Precision DC References and System Accuracy

SYSTEM ACCURACY

Voltage references are utilized in system designs where precise output voltages are required. An example being data acquisition systems where voltage references are used for system calibration. Analog to Digital Converters (ADC's) require an accurate reference for setting the full scale input of the converter. Selection of the reference is therefore an important consideration in the overall accuracy of any data acquisition system.

System designers have to also be concerned with the operating temperature range for their equipment. A designer who needs a 16 bit accurate data acquisition system for the industrial temperature range, will need a voltage reference with a temperature coefficient (TC) of 0.2ppm/C. See Figure 1.

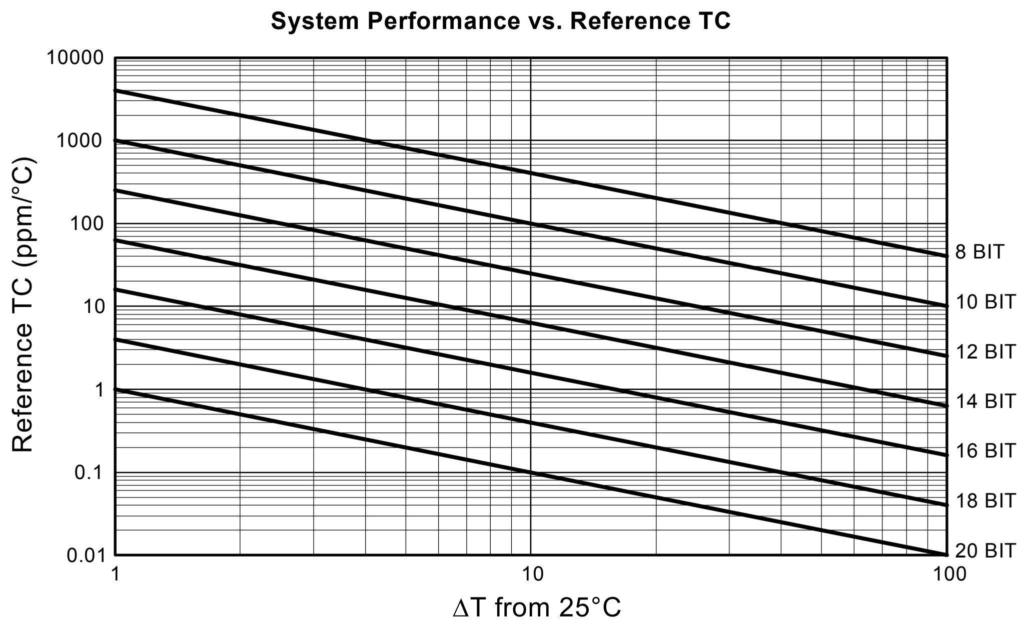

Figure 1. System Performance

REFERENCE SELECTION

Specified parameters for voltage references include line regulation, load regulation, initial voltage error, output voltage temperature coefficient, output voltage noise, turn-on settling time, and quiescent supply current, and long term stability.

The key parameters for most designs are initial error, output voltage temperature coefficient, noise, and long term stability of the device.

There are two types of references commonly used today, bandgaps and zener diodes. Each technology offers inherent performance characteristics which can be enhanced with compensation networks or additional active circuitry.

Bandgap references are the least expensive and typically are used in system designs where only 10 bit accuracy is required. Bandgaps typically have an initial error of 0.5-1.0% and a TC of 25-50 ppm/°C. The output voltage noise is typically 15-30mVp-p(0.1- 10Hz.) and a long term stability of 20-30ppm.

Zener-diode references are more expensive than bandgap references and provide a higher performance level. They typically have an initial error of .04-.06%, a TC of 5-20 ppm/°C, and less than 10mVp-p (0.1-10Hz.) noise. The long term stability is typically 10-15 ppm. Zener based references are frequently used for 12 bit accurate systems.

Apex Microtechnology has extended the performance of zener based references by incorporating a patented* nonlinear temperature compensation network into the design. The compensation network is trimmed at several

* Patent 4,668,903

temperatures to optimize the electrical performance over the operating temperature range.

Apex Microtechnology references have an initial error of .01-.02% and a TC of 0.6-2.0 ppm/°C. The output voltage noise is the same as other zener diode based references.

Figure 2 summarizes the initial error and TC performance for the various references that are available on the market. The data represents the high grade for each respective model in the 8 pin plastic dip package. The worst performing references occupy the upper right hand quadrant of the chart. The zener diodes are in the center of the chart.

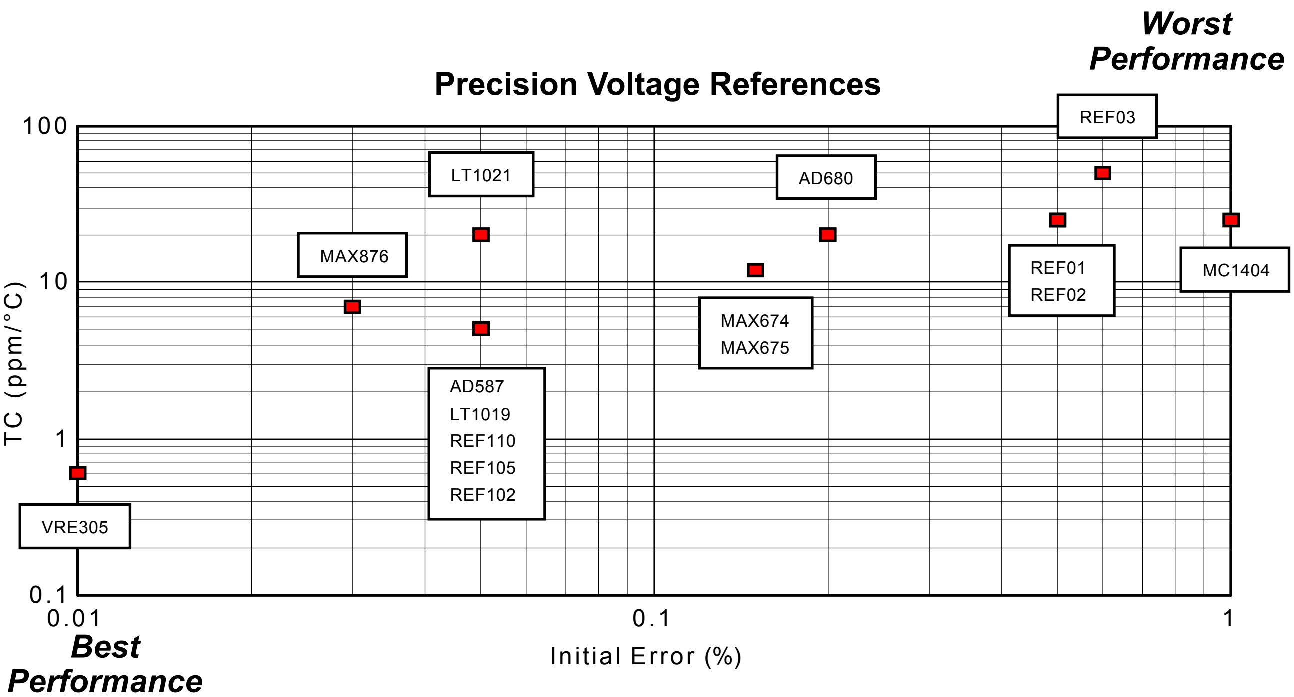

Figure 2. Precision Voltage Reference Performance

REFERENCES FOR A/D CONVERTERS

In data acquisition systems, voltage references can be internal or external to the A/D converter. Monolithic converters are based on bipolar, CMOS, or a combination of the two technologies.

Bipolar A/D converters are typically powered from ±15V and +5V supplies and frequently have a zener diode reference incorporated into the design. The on chip reference provides adequate calibration for 12 bit accurate systems. For higher accuracy, external references are required.

CMOS A/D converters are typically run from +5V supplies which limits the on chip reference to a bandgap design.

With the design push to lower power systems, CMOS and it's affiliated technologies are used more frequently for new designs. Many new data converters do not include an internal voltage reference. This allows for flexibility in selecting a voltage reference commensurate with the required system accuracy.

THE CONSTANT TEMPERATURE ENVIRONMENT

System accuracy is relatively easy to achieve if temperature is held constant. An example of such an environment is an electronic component manufacturing floor, such as for hybrid microcircuits. In such an environment, ambient temperature is closely controlled to 25°C. Many automatic test equipment systems used in such conditions depend on this constant temperature. In fact, many are equipped to automatically recalibrate should temperature vary excessively or to completely stop testing for large temperature swings.

Even in such environments, the power dissipation inside an instrument such as DVM will cause a temperature rise inside the instrument. But the final temperature will be constant. Some DVM calibration procedures account for this requiring that the housing be on the instrument except when adjustments are made.

VARYING TEMPERATURE

Accuracy is more difficult to achieve in an uncontrolled environment. The amount of accuracy that can be achieved can be predicted. And in doing so, some surprising combinations of components come out as winners when temperature variations are factored in.

One of the best examples to use for discussing system accuracy are data conversion applications. Either Analog to Digital Converters (ADC's) or Digital to Analog Converters (DAC's) can be used for this discussion since the error specifications and sources are the same.

Maximum error over temperature for a data conversion system can be defined by the following formula:

Error= (linearity error)+(scale factor TC x temp)

This states that the expected total error due to all sources for any code output is the sum of linearity error and scale factor temperature coefficient (TC) times the temperature deviation from room temperature.

The formula assumes that offset errors are nulled. In most data converters, offset errors have an insignificant effect on drift.

A perusal of data converter data sheets will generally show excellent figures for linearity, including linearity over temperature. This is because linearity is strictly a function of relative values within the converter. Linearity may not be shown as a drift specification, but rather as a min/max limit over temperature.

The scale factor TC is another matter. Scale factor is also known as gain TC or gain error. This error is the sum of data converter scale factor TC and the reference TC. Some data converters use internal references, some external, and some can be used with either. Converters that can be used with external references have two scale factor TC specifications, one using the internal reference and one using the external reference. The scale factor TC of the data converter and external reference is usually much better than that of the internal reference.

A DESIGN EXAMPLE

An example of a data conversion system design for wide temperature range will be used to illustrate the relevance of the total error equation. Two data converters will be compared.

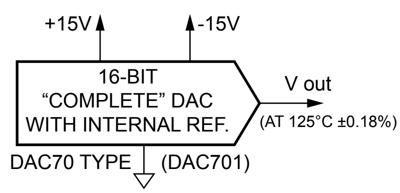

FIGURE 3. DAC70 Type 16-Bit D/A Converter.

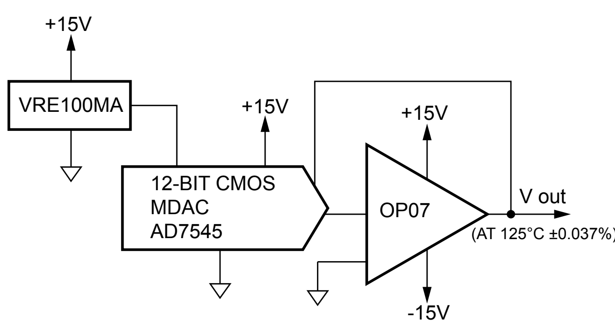

FIGURE 4. AD7545 12-Bit D/A Converter with the VRE100MA 10V Reference.

1. A 16-bit complete device with internal reference i.e. DAC701.

   Lin. error (1) = 0.003% Scale Factor TC = 15 ppm/°C

2. A 12-bit external reference device i.e.. AD7545

   Lin. error (1) = 0.012% Scale Factor TC= 2.0ppm/°C

At room temperature the 16-bit converter is 4 times as accurate. To calculate for accuracy at 125°C using a 0.5ppm/°C reference for the 12-bit converter:

12-bit solution: 0.012%+(2.5ppm[2] x 100°C)=0.037%

16-bit solution: 0.003%+(15ppm x 100°C)=0.153%

Notes:
1) Linearity error is often given in LSB. Percent is found by:

Lin. Error % = ($1/2^n$ x LSB) x 100%
n = number of bits of converter.

2) Includes scale factor TC for DAC and Voltage Ref.

At 125°C, the 12-bit system is almost 5 times more accurate.

How much temperature swing is required to justify this close of an examination? Solving for the temperature excursion where total error of both systems is equal:

$$\begin{array}{r} 2.5ppm / °C \times t = -0.012\% \\ \underline{15ppm / °C \times t = -0.003\%} \\ -12.5ppm / °C \times t = -0.009\% \\ t = 7.2°C \end{array}$$

With a temperature excursion greater than 7.2°C, the 12-bit solution is the most accurate. Scale factor error of data converters will dominate as temperature swing. This will favor the converter with the lowest scale factor TC which can be used with an external reference. Using the data conversion error equation and setting linearity error to zero will allow use of the formula to define just what various references can achieve over temperature. This reduces the formula to a simple:

reference TC x temp = error

Designing over full military temperature range is the most demanding. Using 25°C as a reference point, the maximum temperature excursion is from 25° to 125°C. Using an Apex reference as an example:

0.5ppm x 100°C = 50ppm

50ppm = .005% for approximately a 14-bit level of accuracy.

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