

# Reliable Precision Voltage Reference with 5ppm/°C Drift is Factory Trimmed and Tested at -40°C, 25°C and 125°C

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## Introduction

High precision requirements are no longer limited to the most exotic and expensive measurement equipment. Designers of industrial monitors and automotive monitor and control circuits are using precision circuits to maximize the performance and uninterrupted operating times of their products. Improved precision allows for more accurate assessment of sensor outputs that measure ambient conditions, equipment position, battery condition, component wear and many other system indicators. Precise and consistent measurements are the key to managing system elements that change very little over their operating lives. Recognizing these slight changes can allow estimation of the remaining lifetime of lamps, motors, and other components, or allow control of battery charge and discharge to maximize operating life. These applications not only require high accuracy, low drift and low noise, but also a wide operating temperature range and reasonable cost.

## Factory Calibration Means Dependable Precision

The LTC6652 reference is a precision low drift voltage reference that includes advanced curvature compensation circuitry and post-package trim. To guarantee reliable performance, these parts are tested at -40°C, 25°C and 125°C to verify they meet specification across the entire temperature range. This comprehensive testing ensures that the LTC6652 can be used with confidence in demanding applications. One result of this testing is demonstrated in Figure 1. The output voltage versus temperature for several randomly chosen parts shows a drift characteristic that is consistent from part to part. This is a result of a propri-

etary curvature compensation circuit that tracks the operating conditions and the manufacturing process, yielding consistent results. Figure 2 shows a typical temperature drift distribution of randomly selected production tested LTC6652s, illustrating how well the design and testing methodology works. Finally, the initial accuracy distribution is tightly controlled, as shown in Figure 3.

## Compare the Real Specs: Is the Temperature Range Operating or Functional?

When comparing voltage references for use in demanding environments, it is important to know, with confidence, how the voltage reference performs at the extremes. When it is important for the reference to provide precision (not just survive) in a harsh environment, the LTC6655 leaves most competing voltage references behind.

For example, many applications requiring a precision reference are designed to work over the industrial temperature range (-40°C to 85°C). If the ambient temperature reaches 85°C, the interior of the enclosure and the temperature of the reference will

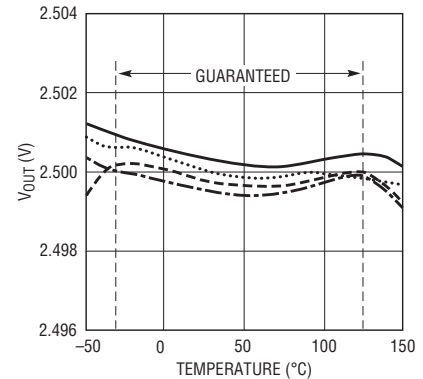


Figure 1. Typical drift characteristics of production trimmed and tested parts

likely exceed 85°C. It is not uncommon in this case for the interior of a circuit enclosure to climb above 100°C due to the thermal dissipation of its components. In addition, any comparable voltage reference fully loaded at 5mA with a 13.2V input voltage would self-heat an additional 18°C, raising its own internal junction temperature to 118°C. This temperature is well outside the useful range of most voltage references. The LTC6652, however, maintains exceptional performance in these conditions, despite the extreme environment. By comparison, the drift of a reference specified only to 85°C will

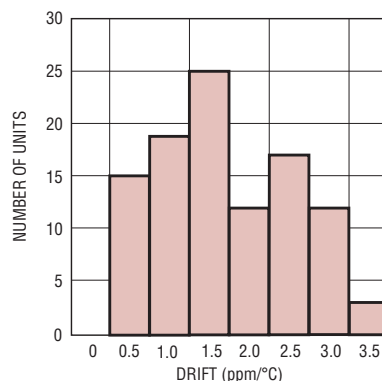


Figure 2. Drift distribution (-40°C to 125°C)

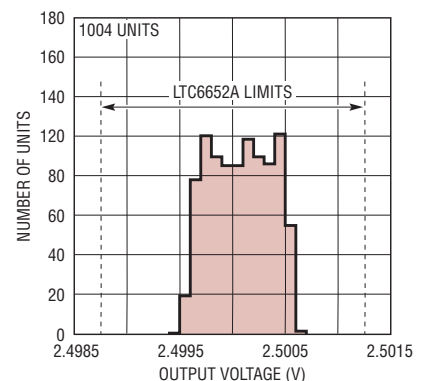


Figure 3. Typical  $V_{OUT}$  distribution for LTC6652-2.5

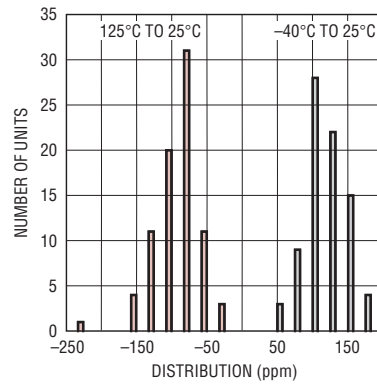
likely exhibit substantial additional error, or it may even fail to operate. Other references that claim similar performance to the LTC6652 often are only “functional”, meaning they don’t fail, but they don’t meet specification either at temperatures exceeding 85°C or below 0°C. These competing parts are rarely tested across their entire specified temperature range. The reality of industrial circuit design is that in many cases, component specifications over “industrial” temperatures are woefully inadequate.

In contrast, every LTC6652 is fully tested at 25°C, -40°C and again at 125°C for every device, not just a small sample. This extensive testing proves the consistently high quality of the LTC6652 over its entire wide temperature range.

Further, the LTC6652 was designed from the ground up to accommodate a wide temperature range. Figure 1 clearly illustrates its consistent performance over the entire range. There is no need to question or derate the performance of a system that uses the LTC6652 at its temperature extremes. The consistent, guaranteed performance makes it easy to design, specify and calibrate a high performance system. This is not the case with some competing products.

**Eliminate Field Calibration**

After any precision reference is soldered onto a printed circuit board, thermal hysteresis will likely shift the output from its factory trimmed value. Further temperature cycling will also contribute to a shift in the output voltage. Over time, the output will tend to drift slightly as well due to aging of the circuit. The circuit design, fabrication process and mechanical design of the LTC6652 is optimized for low thermal hysteresis and excellent long-term stability, reducing the need for field calibration. Thermal hysteresis is caused by differing rates of expansion and contraction of materials within a packaged semiconductor device as the device experiences temperature changes. As the package material and the semiconductor die expand and contract at different rates, mechani-



**Figure 4. Hysteresis plot (-40°C to 125°C)**

cal force changes device parameters (ever so slightly) and cause the output voltage to change. This change is measured in parts per million (ppm) and is shown in Figure 4.

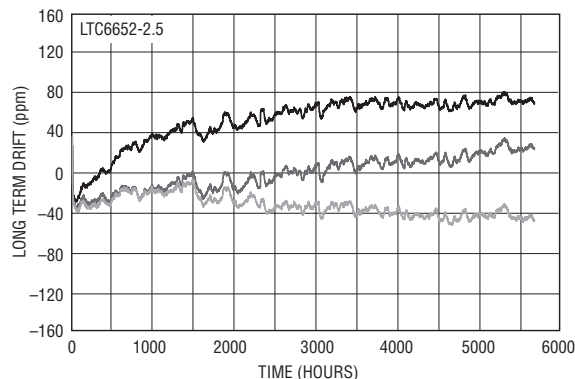
The LTC6652 boasts a typical thermal hysteresis value of 105ppm over its full temperature range. What this means is that when a device goes

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from room temperature to 125° and back again to room temperature, the output will typically shift 105ppm. For a 2.5V voltage option, the output would shift -260µV. A cold excursion would shift the most recent room temperature measurement +260µ. Typical hysteresis of 105ppm is equivalent to 0.0105%; just a small fraction of the initial accuracy.

It may be convenient to compare typical values for thermal hysteresis when choosing a voltage reference. It is important to remember that these numbers do not tell the whole story. It is the distribution of expected hysteresis that must be used to determine the expected error caused by temperature cycling. Referring to Figure 4, some parts will have better or worse hysteresis. This chart helps to estimate a realistic error budget. This is something our competitors don’t always include, yet is critically important when specifying precision systems.

Over time a reference is likely to shift on its own even if it’s kept at a constant temperature. This is known as long-term drift. Long-term drift is measured in ppm/√khr and has a logarithmic characteristic where the change in output voltage decays as time passes. Figure 5 shows the long-term drift of the LTC6652. Note that most of the drift occurs within the first 1,000 or 2,000 hours as the PCB and package settle. Afterward the drift tends to settle, and the slope is reduced over time as a function of √khr. Direct measurement on soldered down parts is the only way to determine



**Figure 5. Example of long-term drift**

long-term drift. Accelerated testing does not work. Some users burn in their boards, which helps eliminate this initial slope, further reducing the effect of long-term drift.

The three curves shown in Figure 5 give a general indication of how much long-term drift to expect. The typical specification is  $60\text{ppm}/\sqrt{\text{kHz}}$ , which translates into  $150\mu\text{V}$  drift. Combining the typical thermal hysteresis and long-term drift numbers yields  $165\text{ppm}$ . To put this in perspective, the LTC6652 temperature coefficient is typically  $2\text{ppm}/^\circ\text{C}$  over  $165^\circ\text{C}$  temperature range, which yields  $330\text{ppm}$  due to drift alone. The combined thermal hysteresis and long-term drift is half this number (or just 20% of the maximum drift specification). The superior thermal hysteresis and long-term drift performance of the LTC6652 ensures accuracy and reliability over the product lifetime, virtually eliminating the need for field calibration.

### Small Footprint and Output Capacitor Optional

The performance of the LTC6652 is often only found in larger packages such as an SOIC. However, the LTC6652 is packaged in a small 8-lead MSOP and does not require an input or output capacitor. This minimizes required board space, thus simplifying the design of applications with tight PCB constraints such as small sensor enclosure applications. Another advantage of not using capacitors is eliminating energy storage devices tied to sensitive circuits. This

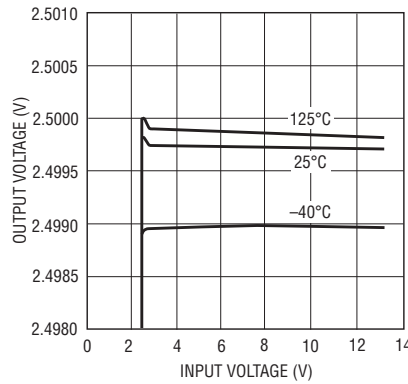


Figure 6. Line regulation

**The LTC6652 reference family has seven output voltage options, making it suitable for a variety of today's demanding applications. These options are 1.25V, 2.048V, 2.5V, 3V, 3.3V, 4.096V, and 5V.**

is a useful feature in safety critical systems, where energy storage must be minimized. If, however, low noise is a priority, an input capacitor may be added to suppress high frequency transients on the supply line, while an output capacitor will reduce wideband noise and improve AC PSRR. Either way, the LTC6652 offers stable operation. Small size and a range of useful input and output capacitors allows the LTC6652 to satisfy the requirements of many different applications. This includes everything from small,

tight-fitting portable applications to high precision, low noise measurement applications.

### Output Can Source and Sink Current

The LTC6652 is a series voltage reference that can source current, but it can also sink current like a shunt reference. Some series voltage references can only source output current and rely on a resistor divider for feedback and to sink a small amount of current. These types of devices can experience long settling times, especially when charge is kicked back from a switched capacitor circuit causing the output voltage to rise. The sink (overvoltage) settling time on a source only reference is dominated by the RC time constant of the output capacitor and the resistive divider. For example, a  $2.2\mu\text{F}$  output capacitor and a  $125\text{k}\Omega$  resistive divider will have a  $275\text{ms}$  time constant. Depending on the size of the perturbation and the system precision, a source only reference may not settle in a timely fashion. The LTC6652 current sink capacity is  $5\text{mA}$  and will dynamically respond for faster settling.

Shunt references are two terminal devices that maintain the output voltage by sinking more or less current. The sinking ability of the LTC6652 allows it to operate in a similar, but more efficient manner. In fact, for voltage options of  $3\text{V}$  or higher, the  $V_{\text{IN}}$  pin can actually go below the  $V_{\text{OUT}}$  pin while sinking currents of  $100\mu\text{A}$  and higher and still maintain good regulation.

### Wide Input Range, Low Dropout, and Seven Voltage Options

The LTC6652 reference family has seven output voltage options to choose from, making it suitable for a variety of today's demanding applications. These options are  $1.25\text{V}$ ,  $2.048\text{V}$ ,  $2.5\text{V}$ ,  $3\text{V}$ ,  $3.3\text{V}$ ,  $4.096\text{V}$ , and  $5\text{V}$ . For low input voltage requirements, the  $1.25\text{V}$  and  $2.048\text{V}$  options work with input voltages down to  $2.7\text{V}$ . The other five options require only  $300\text{mV}$  input-to-

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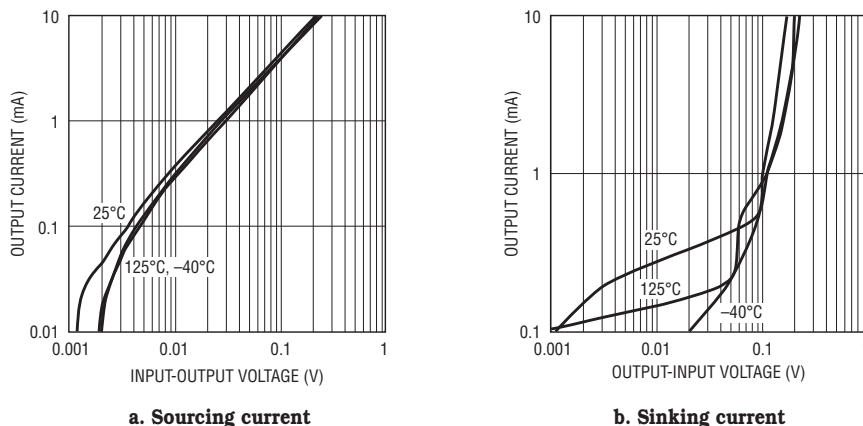


Figure 7. Dropout voltage sourcing and sinking current

**Table 2. Noise margins are good for radiated emission results shown in Figure 13**

Frequency (MHz)	Antenna Polarization	EUT Azimuth (Degrees)	Antenna Height (cm)	Uncorrected Amplitude (dB $\mu$ V)	ACF (dB/m)	Pre-Amp Gain (dB)	CBL (dB)	DCF (dB)	Corrected Amplitude (dB $\mu$ V)	Limit (dB $\mu$ V)	Margin (dB)
134.31	H	354	364	1.3	11.428	0	1.532	0	14.26	30	15.74
119.96	V	184	110	3.5	12.694	0	1.456	0	17.65	30	12.35
160.02	H	0	354	0.5	10.499	0	1.793	0	12.792	30	17.208
174.37	H	0	100	1.2	9.638	0	1.944	0	12.782	30	17.218
224.28	V	0	100	-1.87	10.586	0	2.044	0	10.76	30	19.24
263.63	H	0	371	-4.72	12.6	0	2.385	0	10.265	37	26.735

a linear DC power supply is used for the input, and a resistive load is employed on the output. The baseline noise is checked with the power supply providing a DC current directly to the resistive load. The baseline emission scan results are shown in Figure 11. There are two traces in the plot, one for the vertical and horizontal orientations of the receiver antenna.

Figure 12 shows the peak scan results of a  $\mu$ Module buck regulator—not the LTM4606 or LTM4612—without the integrated low noise feature. The scan results show that the noise below 350MHz is produced by the  $\mu$ Module switching regulator, when compared to the baseline noise level. Radiated EMI here does not meet the Class B of CISPR 22 (quasi-peak) radiated emission limit.


In contrast, Figure 13 shows the peak scan results of the low noise LTM4606 module. To ensure enough margin to the quasi-peak limit for different operation conditions, the six highest noise points are checked as shown in the table of Figure 13 using the quasi-peak measurement. The results show that it has more than 12dB $\mu$ V margin below the Class B of CISPR 22(quasi-peak) radiated emission limit.

Figure 14 shows the results for the LTM4612 meeting the Class B of CISPR 22 radiated emission limit at 24V  $V_{IN}$ , 12V/5A  $V_{OUT}$ .

### Conclusion

The LTM4606 and LTM4612  $\mu$ Module regulators offer all of the high performance benefits of switching regulators minus the noise issues. The ultralow

noise optimized design produces radiated EMI performance with enough margin below the Class B of CISPR 22 limit to simplify application in noise-sensitive environments.

Design is further simplified by exceptional thermal performance, which allows them to achieve high efficiency and a compact form factor. A low profile 15mm  $\times$  15mm  $\times$  2.8mm package contains almost all of the support components—only a few input and output capacitors are required to complete a design. Several  $\mu$ Module regulators can be easily run in parallel for more output power. The versatility of these parts is rounded out by optional features such as soft-start, RUN pin control, output voltage tracking and margining, PGOOD indicator, frequency adjustment and external clock synchronization. 

*LTC6652, continued from page 9*

output headroom while fully loaded, and they require less headroom with a reduced load or while sinking current. Popular application requirements, such as a 2.5V reference operating on a 3V supply, or a 4.096V reference operating on a 5V supply, are easily accommodated. For high input voltage requirements, all voltage options work up to 13.2V. Regardless of input voltage the LTC6652 maintains its excellent accuracy as shown in the line regulation plot in Figure 6. A plot of the dropout voltage for both sourcing and sinking current is shown in Figures 7a and 7b, respectively.

### Superior Performance

While many references share some features of the LTC6652, it's difficult to find any that include all the features at the same level of performance and reliability. Additional features include low noise, good AC PSRR, and excellent load regulation (both sourcing and sinking current). Low power consumption and a shutdown mode round out the feature list.

### Conclusion

The LTC6652 reference family is designed and factory trimmed to

yield exceptional drift and accuracy performance. The entire family is guaranteed and production tested at -40°C, 25°C and 125°C to ensure dependable performance in demanding applications. Low thermal hysteresis and low long-term drift reduce or eliminate the need for field calibration. The small 8-lead MSOP package and sparse capacitor requirements minimize required board space. The wide input range from 2.7V to 13.2V and seven output voltage options will tackle the needs of most precision reference users. 