INTRODUCTION

Advancements in microelectromechanical systems (MEMS) and silicon microfabrication have enabled pressure sensors to achieve not only lower cost per function, but also higher levels of accuracy, repeatability, and thermal stability. A major limiting factor in high-performance sensor applications remains the inherent temperature dependence of the sensor's output characteristics.

This application note outlines a method for compensating temperature-related performance shifts in piezoresistive pressure sensors. It provides a practical overview of hardware-level compensation techniques. In addition to the approach described herein, AVSensors also offers factory-calibrated and thermally compensated sensor models designed to meet application-specific requirements.

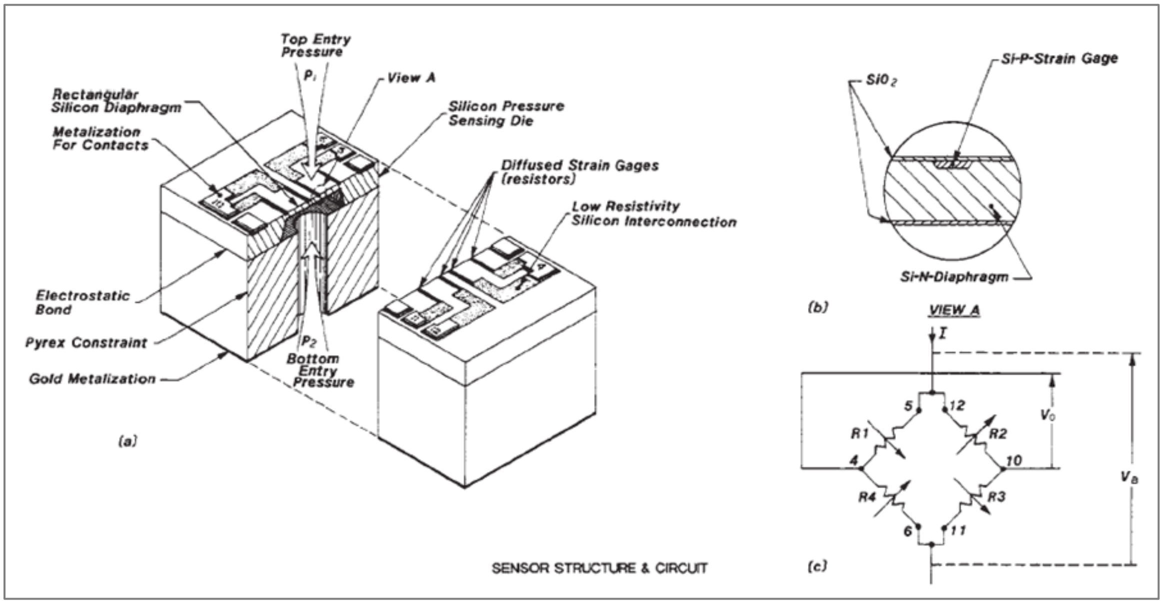

Figure 1a,1b,1c - Sensor Structure and Circuit

INTEGRATED SENSOR DESIGN

AVSensors designs incorporate micromachined silicon diaphragms to convert pressure into mechanical strain. Using anisotropic etching techniques, highly consistent diaphragm structures are fabricated across full silicon wafers. These diaphragms are bonded to Pyrex glass plates to isolate the active sensor element from external mechanical stress. Depending on the presence or absence of a vent hole in the constraint plate, the sensor responds to either differential pressure across the diaphragm or sealed reference pressure conditions

Each diaphragm contains four P-type resistors formed by boron diffusion, arranged in a Wheatstone bridge configuration. These resistors, diffusion-bonded directly to the silicon lattice, provide long-term stability and eliminate mechanical creep typically found in metallic strain gage sensors.

P+ diffused interconnects minimize thermal hysteresis and ensure consistent signal integrity. Electrical passivation is achieved using thermal silicon dioxide layers deposited on both sides of the diaphragm.

Sensor die are housed in various packaging configurations to suit different media compatibility requirements. TO-8 and HIT packages are suited for dry, non-corrosive gases, while ISO models are designed for rugged liquid or corrosive media applications. Under differential pressure, part of the diaphragm is in tension and part in compression, causing tension gage to increase in resistance and compression gage to decrease in resistance arrange in whetsone bridge that produces an output proportional to the applied load. (Figure 1c).

TEMPERATURE CHARACTERISTICS OF A SENSOR

Ambient temperature changes influence three critical electrical characteristics of piezoresistive pressure sensors: zero pressure output voltage (offset), pressure sensitivity (span), and bridge resistance. These temperature dependencies are typically evaluated relative to a reference temperature of 25°C and are presented as a percentage of the full-scale span.

The zero pressure output—defined as the bridge output when no pressure is applied—often exhibits a temperature-dependent slope that aligns with its initial polarity. For instance, a positive offset at room temperature may increase with rising temperature. However, this relationship is not universally predictable and may vary depending on sensor architecture and material behavior.

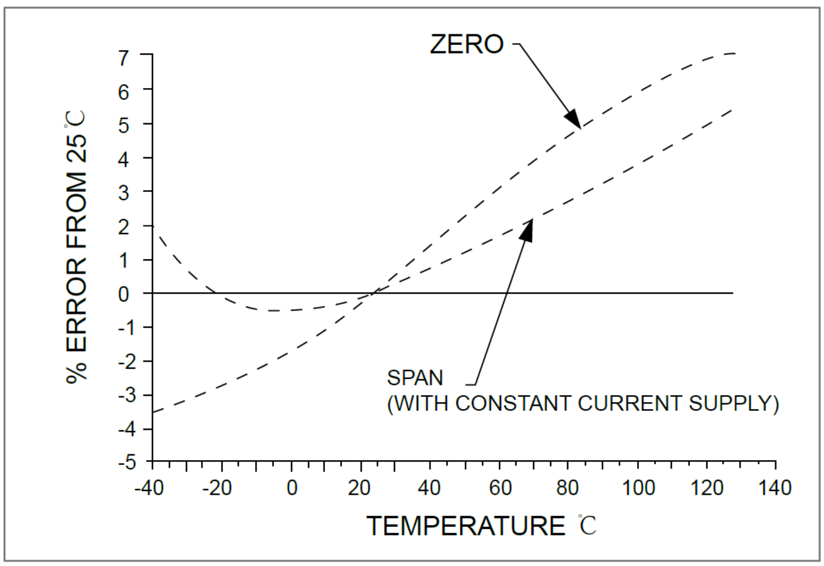

Figure 2. Temperature Dependence of Zero and Span

Pressure sensitivity, under voltage excitation, is defined as the normalized span and is typically specified in units of millivolts per volt per PSI (mV/V/PSI). This parameter reflects the sensor's intrinsic gage factor and is independent of both the excitation method (voltage or current) and the applied pressure range. As ambient temperature increases, sensitivity generally decreases, exhibiting a negative temperature coefficient inherent to the piezoresistive sensing mechanism.

Span is defined as the difference in bridge output voltage between full-scale pressure and zero pressure. The temperature behavior of span depends on the chosen excitation mode—voltage or current. For a given sensor the span S is a product of normalized pressure sensitivity G, bridge voltage Vb and rated pressure P:

S = G Vb P

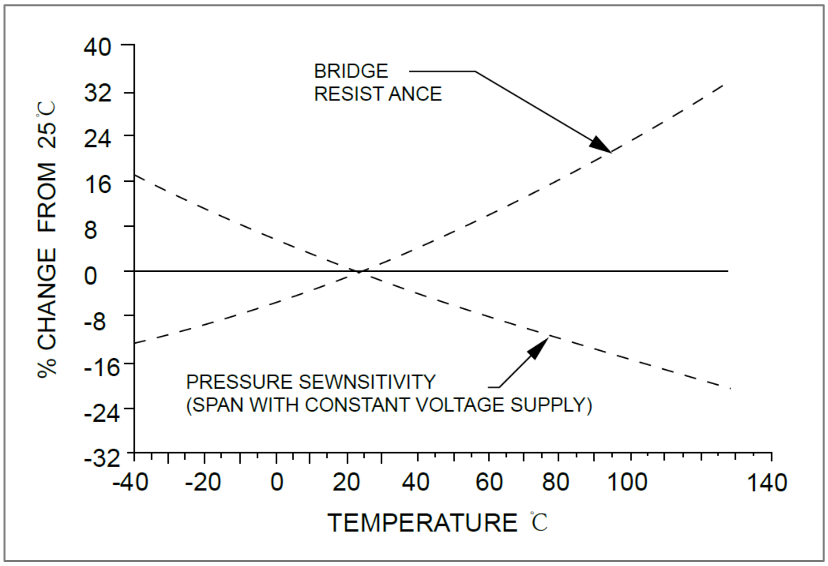

Figure 3. Temperature Dependence of Bridge Resistance

Under constant voltage excitation, the span exhibits a negative temperature coefficient, primarily driven by the thermal dependence of pressure sensitivity. For AVSensors' standard 5 kΩ process, this coefficient is typically around −0.21%/°C. In contrast, when operating under constant current (I) excitation, the bridge voltage varies proportionally with the bridge resistance Rb and span can be expressed as:

S = G Rb I P

Because bridge resistance increases with temperature, the total span error under constant current excitation results from the combined effects of the pressure sensitivity temperature coefficient (TCG) and the bridge resistance temperature coefficient (TCR). For AVSensors' standard 5 kΩ process, the uncorrected TCR is typically +0.26%/°C, while the TCG is approximately −0.21%/°C. These opposing trends yield a net span temperature coefficient of roughly +0.05%/°C under constant current operation. AVSensors has tuned various product families to achieve different TCR and TCG profiles by adjusting ion implantation parameters used during the formation of the strain gage resistors. For specific performance details, refer to the appropriate product datasheets.

In compensated sensor designs, the effective temperature coefficient of resistance (TCR) can be reduced to match the magnitude of the pressure sensitivity coefficient (TCG) by incorporating resistor R5 into the circuit (as shown in Figure 8). This adjustment flattens the overall span response across temperature. Controlling the temperature sensitivity of bridge resistance is a critical aspect of AVSensors’ approach to achieving precise and stable thermal compensation.

ZERO COMPENSATION

Zero compensation corrects both the initial offset at 25°C and its drift over temperature. Series resistors R3 and R4 are used to null the initial offset. A positive offset is reduced by inserting R4 and shorting R3, and vice versa for a negative offset. (Figure 4).

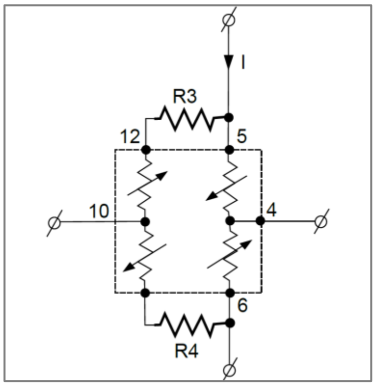

Figure 4. Offset Compensation

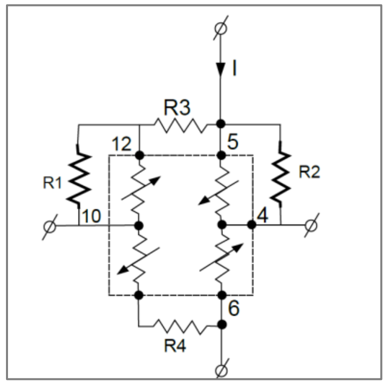

Figure 5. Offset TC

Temperature-induced offset drift is corrected by modifying the effective TC of the bridge arms. This is done by adding high-stability resistors R1 or R2 in parallel with the appropriate leg of the bridge. Only one of these is typically used, depending on the direction of drift. (Figure 5).

Compensation resistors impact both initial zero and its thermal slope. A full compensation strategy uses measurements at three temperatures—typically 0°C, 25°C, and 50°C. Based on this data, resistor values are calculated to bring the offset to zero at T_{ref} and minimize errors at T_{cold} and T_{hot}.

Typical residual error at the cold and hot ends is about 0.1% of span. This is mainly due to thermal nonlinearity and resistor tolerances. Additional minor offset shifts may occur with changes in excitation current due to self-heating effects. (Figure 6).

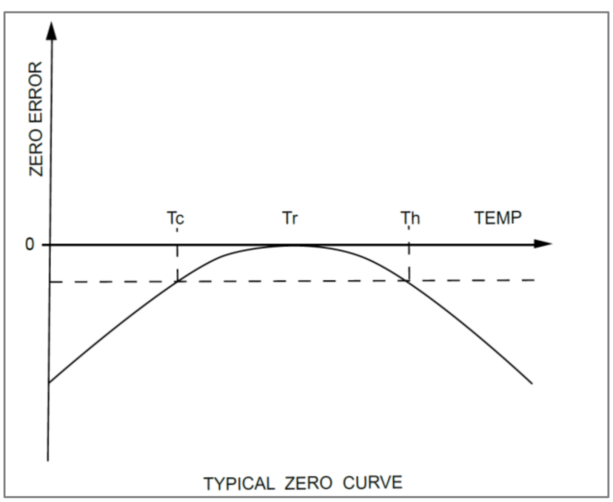

Figure 6. Typical Zero Curve

SPAN TEMPERATURE COMPENSATION

The most straightforward method for span temperature compensation involves selecting sensor excitation with a constant current. In this configuration, span variation with temperature results from the additive effect of two opposing coefficients: the negative temperature coefficient of pressure sensitivity (**TCG**) and the positive temperature coefficient of bridge resistance (**TCR**). By matching their magnitudes, the sensor achieves intrinsic thermal compensation without external circuitry. However, this self-compensating approach is limited at lower temperatures due to the nonlinear behavior of bridge resistance in that range

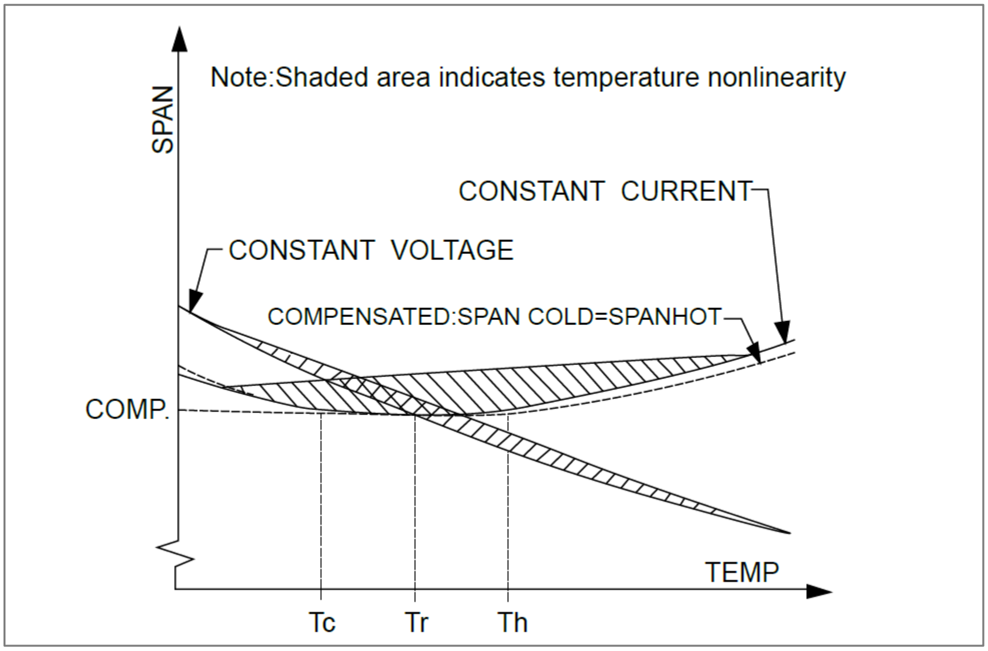

Figure 7. Span vs. Temperature

AVSensors has selected a fabrication process that yields a bridge resistance temperature coefficient (**TCR**) greater in magnitude than the pressure sensitivity temperature coefficient (**TCG**). As a result, under constant voltage excitation, span exhibits a negative temperature coefficient, while under constant current excitation, it becomes positive (as shown in Figure 7). Temperature compensation can be achieved by adjusting the input resistance of the sensor bridge: adding resistor **R_5** in parallel for constant current mode, or in series for constant voltage mode (Figure 8). This resistor shifts the effective TCR, enabling precise alignment with the opposing TCG to minimize span drift.

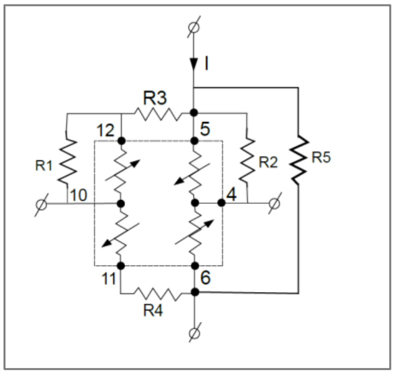

Figure 8. Span Temperature Compensation (Span TC)

For AVSensors' standard 5 kΩ process, the optimal value of resistor **R_5** is approximately 33 kΩ, or 6.6 times the bridge resistance at 25°C. Adding this resistor reduces the overall span, but the impact depends on the excitation method. Under constant current excitation, the reduction in uncompensated output is typically around 13%. In contrast, achieving similar thermal compensation in constant voltage mode would result in an 87% loss of span. This performance difference strongly supports the use of constant current excitation for temperature-stable sensor designs.

Span linearity in constant current mode is typically less accurate than in constant voltage mode (see Figures 2 and 3). AVSensors' standard compensation algorithm is optimized to equalize span at two calibration points—0°C and 50°C—for standard CTO-8 Series packaged sensors. However, at extreme low temperatures, such as −40°C, the span error in constant current mode may reach approximately +3% of full-scale.

Despite this, span error variation between individual units is significantly tighter than zero offset error variation. Applying digital correction—by comparing each sensor's span deviation from a reference curve and leveraging bridge voltage as an internal temperature proxy—can further enhance compensation accuracy across the operating range.

REQUIRED PERFORMANCE OF COMPENSATING RESISTORS

Figures 9 through 11 illustrate how both resistor tolerance and temperature coefficient of resistance (TCR) influence sensor compensation performance. The analysis assumes a typical bridge resistance of 5000 Ω at 25°C with a TCR of +0.26%/°C, and a pressure sensitivity of 15 mV/V/PSI under 1.5 mA constant current excitation, exhibiting a TCG of −0.21%/°C.

Expected compensation resistor value ranges are as follows:

- **R1, R2**: 100 kΩ to 10 MΩ (typical: 300 kΩ to 1.5 MΩ)
- **R3, R4**: 0 to 300 Ω (typical: 0 to 100 Ω)
- **R5**: 10 kΩ to 300 kΩ (typical: 15 kΩ to 100 kΩ)

For most applications, resistors with 1% tolerance and 100 ppm/°C TCR—such as RN55D series—are suitable and provide acceptable compensation accuracy.

As a practical example, suppose the compensation procedure determines the following resistor values:

- **R1 = 0.5 MΩ**
- **R2 = Open**
- **R3 = 90 Ω**
- **R4 = Shorted**
- **R5 = 20 kΩ**

These values represent a typical configuration for achieving balanced zero and span temperature performance in a compensated sensor.

Resistor tolerance and TCR of these resistors directly influence compensation accuracy. For example, a 1% deviation in R1 (500 kΩ) changes offset by 0.19 mV and contributes 0.06 mV/50°C error. A 100 ppm/°C drift adds another 0.12 mV/50°C.

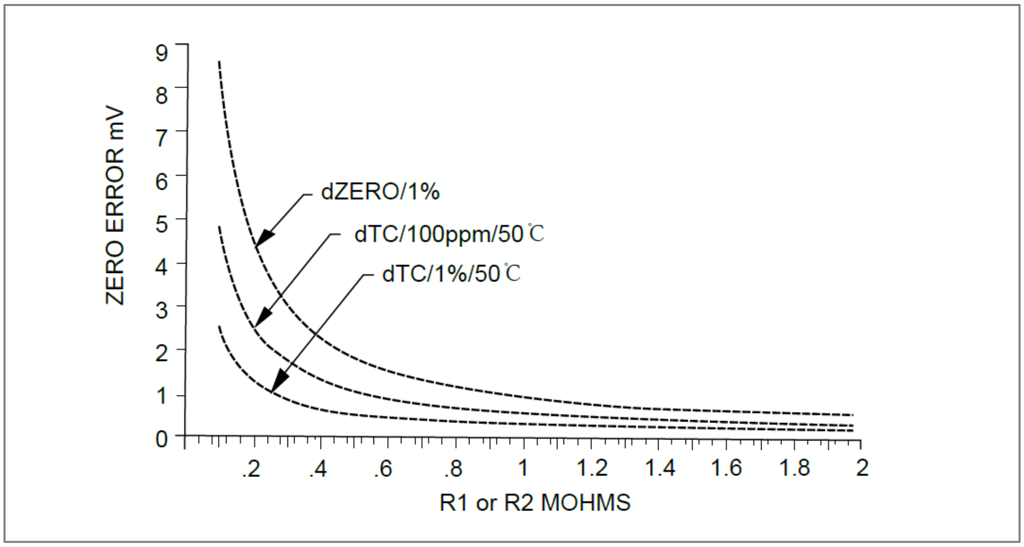

Figure 9. R1 or R2 Resistor Tolerance

R3 and R4 influence initial offset but not its temperature slope. A 1% variation in R3 (90 Ω) shifts offset by 0.33 mV, and a 100 ppm/°C drift adds 0.17 mV/50°C.

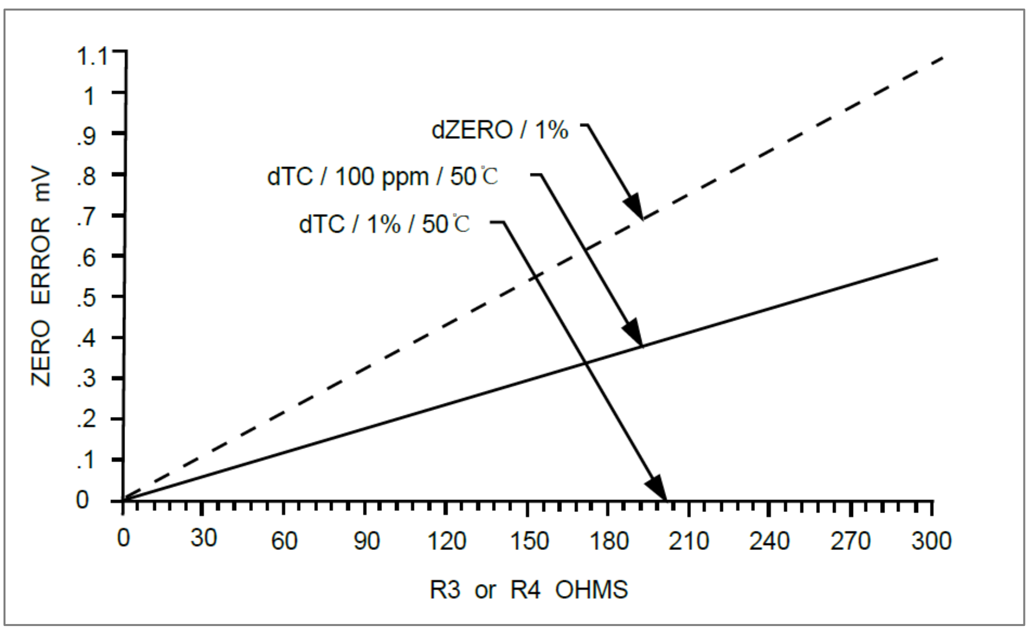

Figure 10. R_3 or R_4 Resistor Tolerance

While R5 does not affect zero compensation, it controls span slope. A 1% change in R5 (20 kΩ) causes a 0.19% span shift and 0.02%/50°C slope error. A 100 ppm/°C TCR introduces another 0.15%/50°C.

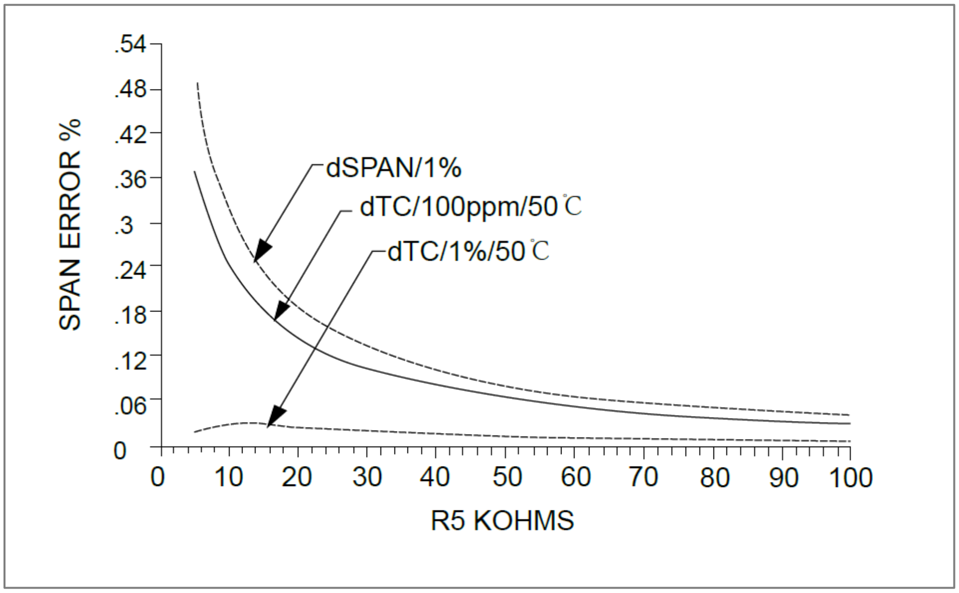

Figure 11. R_5 Resistor Tolerance