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APPLICATION NOTE 4419

Understanding Voltage-Reference Temperature Drift

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Abstract: A perfect voltage reference produces a stable voltage independent of any external factors. Real-world voltage references, of course, are subject to errors caused by many external factors. One cause of these major errors is temperature. Without care, it is easy to operate a voltage reference outside its operating temperature range. This application note describes how references respond to temperature changes, and how self-heating can cause a voltage reference to operate outside its recommended temperature range. Once understood, this knowledge can then be used to avoid making this design error.

How Voltage References Are Specified over Temperature

Temperature coefficient (tempco) is the specification that defines how a voltage reference's output voltage will drift over a given temperature. **Figure 1** shows how two voltage references drift with temperature. These plots were taken from three typical units.
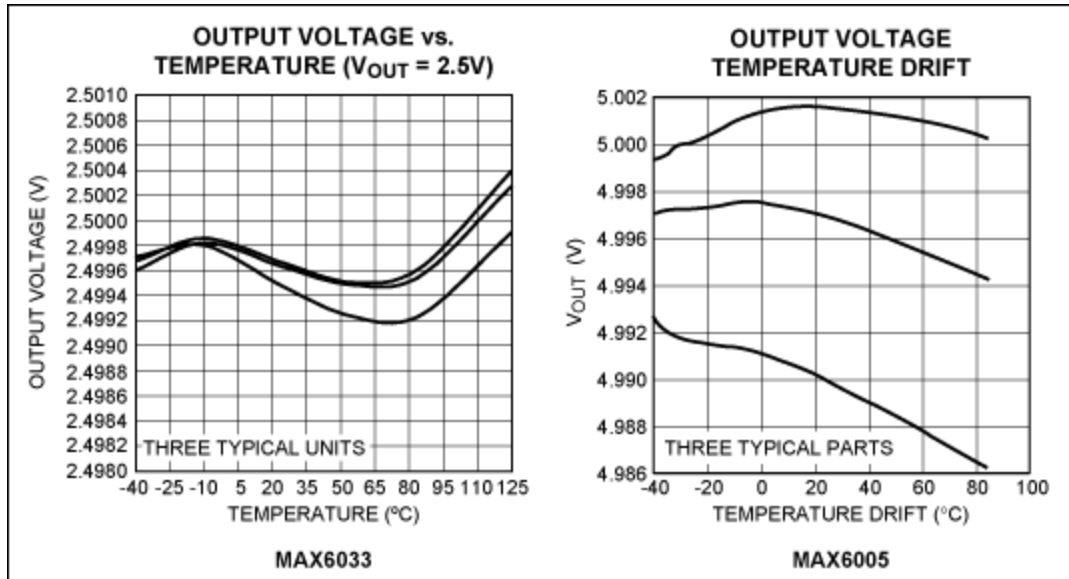
Figure 1. Typical voltage references like the MAX6033 and MAX6005 drift with temperature.

The first plot shows data for the MAX6033 and the second plot is data for the MAX6005. It is immediately apparent that the devices have significantly different shaped characteristics. The MAX6033A is specified as a 7ppm (max) reference, while the MAX6005 is specified as a 100ppm (max) reference. What does this really mean for a design? It certainly does not mean that if we increase the temperature of a part by 1°C, we will change the output voltage by the tempco. To understand what is happening, you must remember that Maxim specifies its series voltage references using the "box" method. This method makes it easy to compare a whole family of voltage references, and is the industry-standard method.

The MAX6033A serves as a good example of how the box method works. This device is specified as a 7ppm (max) reference over a temperature range of -40°C to +85°C. It's also worth noting that the MAX6033 is also specified over the wider -40°C to +125°C, which is why Figure 1 goes all the way to +125°C. To calculate how accurate it will be over the specified temperature range, simply multiply the tempco by the device's specified temperature range. The MAX6033A is 7ppm/°C x 125°C = 875ppm. This value is always positive and negative. So over the device's specified temperature range, we can guarantee that the reference will drift by less than ±875ppm of the initial value. This is shown graphically in **Figure 2**, where the data are very impressive for a SOT23-packaged device. The "box" is bounded on the top and bottom by the maximum drift and on the left and right by the temperature extremes.

It is also important to mention that the initial value of any reference is defined as the range of output voltages for a defined set of conditions: temperature, input voltage, load current, etc. For the MAX6033A, this is ±0.04% and for the MAX6005A, this is ±1%.
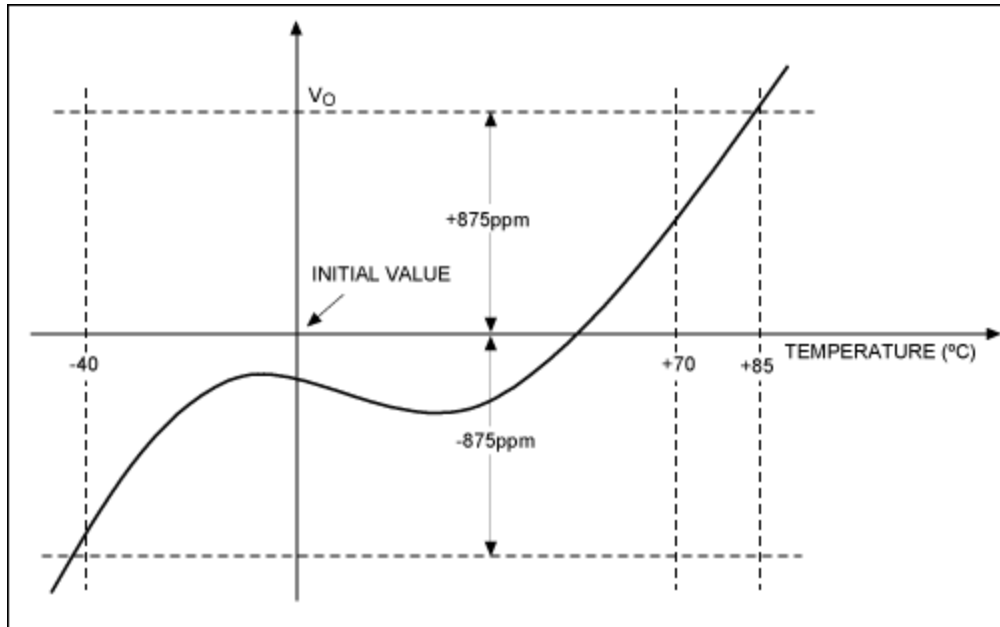
Figure 2. The MAX6033's temperature drift.

An example illustrates why this is an important exercise. Suppose a design requires the reference to drift no more than ±1100ppm over the temperature range of 0°C to +70°C. The MAX6033A would easily meet this specification. The MAX6033B, however, has a tempco of 10ppm, leading to a drift of 1250ppm so this device would not work in the application.

Turn now to the parametric search on the Maxim website, A hypothetical search locates the MAX6025A voltage reference, which is specified as 20ppm over -40°C to +85°C. Clearly this device will not work since it would result in a drift of ±2500ppm. There is, however, something critically important to note: this device is also specified as 15ppm over 0°C to +70°C, which results in ±1050ppm. This device costs around half the price of the MAX6033A, so it is clearly a better choice for the example application.

There is another very important point to understand about voltage-reference tempco specifications. Tempco is specified at die temperature and not at ambient temperature, as is normal with many other device specifications.

Voltage-Reference Self-Heating and Calculation of Die Temperature

As stated above, the temperature range used when specifying tempco is the die temperature. A device may not typically dissipate much power and, therefore, its die temperature will be very close to ambient. There may be times, however, when a design requires a reference to dissipate more power. Such an "extreme" design could use a MAX6043, which is special because its maximum supply voltage can be 40V. It can supply a minimum of 10mA. The ABSMAX specifications for the MAX6043 are shown below:

Absolute Maximum Ratings

IN to GND	-0.3V to +42V
OUTF, OUTS to GND	-0.3V to (V_{IN} + 0.3V)
Continuous Power Dissipation (T_A = +70°C) 6-Pin SOT23 (derate 9.1mW/°C above +70°C)	727mW
OUT_Short-Circuit Duration	5s
Operating Temperature Range	-40°C to +125°C
Storage Temperature Range	-65°C to +150°C
Junction Temperature Range	-65°C to +150°C
Lead Temperature (soldering, 10s)	+300°C

This 6-pin SOT23 package is rated at 727mW dissipation, but must be derated at 9.1mW/°C above +70°C. The maximum operating junction temperature is +125°C, as referred to by the operating temperature range.

Given these specifications, you can determine the device's maximum ambient temperature. The die temperature is calculated from:

$$T_A = T_J + R_{\Theta JA} \times P_{DISS}$$

Where:

- T_J is the junction temperature.
- T_A is the ambient temperature.
- $R_{\Theta JA}$ is the thermal resistance from junction to ambient.
- P_{DISS} is the power dissipation.

Note that although R?JA is not specifically shown, it can be calculated from 1/derating factor. In this case that is:

1/9.1mW/°C = 110°C/W.

Consider another example with a power supply of 40V, a reference voltage of 2.5V, and a load current of 10mA. This results in a power dissipation of 375mW. Using the above equation, the maximum ambient temperature is +84°C. Self-heating accounts for +41°C.

So even though the MAX6043 reference is specified up to +125°C, at high loads it can only be used up to +84°C.

Conclusions

The box method works to define how voltage references are specified over temperature. Understanding

this method then helps you select the best component for an application. Unlike many specifications, the operating temperature range of voltage references is the die temperature and not the ambient temperature. An example has shown how to calculate the die temperature, and how this can lead to significant reductions in the operating temperature range that is achievable for a specific reference.

More Information

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