Interpretation of TCR Specifications for Precision Resistors

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Introduction

One of the main specifications for precision resistors is the temperature coefficient of resistance (TCR), which is intended to determine a reversible shift of the resistance from its ohmic value (as measured at room temperature, e.g., 25°C) when operating at different temperatures within the working range. The temperature of the resistor is influenced both by the environment and by heat generated by the applied power. For more details, see reference (1).

The problem is that manufacturers use different methods for defining the TCR of their resistors in their datasheets. In most cases requiring high precision, the definition does not provide enough information to enable the customer to accurately predict the influence of temperature changes on the resistance value.

Some manufacturers will just specify the TCR as ±5 ppm/°C or ±10 ppm/°C, without referring to the temperature range. Others may specify ±5 ppm/°C from 25°C to 125°C, but not address other temperatures.

In high-precision devices like Bulk Metal® Foil resistors, the specifications include nominal typical curves, normally from –55°C to 125°C. The curves define the nominal "cold" (–55°C to 25°C) and "hot" (25°C to 125°C) chord slopes, and the datasheet specifies the maximum spread for each slope (e.g., ±0.2 ppm/°C and ±1.8 ppm/°C).

The default interpretation for a specified TCR of ±5 ppm/°C, for example, would be that at any point across the working temperature range, the resistor would not change more than +5 ppm/°C or –5 ppm/°C.

The purpose of this article is to show that this interpretation is incorrect, and more specifically, to show by how much this can vary depending on the technology and the definition of the TCR specifications.

Content of Work

The following discussion compares TCR performance of Bulk Metal Foil resistor technology and thin film technology. The comparison is based on the testing of two different precision NiCr resistor products built on thin film technology, with TCR of 5 ppm/°C, and the results are analyzed for a better understanding of their performance. The samples demonstrated are surface mount chip resistors, size 1206, with resistance value of 10k ohm and outlined below.

Description

Series 1: Z Foil type resistors with a nominal typical TCR of ±0.2 ppm/°C nominal, ±1.8 ppm/°C spread.

Series 2: The worst-case negative TCR for Z Foil type resistors: –2 ppm/°C.

Series 3: The worst-case positive TCR for Z Foil type resistors: +2 ppm/°C.

Series 4: An actual measurement of a randomly sampled Z Foil type resistor (for capability demonstration).

Series 5: The best-case TCR for a thin film resistor from manufacturer A, specified as ±5 ppm/°C (out of an arbitrary sample of five resistors).

Series 6: The worst-case TCR for a thin film resistor from manufacturer A.

Series 7: An actual sample of a thin film resistor from manufacturer B, specified as ±5 ppm/°C, +25°C to +125°C (out of an arbitrary sample of five resistors). This sample also meets the 5 ppm/°C limit in the cold range.

Series 8: Another actual sample of a thin film resistor from manufacturer B. This sample exceeds 5 ppm/°C in the cold range.

Series 9: The theoretical extreme case, +5 ppm/°C "hot slope," of a thin film resistor from manufacturer B.

Measurement Results

Bulk Metal Foil Resistors (Series 4)								
T°C	**–55°C**	**–25°C**	**0°C**	**25°C**	**50°C**	**75°C**	**100°C**	**125°C**
ΔR/R ppm	18	–7	–7	0	5	23	51	76

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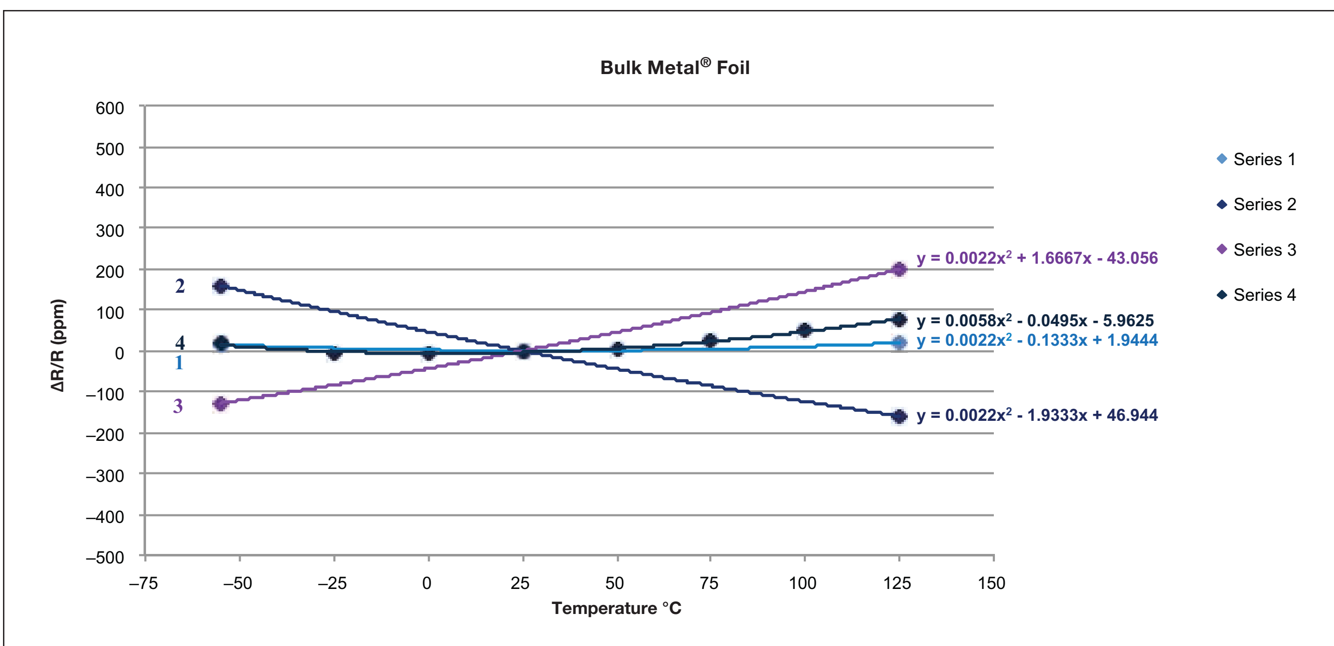
Manufacturer A								
T°C	–55°C	–25°C	0°C	25°C	50°C	75°C	100°C	125°C
ΔR/R ppm	–303	–139	–45	0	23	16	–24	–91
	–383	–178	–71	0	38	36	3	–64
	–342	–154	–61	0	34	37	5	–53
	–394	–183	–67	0	52	68	52	8
	–412	–191	–82	0	57	78	68	32

Manufacturer B			
T°C	–55°C	25°C	125°C
ΔR/R ppm	806	0	10
	520	0	–60
	328	0	140
	360	0	160
	472	0	–30

Graphic Presentation — Resistance Shift (ΔR/R) of Precision Resistors Due to Their Temperature (T)



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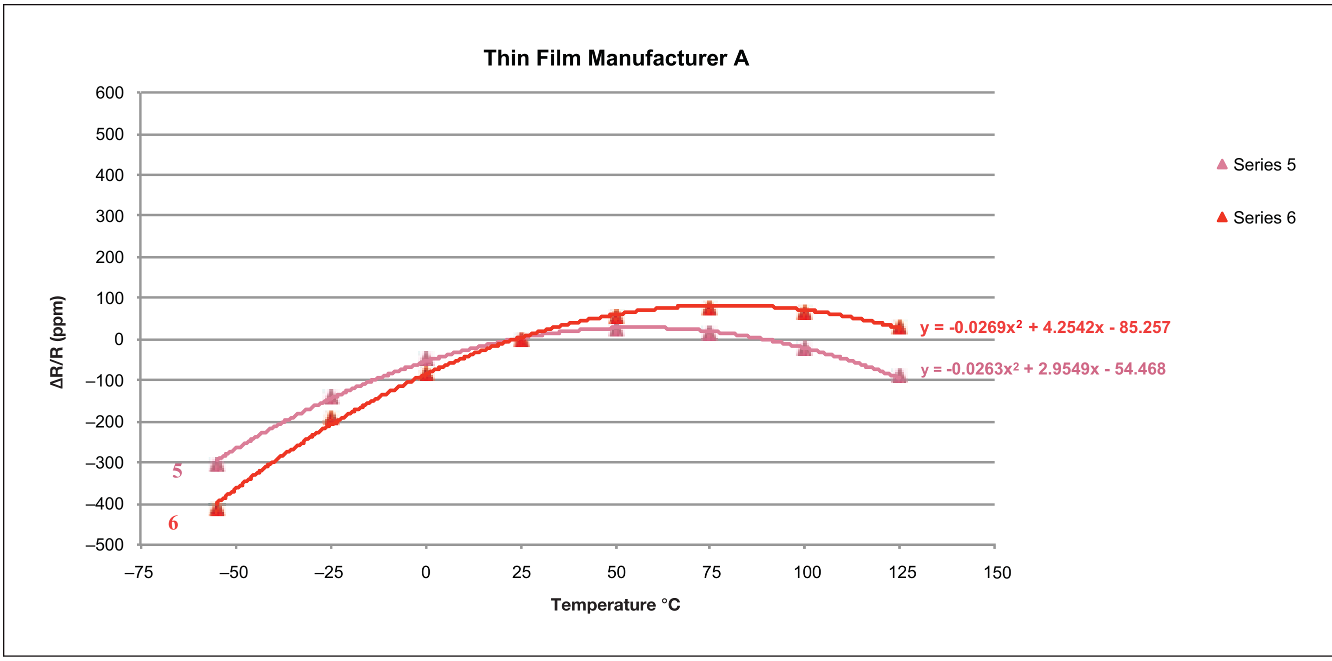

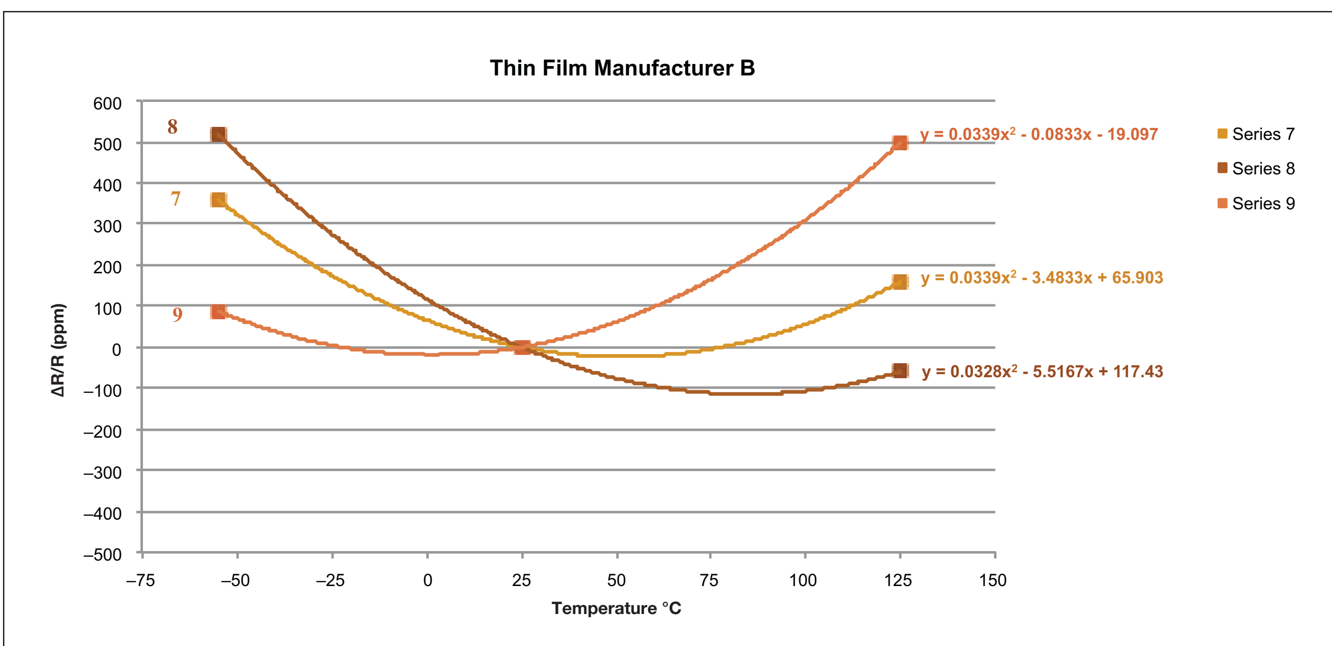

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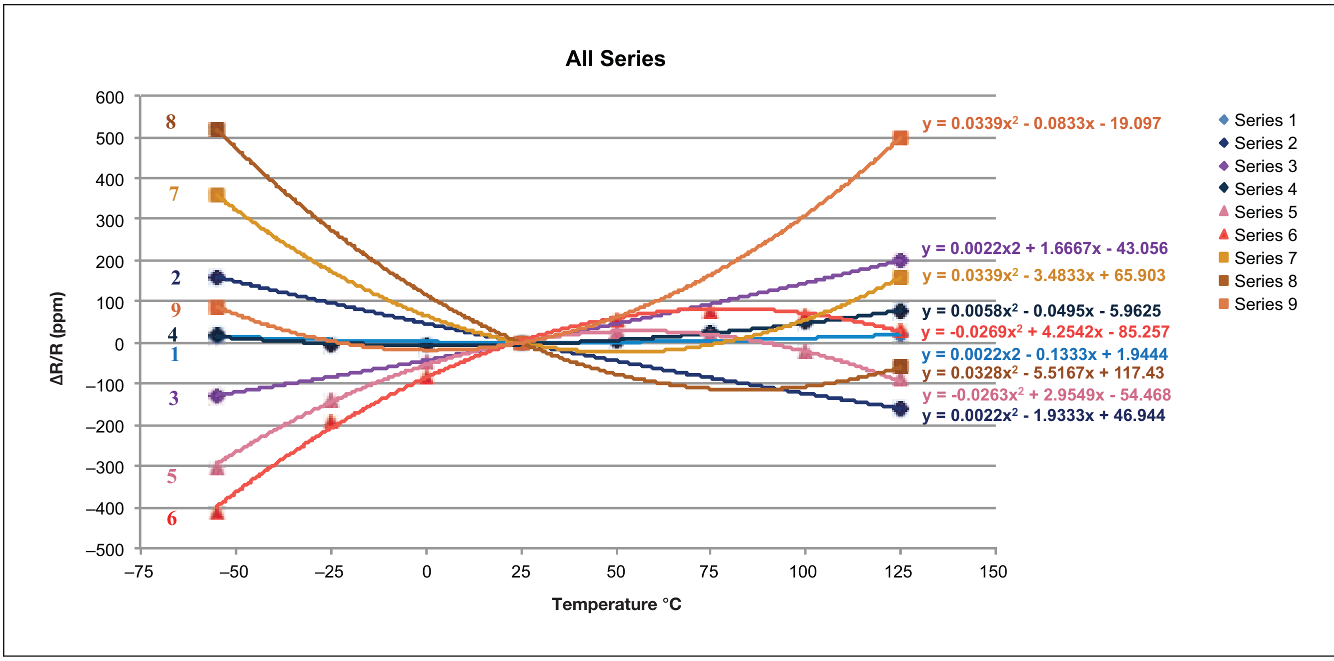

Chord Slopes and Change Rate Analysis

It is well known that the change in resistance versus temperature in NiCr resistors is not linear[2], and normally follows a parabola pattern. Mathematically this function can be described by:

$$Y = aX^2 + bX + c$$

where: $Y = \Delta R/R$ (normally expressed in ppm)

$X = T$ (Temperature in °C).

In this case, for any temperature T, Y will express the value of the change in resistance ΔR/R from the nominal value (at 25°C) in ppm.

The TCR is defined as the rate of change per °C (normally expressed in ppm/°C). It can be defined as the resistance change between two temperatures divided by the temperature difference (chord slope):

$$TCR = \frac{\Delta R/R}{\Delta T}$$

It is a common practice to define the cold chord slope from –55°C to 25°C [in this case $\Delta T_{cold} = 25 - (-55) = 80°C$], and the hot chord slope from 25°C to 125°C (in this case $\Delta T_{hot} = 125 - 25 = 100°C$). However, any other temperature interval (ΔT) can be defined as well.

In order to define the resistance change rate at any temperature on the curve, the mathematical way is to calculate the TCR when ΔT becomes infinitely small (ΔT→0):

$$TCR_{(\Delta T \to 0)} = \frac{dR/R}{dT}$$

In other words, for the function Y this will be expressed by the derivative function Y′. This function defines the slope (TCR) of a line tangent to the parabola and indicates how the TCR is changing. For the above parabola function:

$$Y' = 2aX + b \text{ (Y' is expressed in ppm/°C)}$$

For simplicity, one can also use the fact that a chord slope equals the tangent value in the middle of the relevant temperature range.

For example, the value of the hot slope (25°C to 125°C) equals the tangent value (Y′) at the middle point, T = 75°C.

The following table shows the cold and hot chord slopes of the resistors presented above, and the calculated tangent value (TCR) at three reference temperatures.

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Series #	Chord Slopes ppm/°C		Parabola Equation $Y = aX^2+bX+c$	Change Rate $Y' = 2aX+b$	Calculated Tangent Value TCR at:		
	Cold	Hot			–55°	25°C	125°C
1	+0.2	–0.2	$Y= 0.0022X^2–0.1333X+1.9444$	$Y'= 0.0044X–0.1333$	–0.37	+0.02	0.42
2	–2.0	–1.6	$Y= 0.0022X^2–1.9333X+46.944$	$Y'= 0.0044X–1.9333$	–2.17	–1.80	–1.38
3	+1.6	+2.0	$Y= 0.0022X^2+1.6667X–43.056$	$Y'= 0.0044X+1.6667$	+1.40	+1.80	+2.20
4	–0.2	+0.7	$Y= 0.0058X^2–0.0495X–5.9625$	$Y'= 0.0116X–0.0495$	–0.07	+0.24	+1.40
5	+3.8	–0.9	$Y= –0.0263X^2+2.9549X–54.468$	$Y'= –0.0526X+2.9549$	+5.80	+1.63	–3.60
6	+5.1	+0.3	$Y= –0.0269X^2+4.2542X–85.257$	$Y'= –0.0538X+4.2542$	+7.20	+2.90	–2.50
7	–4.5	+1.6	$Y= 0.0339X^2–3.4833X+65.903$	$Y'= 0.0678X–3.4833$	–7.20	–1.80	+4.99
8	–6.5	–0.6	$Y= 0.0328X^2–5.5167X+117.43$	$Y'= 0.0656X–5.5167$	–9.10	–3.90	+2.70
9	–1.1	+5.0	$Y= 0.0339X^2–0.0833X–19.097$	$Y'= 0.0678X–0.0833$	–3.80	+1.60	+8.39

Discussion

It is a common practice for thin film manufacturers to target for the best hot slope, while keeping the cold slope within the specified limit.

This case deals with precision thin film resistors with a specified TCR of ±5 ppm/°C.

A. Since the thin film resistors of manufacturer A demonstrate a positive cold slope, the following compares the worst-case +1.6 ppm/°C cold slope of Bulk Metal Foil resistors (+2 ppm/°C hot slope, Series 3) with the worst-case +5.1 ppm/°C cold slope (Series 6) and the best-case +3.8 ppm/°C cold slope (Series 5) of thin film manufacturer A.

The change rate of the TCR along the temperature axis, from –55°C to +125°C, is practically constant for Bulk Metal Foil resistors (following the parabola curve). The TCR is slightly varying, from +1.4 ppm/°C at –55°C to +1.8 ppm/°C at 25°C and +2.2 ppm/°C at +125°C.

In the case of thin film manufacturer A, the TCR change rate is also constant (but different since the parabola is different) and the TCR varies from +5.8 ppm/°C and +7.2 ppm/°C at –55°C to +1.63 ppm/°C and +2.9 ppm/°C at 25°C and to –2.5 ppm/°C and –3.6 ppm/°C at 125°C.

B. The following compares the worst-case, –2 ppm/°C cold slope of Bulk Metal Foil resistors (Series 2) with the worst-case –4.5 ppm/°C cold slope of thin film manufacturer B (meeting the 5 ppm/°C limit in both cold and hot slopes, Series 7) and with the worst-case –6.5 ppm/°C cold slope of manufacturer B (meeting the 5 ppm/°C only in the hot slope, according to the specification, Series 8).

In the case of Bulk Metal Foil resistors, the TCR varies from –2.17 ppm/°C at –55°C to –1.8 ppm/°C at 25°C and to –1.38 ppm/°C at 125°C.

In the case of thin film manufacturer B (Series 7 and Series 8), the TCR varies from –7.2 ppm/°C and –9.1 ppm/°C at –55°C to –1.8 ppm/°C and –3.9 ppm/°C at 25°C and to +2.7 ppm/°C and +4.99 ppm/°C at 125°C.

Conclusion

The resistance change due to temperature can be significantly larger than the TCR limits specified in a datasheet.

Based on the datasheet specifications for thin film resistors, they can, at given temperatures, exhibit a TCR up to four times larger than the worst case of Bulk Metal Foil resistors.

The maximum change in resistance (TCR) when the temperature changes across the temperature axis from –55°C to +125°C will vary in Bulk Metal Foil resistors from –2.17 ppm/°C to +2.2 ppm/°C, for a total of less than 4.37 ppm/°C.

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For the same range of temperatures, the TCR of samples from thin film manufacturer A will vary from –3.6 ppm/°C to +7.2 ppm/°C, for a total of nearly 11 ppm/°C, and in the case of manufacturer B, from –9.1 ppm/°C to +4.99 ppm/°C, for a total of 14 ppm/°C.

It is important to highlight the fact that the variations in TCR in the case of Bulk Metal Foil resistors take into consideration the extreme theoretical conditions within the specification limits, while in both cases of thin film only the actual extreme demonstrated limits have been considered. This means that even larger variations in TCR may be assumed for those thin film specifications. For example, if referring to Series 9, which represents an extreme theoretical condition within the TCR specification of manufacturer B, the TCR may vary across the same temperature range, from –9.1 ppm/°C to +8.39 ppm/°C, for a total of more than 17 ppm/°C.

Acknowledgment

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References

(1) Vishay Foil Resistors Technical Note 104, "Predicting Drift in Foil Resistors" (by J. Szwarc)

(2) Vishay Foil Resistors Technical Note 108, "Non-Linearity of Resistance/Temperature Characteristic: Its Influence on Performance of Precision Resistors" (by Dr. F. Zandman & J. Szwarc)