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Precise Voltage Reference Achieves <1ppm/°C Performance

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Introduction

Selecting precision voltage references can be an arduous task. Today, there are hundreds of products offered by dozens of chip companies, all striving to achieve the next best level of performance. Not only must the designer consider all the system requirements of an application when selecting a proper voltage reference, but additionally, cost must be looked at with the ultimate goal of achieving the most optimum performance at the best price point. This is often a difficult task that requires considerable research into the details of the datasheets as well as sourcing volume pricing quotations.

While several parameters are important in the selection of voltage references, the two that stand out as potentially contributing the greatest errors are initial accuracy and temperature coefficient (TC). Noise, thermal hysteresis, line and load regulation and long term stability should not be neglected when making a selection, but their contributions to error are shadowed by initial accuracy and TC. It is not surprising therefore, that chip manufactures concentrate their marketing efforts to proclaim best in class performance achievements in these two domains.

Figure 1, below, offers a brief glimpse of the positioning of several popular precision voltage references based upon their initial accuracy and temperature coefficient.

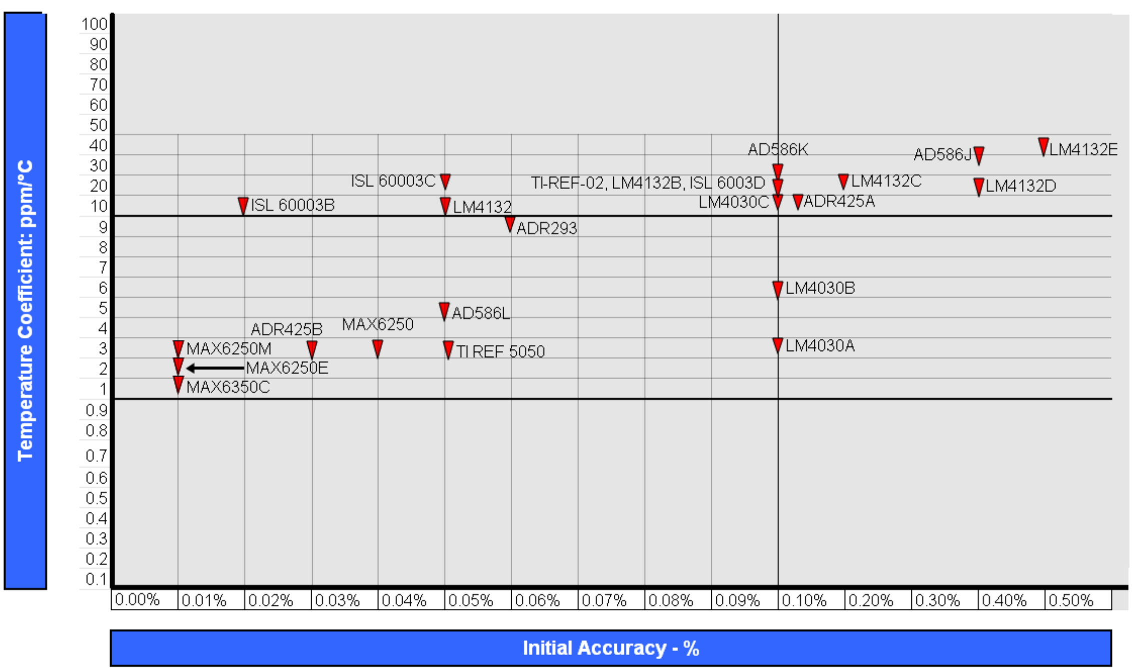


Figure 1: Popular precision voltage references showing their initial accuracy and temperature coefficients.

These external precision voltage references offer improved performance when compared to on-chip solutions typically found in CMOS ADC and DAC products and thus facilitate applications requiring 14 or 16 bit accuracy.

Initial Error

Initial error is the deviation of the actual output voltage from the desired specification. Many voltage references have trim pins that allow the user to set or pre adjust the output value in an attempt to offset the inherent initial error in output voltage. (See Fig. 2) The output is adjusted by setting the ratio of resistance above and below the “wiper” shown in the figure.

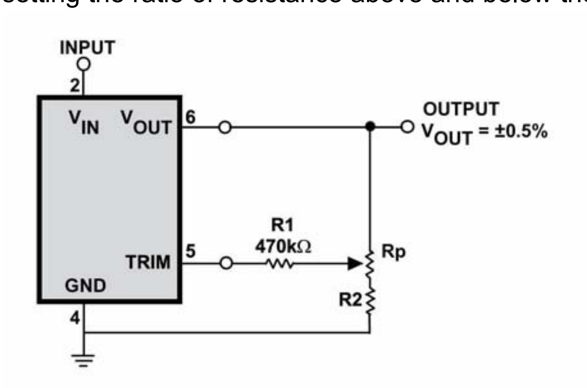


Figure 2: Typical external resistor configuration to trim a precision voltage reference

Of course the ability to precisely select the desired output voltage then becomes an issue of finding the correct resistance values, taking into consideration their initial accuracies (or perhaps more correctly, their inaccuracies) as well as their contribution to the TC of the output voltage. The specific ratios attainable are constrained by the limited selection of resistance values. The greater the accuracy being sought, the more difficult it is to attain an arbitrary resistance ratio. (See Table 1)

1	1.01	1.02	1.04	1.05	1.06	1.07	1.09	1.1	1.11	1.13	1.14	1.15	1.17	1.18	1.2
1.21	1.23	1.24	1.26	1.27	1.29	1.3	1.32	1.33	1.35	1.37	1.38	1.4	1.42	1.43	1.45
1.47	1.49	1.5	1.52	1.54	1.56	1.58	1.6	1.62	1.64	1.65	1.67	1.69	1.72	1.74	1.76
1.78	1.8	1.82	1.84	1.87	1.89	1.91	1.93	1.96	1.98	2	2.03	2.05	2.08	2.1	2.13
2.15	2.18	2.21	2.23	2.26	2.29	2.32	2.34	2.37	2.4	2.43	2.46	2.49	2.52	2.55	2.58
2.61	2.64	2.67	2.71	2.74	2.77	2.8	2.84	2.87	2.91	2.94	2.98	3.01	3.05	3.09	3.12
3.16	3.2	3.24	3.28	3.32	3.36	3.4	3.44	3.48	3.52	3.57	3.61	3.65	3.7	3.74	3.79
3.83	3.88	3.92	3.97	4.02	4.07	4.12	4.17	4.22	4.27	4.32	4.37	4.42	4.48	4.53	4.59
4.64	4.7	4.75	4.81	4.87	4.93	4.99	5.05	5.11	5.17	5.23	5.3	5.36	5.42	5.49	5.56
5.62	5.69	5.76	5.83	5.9	5.97	6.04	6.12	6.19	6.26	6.34	6.42	6.49	6.57	6.65	6.73
6.81	6.9	6.98	7.06	7.15	7.23	7.32	7.41	7.5	7.59	7.68	7.77	7.87	7.96	8.06	8.16
8.25	8.35	8.45	8.56	8.66	8.76	8.87	8.98	9.09	9.19	9.31	9.42	9.53	9.65	9.76	9.88

Table 1: Normalized standard values of 0.1% resistors. (Values between 1 and 10; the other values can be obtained by multiplying these values for powers of 10).

In this application, for example, analysis of the circuit requirements showed that by replacing the 470K ohm ballast resistor with a 120K ohm, resistor. the Vout could be adjusted precisely using a MBT143E Rejustor™ from Microbridge. This Rejustor has a 1:9 ratio divider with initial resistances of 14K ohm (top leg) and 126K ohm (bottom leg). During the calibration process, software algorithms automatically adjust the two resistances down from their as manufactured values, based on the real time feedback from Vout. The adjustments are accomplished in a series of small steps, taking 1-2 seconds in total, until the desired output accuracy is achieved. The rejustor values will be trimmed to slightly different resistances for each ADR425A to compensate for both the minor manufacturing variances of the precision reference as well as the differing non idealities associated with the board layout. Thus the use of precision fixed resistors would become an almost impossible task without massive reiterative measurement and hand selection.

Potentiometers bring about their own sets of problems associated with stability over temperature and errors associated with vibration. Laser trim brings a bevy of capital equipment costs and often inability to tolerate mechanical stresses. Digital pots introduce quantizing errors (not unlike hand selecting precision resistors), additional power requirements as well as unwanted wiper resistance. The ideal solution can be found with the use of Rejustors. Passive and trimable to better than 0.01% accuracy, these devices offer the perfect solution for precision calibration.

Temperature Coefficient

Temperature coefficient is the measure of the stability of the output of the precision voltage reference with temperature changes. Precision means nothing if it cannot be maintained over the useful operating temperature range of the system into which the precision voltage reference is designed. TC is referred to as the second most important specification to consider when selecting a reference. First-order temperature correction (referred to as linear temperature correction) is the largest contributor to errors associated with temperature variations. Second-order and higher TC errors contribute to the curve in a TC graph. A study of various suppliers' precision voltage reference datasheets will show most, if not all, have some curvature. Curvature correction involves complicated additional circuitry in the reference which again adds cost.

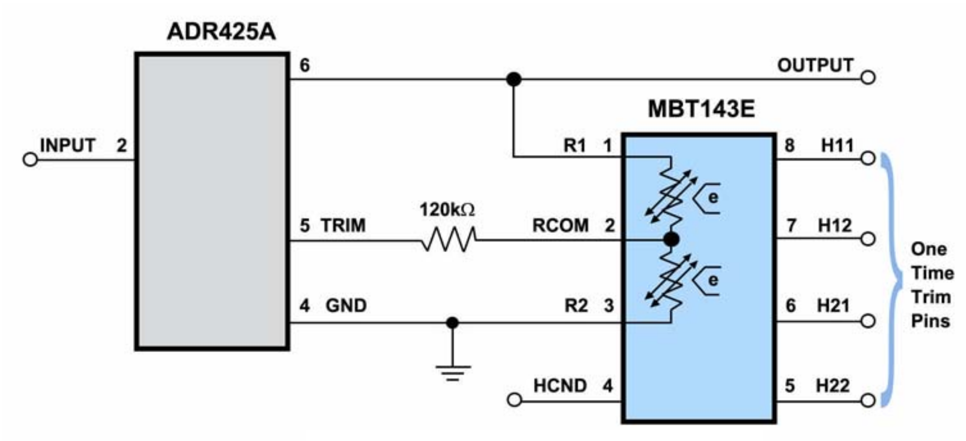
Depending upon the application and reference device selected, curvature may or may not play an important role. Some precision voltage references have only a slight curve to their TC graph while others may have a significant rollover effect. The TC deviation of the references output is additive to 'Initial Error' described above. One way of lessening the criticality of curvature is to improve or reduce the initial error of the device. The closer the precision voltage reference is to its ideal value at room temp, the more curvature can be tolerated in the system design.

An ideal solution would combine the attributes of low cost, trim-ability, extreme precision and an ability to correct for the inherent first order TC effects of the reference itself. By bringing these capabilities together, designers will find that they can develop extremely accurate reference systems in their applications while using lower cost voltage reference devices from established suppliers.

Getting More For Less

In this example we have selected the ADR425A Ultraprecision, Low Noise, 5.00 V XFET® Voltage Reference from Analog Devices. Datasheet examination reveals the device is specified to have an initial accuracy of +/- 3mV (+/- 0.15%) and a TC of 10ppm/°C, making it a strong performer among several competitive devices (refer to Fig. 1)

To calibrate and temperature compensate the ADR425A, a 120K ohm resistor and a 9:1 eTC Rejustor Divider from Microbridge was configured as shown in Figure 3. The MBT143E is a member of the eTC (electrically adjustable Temperature Coefficient) family of rejustors.



Output Trim Adjustment

Figure 3: Fully calibrated and temperature compensated precision reference design using a MBT143A 9:1 Rejustor divider from Microbridge.

Microbridge eTC-Rejustors provide designers with a new tool with which to craft and adjust an application circuit. The TC-Offset vs. Offset characteristics of the MBT143E divider are shown in Fig. 4 below. The Offset is the deviation of the divider output voltage Vin*(R1/(R1+R2)), measured in mV per volt of divider input voltage Vin, away from Vin*(R10/(R10+R20)), where R10 and R20 are the nominal unadjusted divider resistance values.

The TC-Offset is the temperature coefficient of that divider output voltage, measured in µV per degree-C (K) per volt of divider input voltage. Microbridge's eTC adjustment software allows one to pick target values for Offset and TC-Offset as a point within the roughly-parallelogram-shaped region shown in Fig. 4. For example, if initially the divider input voltage were low by 5% (50mV/V) from its designed value, and, additionally, it has an undesired +75µV/VK temperature variation, and if it is desired that the drive level be temperature-stable at the nominal Vin*(R10/(R10+R20), then one programs the divider to the point (+50mV, -75µV/KV), as shown in the figure.

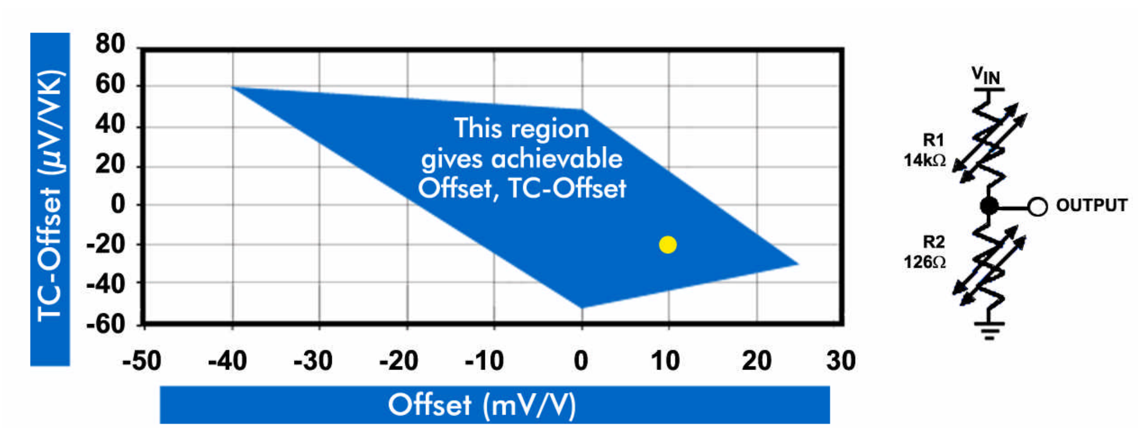


Figure 4: A typical plot of the achievable sets of values for a real voltage divider made from a specific example of eTC Rejustors. The adjustment allows you to pick a target spot within this roughly parallelogram-shaped region. One specific example point is shown, at Offset = +50mV/V and TC-Offset = -75µV/VK, (+50mV/V, -75µV/VK).

For the purposes of this example the ADR425A was characterized over the temperature range of +0°C to +85°C. Characterization and analysis of the temperature stability of the ADR425A reveals an output voltage variation of ~5000μV over the temperature, or ~12ppm/°C , close to the specification for the A grade product (10ppm/°C) shown as the curve in Fig. 5 identified as “ADR425A as it is”.

Based on these characterization results, Rejustor calibration targets were set and the MBT143E was adjusted “in circuit” using Rejust-it software from Microbridge at the same time that the configuration was being tested.

By adjusting the ohmic value of the two rejustor resistances to set the “perfect” divider ratio, the initial output of the ADR425A was improved from 4.99612V to 5.000125V or 0.0025% initial error. By adjusting the TCR of the two resistances in the divider, the majority of the positive temperature coefficient was eliminated, improving the TC from 12ppm/°C to 0.8ppm/°C.

ADR425A Error Improvement

The initial accuracy of the ADR425A is specified as 0.15%, (although our examination indicated it was closer to 0.1%) and its TC is specified as 10ppm/°C, (our measurements indicated 12ppm/°C). Using the following conversion table we can determine the LSB improvement for ADC and DAC applications.

LSB (ppm)	Bits
3906	8
977	10
244	12
61	14
15	16

Assuming other second-order effects to be negligible for the time being, the resultant “out of the box” worse case error for the ADR425A would be:

Initial Error = 0.15% =1,500ppm
Initial TC Error = (10ppm/°C) *(85°C - 0°) = 850ppm
Initial Total Error = 2,350 ppm

Initial LSB Error = (2,350ppm)/ (ppm/LSB)

Bits	Initial LSB Error
10 bit	2.3 bits
12 bit	9.6 bits
14 bit	38.5 bits
16 bit	157 bits

After applying a simple dual eTC rejustor to the output of the reference the following was observed:

Rejustor Compensated Error = 0.0025% =25ppm
Rejustor Compensated TC Error = (0.8ppm/°C) *(85°C - 0°) = 68ppm
Rejustor Compensated Total Error = 93 ppm

Rejustor Compensated LSB Error = (93ppm)/ (ppm/LSB)

Bits	**Initial LSB Error**	**Rejustor Compensated LSB Error**
10 bit	2.3 bits	0.09 bits
12 bit	9.6 bits	0.4 bits
14 bit	38.5 bits	1.5 bits
16 bit	157 bits	6.2 bits

The use of an external Rejustor has propelled the ADR425A into a whole new class of precision voltage reference, significantly beating the performance of its sibling, the ADR425B and at a total cost of less that the ADR425B (based on 1K piece prices)

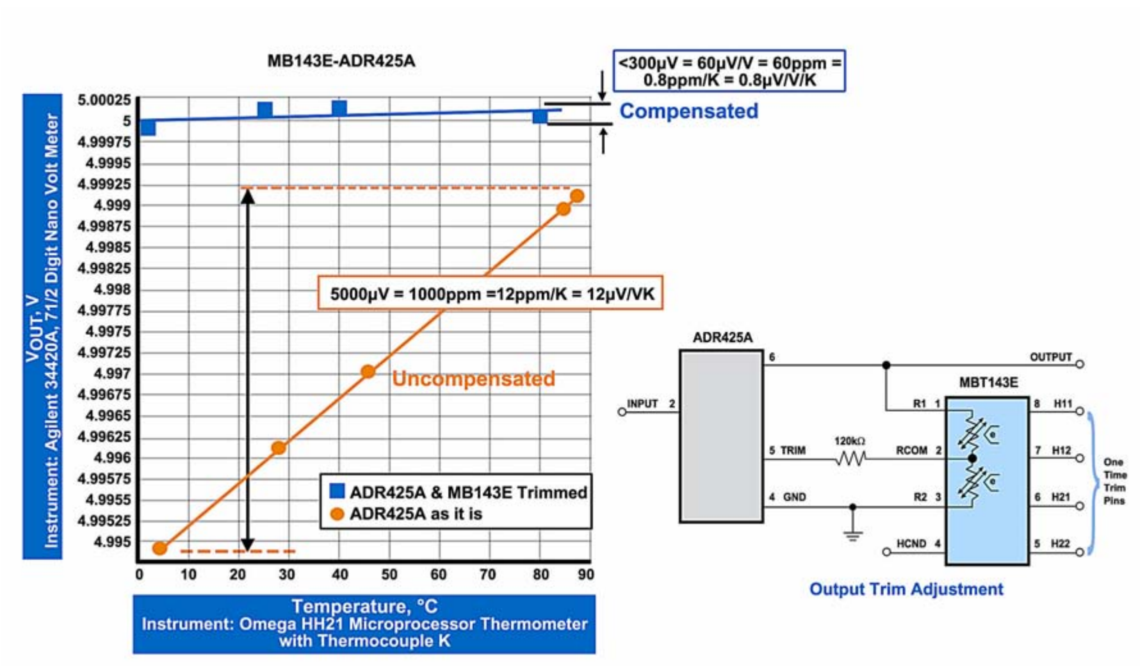
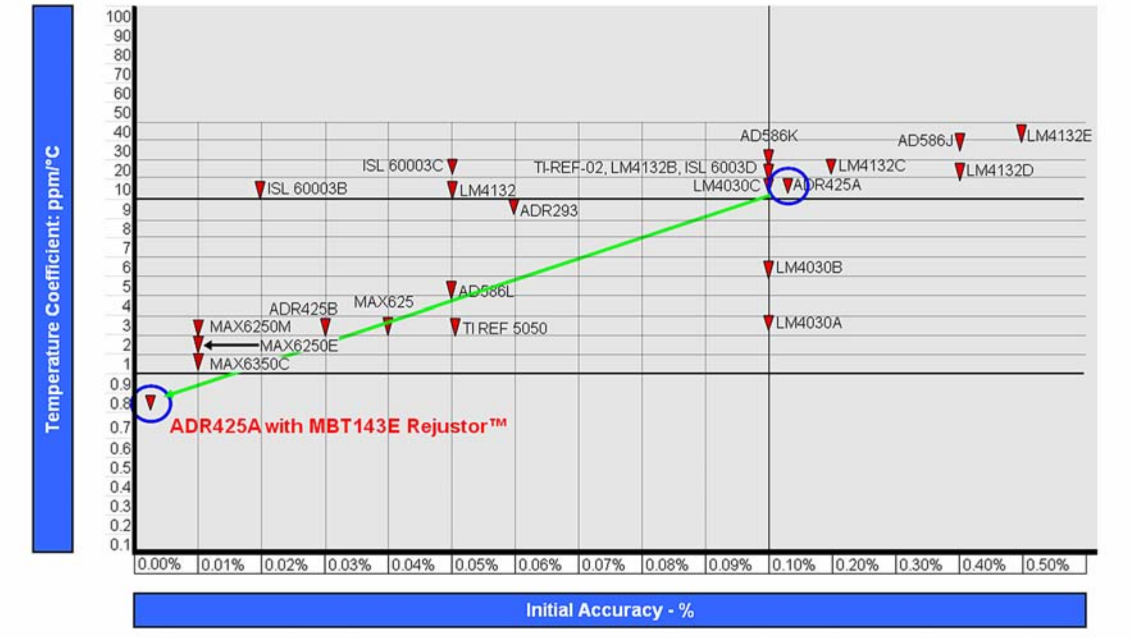
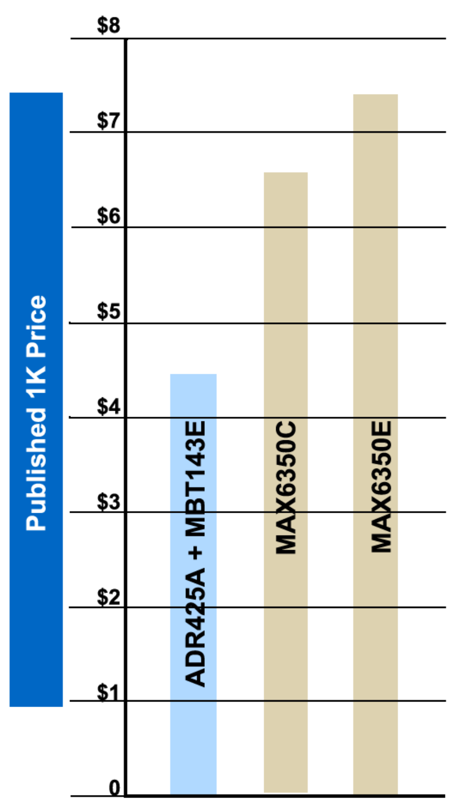


Figure 5: Typical performance of ADR425A precision voltage reference before and after calibration and compensation with MBT143E Rejustor divider



Conclusion

The results speak for themselves. You don't have to pay more for performance. Rejustor technology enhances the performance of precision voltage references. A low cost precision voltage reference has been demonstrated to outperform devices costing more.



Things are not always what they seem. Don't be fooled into thinking inside the box. External components, such as resistors, have an important impact on the average circuit design. The use of rejustor technology in many of those applications has been shown to improve performance of analog ICs, not just with voltage references but also with instrumentation amplifiers, piezoresistive sensors, timing devices and many more.

The rejustor based ADR425A application described in this paper is an example of the kinds of performance enhancements the technology brings to many users. Rejustors won't replace resistors in every application, but when they are suited for the job, when precision is important, when temperature compensation is critical, the improved performance is generally an order of magnitude of more.

For more information about Rejustors visit Microbridge at www.mbridgetech.com

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