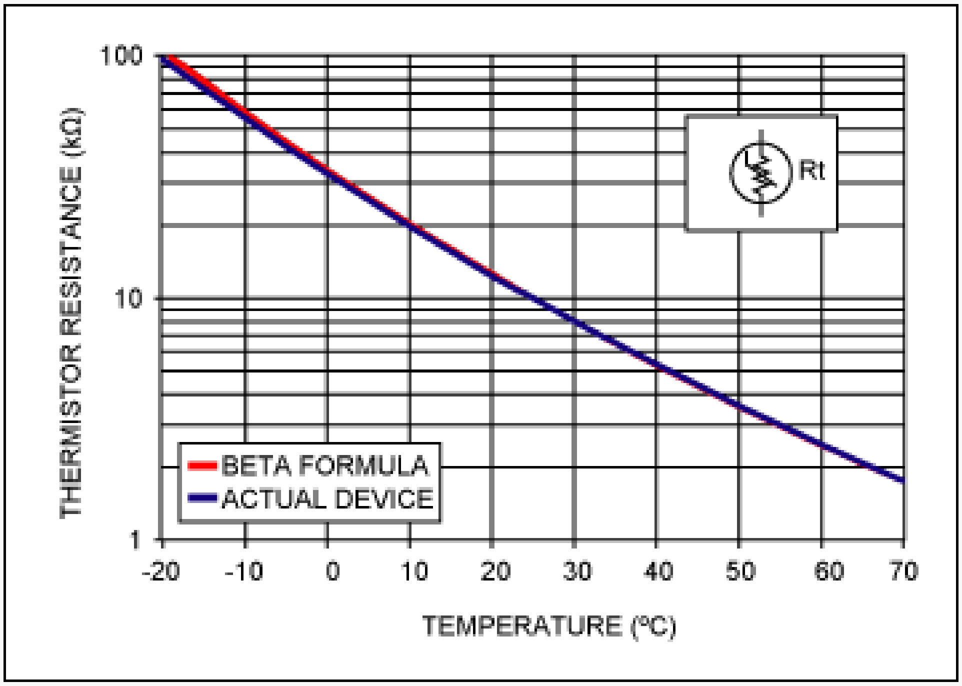

Figure 2. Thermistor resistance versus temperature is almost linear on a semi-log graph. The actual measured thermistor resistance matches the Beta formula to a fairly high degree of precision. (R_{25C} = 10kΩ, β = 3965K).

R_{25C} and β are usually published in the manufacturer's data sheet. Typical values of R_{25C} range from 22Ω to 500kΩ. Typical values of β are from 2500 to 5000K.

As seen in **Figure 3**, higher values of β provide increased temperature dependence and are useful when higher resolution is required over a narrower temperature range. Conversely, lower values of β offer less-sloped temperature dependence and are more desirable when operating over a wider temperature range.

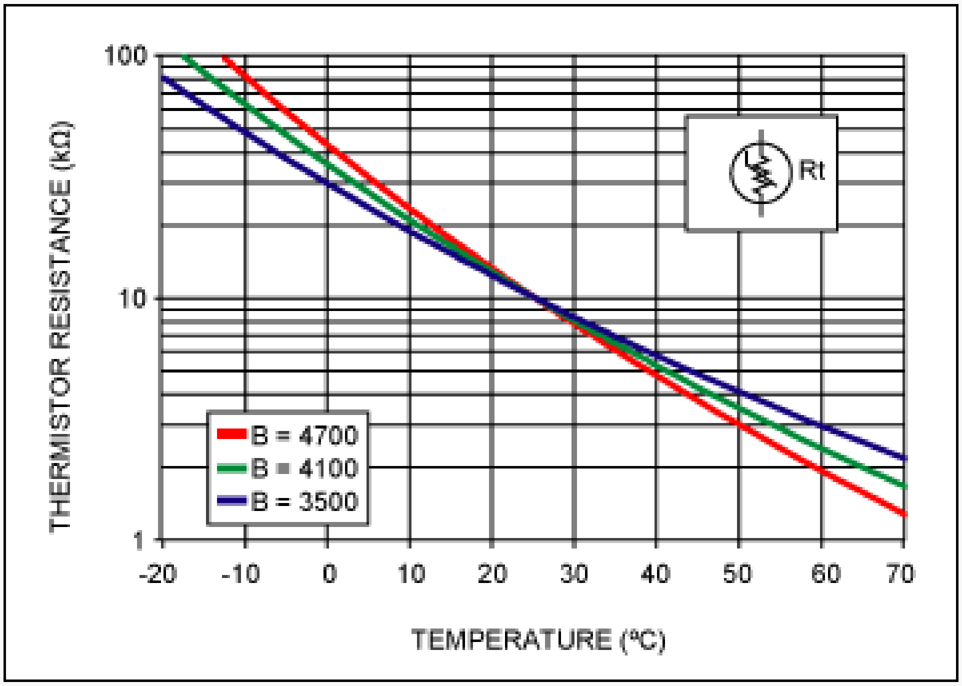

Figure 3. An NTC thermistor is specified by its room temperature resistance (R_{25C}) and its material constant β (Beta). Beta is a measure of the slope of temperature dependence. (R_{25C} = 10kΩ, β in K).

Self Heating
A thermistor is a resistor, and, just like any resistor, it produces heat energy whenever current passes through it. The heat energy causes the NTC thermistor's resistance to reduce which then indicates a temperature slightly above ambient temperature. In the manufacturer's data sheets and application notes, there are usually tables, formulae, and text detailing this phenomenon. However, these may be largely ignored if the current through the thermistor is kept relatively low such that self heating error is small compared to the required measurement accuracy, as in the design examples of this article.

Linearizing

An NTC thermistor is most easily utilized when applied in a linearizing circuit. There are two simple techniques for linearization: resistance mode and voltage mode.

Resistance Mode

In resistance mode linearization, a normal resistor is placed in parallel with the NTC thermistor, which has the effect of linearizing the combined circuit's resistance. If the resistor's value is chosen to be equal to the thermistor's resistance at room temperature (R_{25C}), then the region of relatively linear resistance will be symmetrical around room temperature (as seen in **Figure 4**).

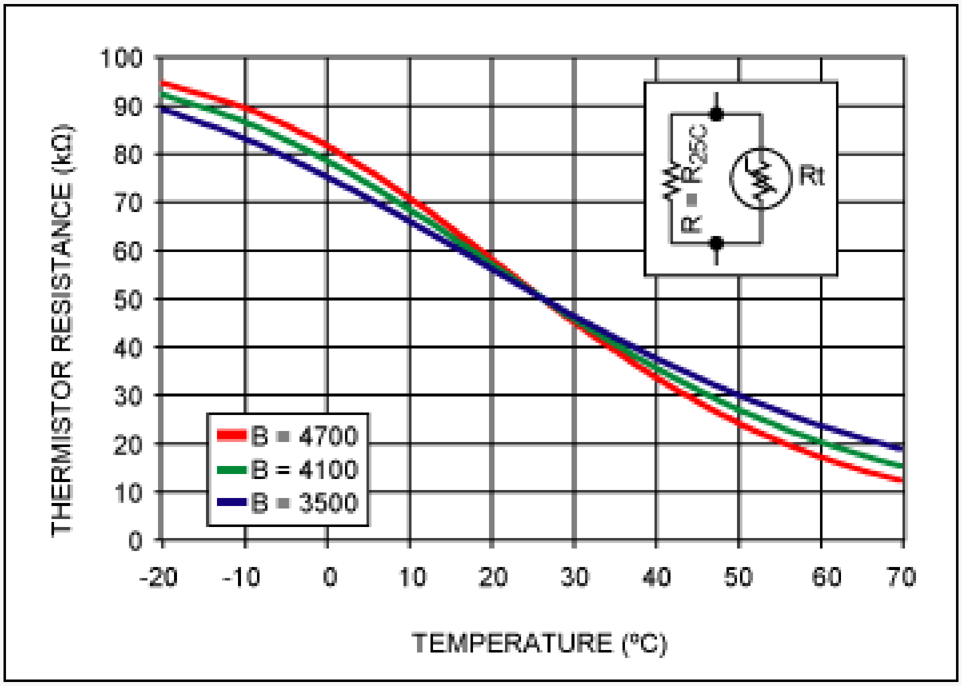

Figure 4. Resistance mode linearization is easily accomplished by placing a normal resistor in parallel with the thermistor. If the normal resistor has the same value as R_{25C}, then the region of nearly linear resistance versus temperature will be symmetrical around +25°C. (R_{25C} = 10kΩ, β in K).

Note that lower values of β produce linear results over a wider temperature range, while higher values of β produce increased sensitivity over a narrower temperature range. The equivalent resistance varies from roughly 90% of R_{25C} at cold (-20°C) to 50% of R_{25C} at room temperature (+25°C) to roughly 15% of R_{25C} at hot (+70°C).

Voltage Mode

In voltage mode linearization, the NTC thermistor is connected in series with a normal resistor to form a voltage-divider circuit. The divider circuit is biased with a regulated supply or a voltage reference, V_{REF}. This has the effect of producing an output voltage that is linear over temperature. If the resistor's value is chosen to be equal to the thermistor's resistance at room temperature (R_{25C}), then the region of linear voltage will be symmetrical around room temperature (as seen in **Figure 5**).

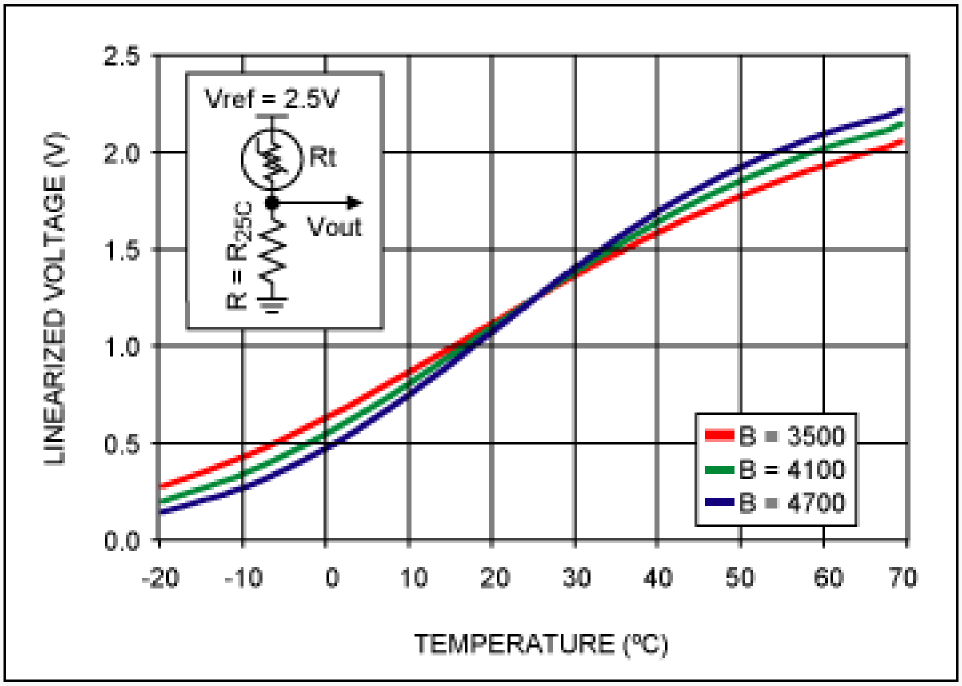

Figure 5. Voltage mode linearization is easily accomplished be placing a normal resistor in series with the thermistor and biasing the resulting resistive voltage divider with a constant-voltage source. If the normal resistor has the same value as R_{25C} , then the region of nearly linear output voltage versus temperature will be symmetrical around +25°C. (R_{25C} = 10kΩ, β in K).

Again, note that lower values of β produce linear results over a wider temperature range, while higher values of β produce increased sensitivity over a narrower temperature range. The output voltage varies from near zero volts at cold (-20°C) to $V_{REF}/2$ at room (+25°C) to near V_{REF} at hot (+70°C).

Design Procedure

To create a regulated output voltage that varies linearly with temperature, the linearized thermistor circuit is applied to the regulator's feedback network.

Resistance Mode

The resistance mode circuit is the simplest solution for creating a temperature-dependent regulated output voltage because regulator feedback networks are almost always comprised of a resistive voltage divider. As seen in **Figure 6**, the linearized thermistor circuit is placed in series with one of the feedback resistors. In this case, the linearized circuit is placed in series with the top resistor of the feedback divider network to create a negative-temperature-coefficient output voltage at Vout, as generally required in LCD bias solutions. (To create a positive-temperature-coefficient output, the linearizing circuit would be placed in series with the bottom resistor, R2, of the feedback divider.)

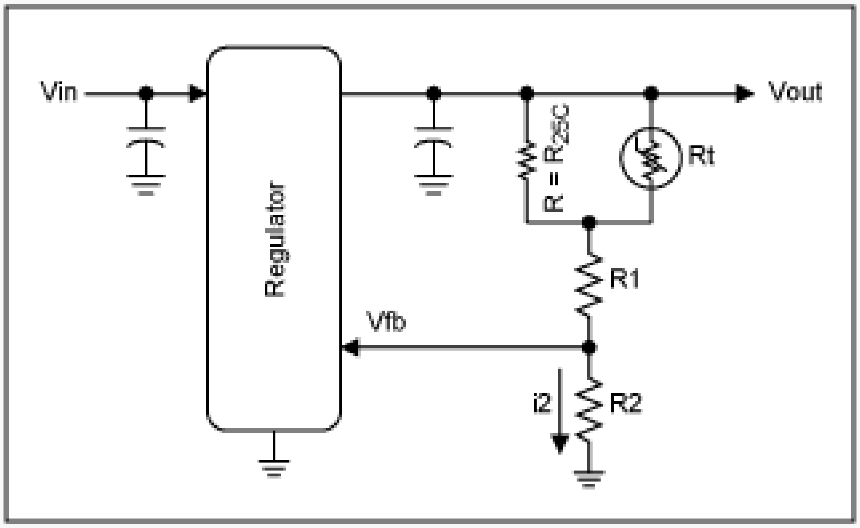

Figure 6. The resistance mode linearized thermistor circuit is applied to the feedback network of a voltage regulator. It essentially replaces a portion of one of the normal feedback resistors - that portion being dependent upon the required temperature coefficient of the regulator's output.

The design procedure is relatively simple. First find the appropriate feedback network bias current, i2, from the regulator's data sheet. It is usually in the 10s to 100s of µA range and there is some latitude in its exact value. Then calculate the NTC thermistor value as:

$$R_{25C} = -T_C\left(\frac{Vout_{25C}}{i2}\right)$$

where T_C is the negative temperature coefficient of Vout in %/°C. The value of i2 should be adjusted until R_{25C} becomes a readily available NTC thermistor value.

For a simplified design calculation, select R2 and R1 as:

$$R2 = \frac{Vfb}{i2}$$

$$R1 = R2\left(\frac{Vout_{25C}}{Vfb} - 1\right) - \frac{R_{25C}}{2}$$

where Vfb is the nominal feedback voltage as given in the regulator's data sheet.

For a more accurate design calculation, the final value of i2 will end up being slightly modified in order to match the thermistor's β to the desired T_C. Therefore, calculate the thermistor's resistance at 0°C and +50°C. The standard formula for NTC thermistor resistance as a function of temperature is given by:

$$R_{0C} = R_{25C}e^{\left\{\beta\left[\left(\frac{1}{273}\right) - \left(\frac{1}{298}\right)\right]\right\}}$$

$$R_{50C} = R_{25C}e^{\left\{\beta\left[\left(\frac{1}{323}\right) - \left(\frac{1}{298}\right)\right]\right\}}$$

Then calculate the linearized resistance at the two temperatures as:

$$RL_{0C} = \frac{1}{1 / R_{0C} + 1 / R_{25C}}$$

$$RL_{50C} = \frac{1}{1 / R_{50C} + 1 / R_{25C}}$$

Calculate the value of R2 and i2 as:

$$R2 = \frac{2 \cdot Vfb}{-T_C \cdot Vout_{25C}} (RL_{0C} - RL_{50C})$$

$$i2 = \frac{Vfb}{R2}$$

And lastly calculate the value of R1 as:

$$R1 = R2\left(\frac{Vout_{25C}}{Vfb} - 1\right) - \frac{R_{25C}}{2}$$

Resistance Mode Design Example

An LCD bias voltage is needed in a system running on a single-cell Li+ rechargeable battery. The desired bias voltage is Vout=20V at room temperature with T_C=-0.05%/°C. The MAX1605 regulator is selected for the task. The above design formulae are used to calculate the required components as follows:

Per the datasheet, i2 should be greater than 10uA for less than 1% output error; therefore, choose i2 to be about five times larger for less error:

$$i2 = 50\mu A$$

$$R_{25C} = 20k\Omega$$

An NTC thermistor is chosen with R_{25C}=20kΩ and β =3965K and linearized with a parallel 20kΩ resistor. The MAX1605 has a nominal feedback voltage of Vfb=1.25V. According to the simplified design formulae, R2 and R1 are then calculated as:

$$R2 = 25k\Omega$$

$$R1 = 365k\Omega$$

Per the more accurate design calculation, the thermistor's resistance at 0°C and +50°C will be:

$$R_{0C} = 6.76k\Omega$$

$$R_{50C} = 7.14k\Omega$$

The linearized resistances at 0°C and +50°C will be:

$$RL_{0C} = 15.4k\Omega$$
$$RL_{50C} = 5.26k\Omega$$

The values for R2, i2, and R1 are then calculated as:

$$R2 = 25.4k\Omega$$
$$i2 = 49.3\mu A$$
$$R1 = 371k\Omega$$

In this case, these more accurate values are not substantially different from those obtained using the simplified calculations. The final circuit can be seen in **Figure 7**.

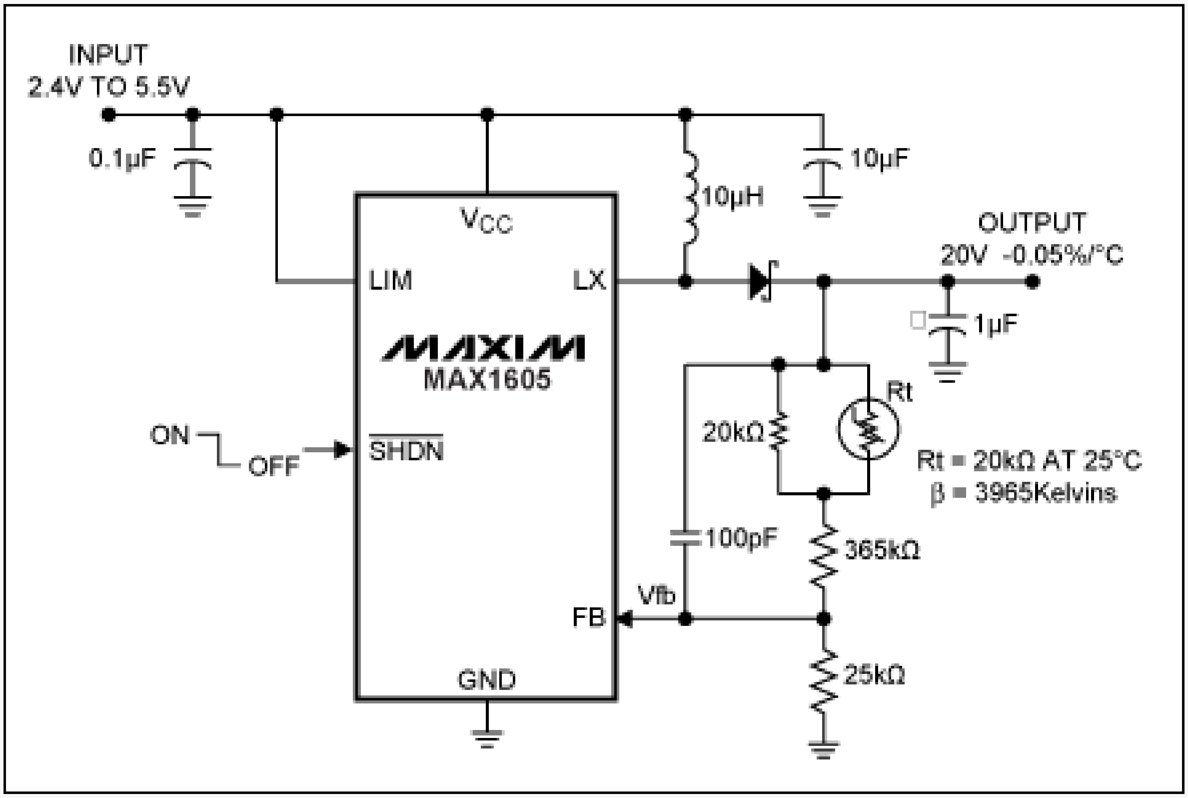

Figure 7. An NTC thermistor is used with the MAX1605 boost converter to realize the resistance mode design example as described in the text.

The output voltage of the circuit of Figure 7 exhibits nearly ideal temperature dependence, as can be seen in **Figure 8**.

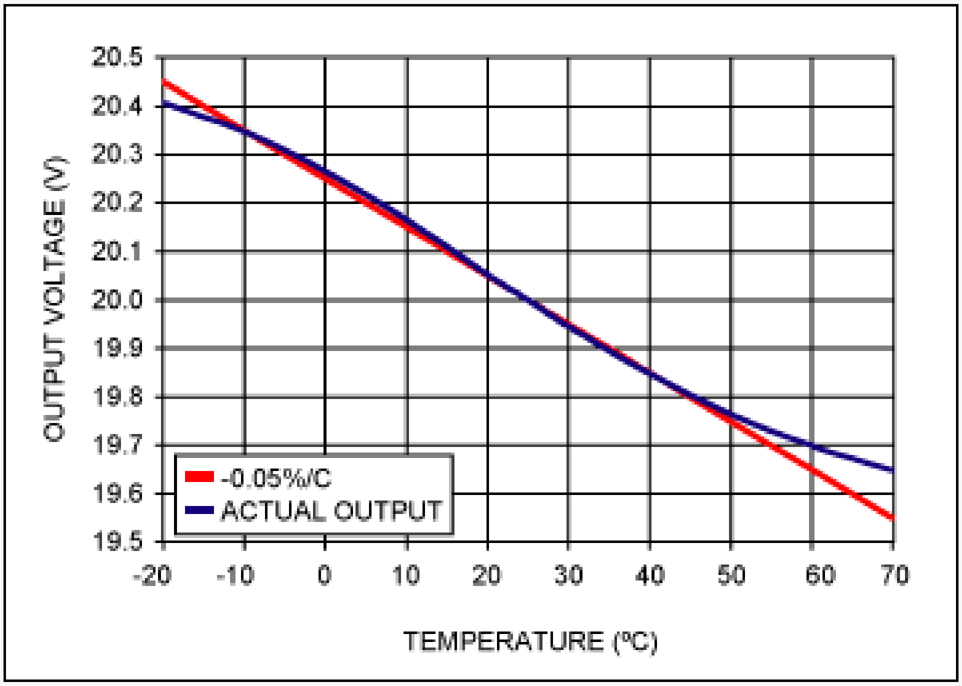

Figure 8. The actual temperature dependence of the circuit of Figure 7 is very close to the target temperature coefficient of -0.05%/°C over most of the extended consumer temperature range.

Voltage Mode

Although more complicated than the resistance mode circuit, the voltage mode circuit has some unique advantages. First, the voltage mode circuit provides a temperature dependent analog voltage that may be easily digitized with an analog-to-digital converter (ADC) to provide temperature information to the system's microprocessor. Additionally, the regulator's output voltage temperature coefficient may be easily adjusted by changing the value of only one resistor. This benefit allows for simple trial-and-error design in the laboratory and may also be very valuable for accommodating multi-sourced thermistors or LCD panels in production.

As seen in **Figure 9**, the linearized thermistor circuit is biased with a voltage reference to generate a temperature-dependent voltage, V_{TEMP}. Then, V_{TEMP} is summed into the feedback node through a resistor, R3, which sets the gain of the temperature dependence. So that V_{TEMP} does not need to be buffered, the nominal resistance of the thermistor should be kept much lower than R3. As connected in Figure 9, the regulator exhibits a negative-temperature-coefficient output voltage at Vout, as generally required in LCD bias solutions. (To create a positive-temperature-coefficient output, the position of R and Rt should be reversed.)

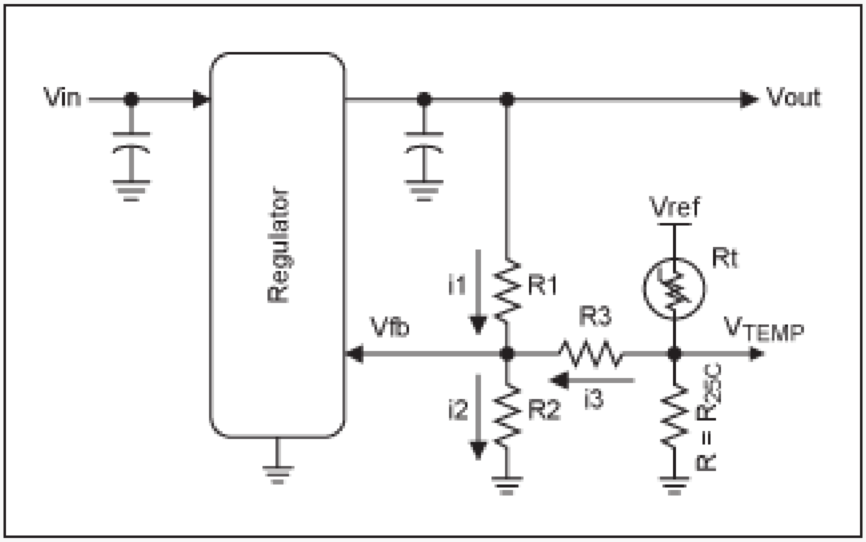

Figure 9. The voltage mode linearized thermistor circuit is applied to the feedback network of a voltage regulator. It essentially adds current i3 into the feedback node such that i1 = i2 + i3. If Vref is twice Vfb, then i3 is zero at 25C, R1 and R2 are calculated as normally described in the regulator's datasheet, and temperature dependence can be adjusted by simply scaling R3. Additionally, Vtemp may be acquired by the host system via an analog-to-digital converter.

Although not mandatory, the simplest implementation of Figure 9 is when Vref=2xVfb. (Conveniently, many regulators have Vfb=1.25V, many voltage references have Vref=2.5V, and many ADCs have input voltage range from 0 to 2.5V.) When Vref=2xVfb, V_{TEMP} will equal Vfb at +25°C and i3 will equal zero. This allows R1 and R2 to set the nominal output voltage at +25°C independent of R3 and the thermistor. Select R2 according to the recommendations in the regulator's data sheet. Then calculate R1 and i2 as:

$$R1 = R2\left(\frac{Vout_{25C}}{Vfb} - 1\right)$$

$$i2 = \frac{Vfb}{R2}$$

Then calculate the approximate value of R3 as:

$$R3 \cong \frac{2 \cdot Vfb \cdot R1}{Vout_{25C} \cdot T_C}$$

where T_C is the negative temperature coefficient of Vout in %/°C. (This value of R3 will suffice for a simplified design calculation and may be later adjusted through experimentation in the laboratory.) Then, to avoid the need for a buffer amplifier between V_{TEMP} and R3, choose a nominal thermistor value of:

$$R_{25C} \leq 0.05 \cdot R3$$

For a more accurate calculation, the final value of R3 will end up being slightly modified in order to match the thermistor's β to the desired T_C. To do this, first calculate the thermistor's resistance at 0°C and +50°C. The standard formula for NTC thermistor resistance as a function of temperature is given by:

$$R_{0C} = R_{25C} e^{\left\{\beta\left[\left(\frac{1}{273}\right) - \left(\frac{1}{298}\right)\right]\right\}}$$

$$R_{50C} = R_{25C} e^{\left\{\beta\left[\left(\frac{1}{323}\right) - \left(\frac{1}{298}\right)\right]\right\}}$$

Then calculate the linearized voltage, V_{TEMP}, at the two temperatures as:

$$V_{TEMP0C} = \frac{R_{25C}}{(R_{25C} + R_{0C})} \cdot Vref$$

$$V_{TEMP50C} = \frac{R_{25C}}{(R_{25C} + R_{50C})} \cdot Vref$$

The more accurate value of R3 is finally given as:

$$R3 = \frac{2 \cdot R1}{Vout_{25C} \cdot T_C} (V_{TEMP0C} - V_{TEMP50C})$$

Voltage Mode Design Example

An LCD bias voltage is needed in a system running on a Li+ battery. The desired bias voltage is Vout=20V at room temperature with T_C=-0.05%/°C. The MAX629 regulator is selected for the task because it has a reference voltage output that may be used to bias the thermistor linearizing network. The voltage mode design formulae are used to calculate the required components as follows:

Per the datasheet, R2 should be in the range of 10kΩ to 200kΩ and Vfb=1.25V; therefore:

$$R2 = 25k\Omega$$
$$R1 = 375k\Omega$$
$$i2 = 50\mu A$$

The approximate value of R3 will be:

$$R3 \cong 938k\Omega$$

The thermistor's nominal resistance should be kept less than 46.9kΩ. Therefore, an NTC thermistor is chosen with R_{25C}=20kΩ and β=3965K and linearized with a series 20kΩ resistor and Vref=2.5V bias.

Per the more accurate design calculation, the thermistor's resistance at 0°C and +50°C will be:

$$R_{0C} = 6.76k\Omega$$
$$R_{50C} = 7.14k\Omega$$

The linearized voltage at 0°C and +50°C will be:

$$V_{TEMP0C} = 0.571V$$
$$V_{TEMP50C} = 1.84V$$

The new value for R3 is then calculated to be:

$$R3 = 952k\Omega$$

In this case, the more accurate R3 value is not substantially different from the value obtained using the simplified calculations, and the nearest standard resistor value should be chosen.

Design Example when Vref ≠ 2xVfb

In the above voltage mode design example, if there isn't already a Vref=2.5V supply in the system, it may be cost prohibitive to add one. Fortunately, any regulated voltage will suffice. For this example, the REF pin of the MAX629 is utilized and Vref'=1.25V. Compared to the above example, V_{TEMP} will now vary over half as wide a range; therefore, R3 must be halved to R3'=475kΩ to maintain the same output voltage temperature coefficient of T_C=-0.05%/°C. Also, it is advisable to reduce the thermistor value and linearizing resistor value to $R=R_{25C}$=10kΩ. Furthermore, because V_{TEMP} is lower than Vfb at 25°C, i3 will be non-zero and the regulator's output voltage will be slightly higher than desired by:

$$\Delta Vout_{25C} = \left(\frac{R1}{2 \cdot R3'}\right) \cdot Vref' = 0.493V$$

To eliminate this, reduce R1 from 375kΩ to:

$$R1' = R1\left(\frac{Vout_{25C}}{Vfb} \cdot R2\right) = 365k\Omega$$

The final circuit can be seen in **Figure 10**.

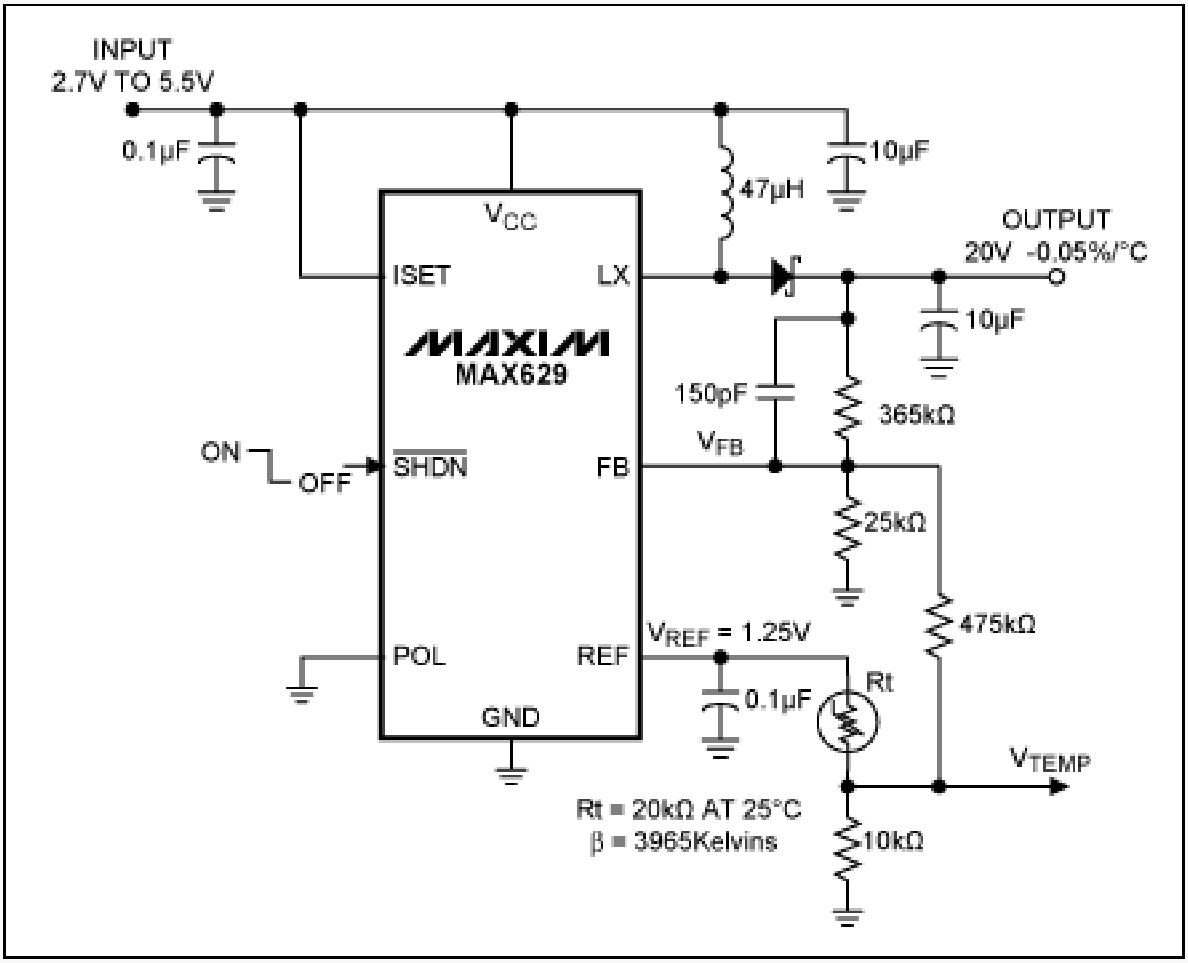

Figure 10. An NTC thermistor is used with the MAX629 boost converter to realize the voltage mode design example with Vref ≠2xVfb as described in the text. The MAX629 was chosen because its REF pin may be utilized to bias the thermistor linearizing circuit.

The output voltage of the circuit of Figure 10 exhibits nearly ideal temperature dependence, as seen in **Figure 11**.

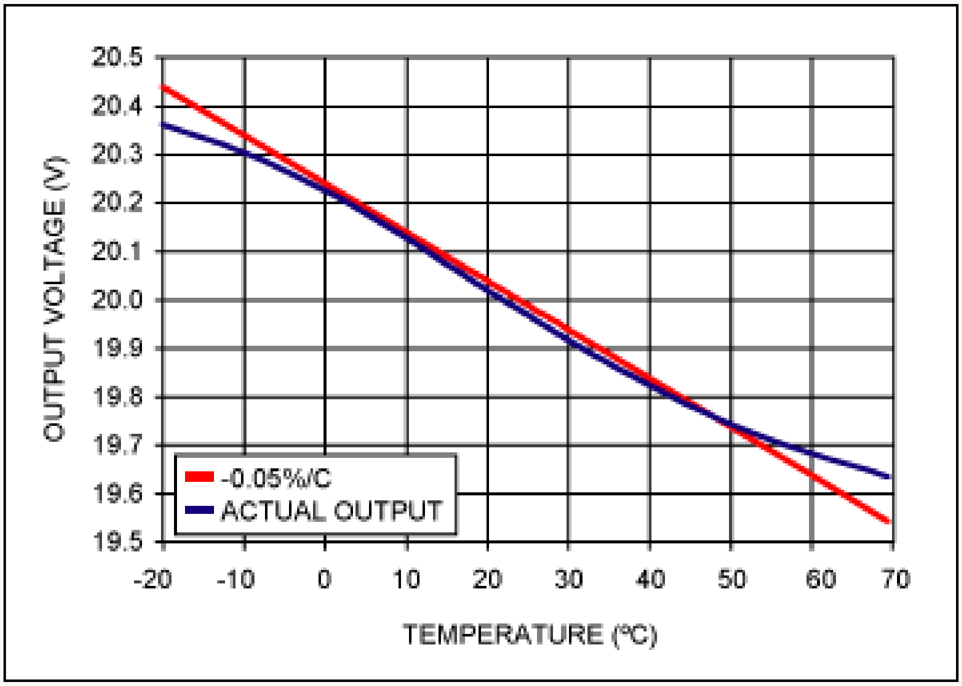

Figure 11. The actual temperature dependence of the circuit in Figure 10 is very close to the target temperature coefficient of -0.05%/°C over most of the extended consumer temperature range.

A similar version of this article appeared in the August 1, 2001 issue of *EDN* magazine.

Related Parts

MAX1605: QuickView -- Full (PDF) Data Sheet

MAX629: QuickView -- Full (PDF) Data Sheet -- Free Samples

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