The design and performance of a precision voltage reference circuit for 14-bit and 16-bit A-to-D and D-to-A converters

By Perry Miller, *Application Specialist—Data Converters, Texas Instruments, Dallas,*
and Doug Moore, *Managing Director, Thaler Corp., Tucson, Arizona*

Abstract

This article describes the performance and design of a complete precision voltage reference circuit consisting of the VRE3050 precision reference, the MAX1682 charge pump voltage doubler, and the THS1265 evaluation board. The MAX1682 provides a stable +10 V for the VRE3050 reference. The output from the VRE3050 is divided down to provide a 2-V differential signal to the THS1265 converter.

The circuit is designed to provide an adjustable external precision voltage reference to minimize voltage drift and to operate over the commercial (0°C to +70°C) temperature range. Such a circuit has been used to provide an adjustable external voltage reference for 12-bit, 14-bit, and 16-bit communication data converters, such as the THS1265 and the THS1470.

Introduction

The first paper on this topic appeared in the November 1999 issue of *Analog Applications Journal* (www.ti.com/sc/docs/apps/analog/data_converters.html). It introduced the VRE3050 precision voltage reference and described the criteria for selecting a reference for data converters that operate over the industrial temperature range and the importance of the external voltage reference for high-resolution data converters in general.

In this article we present the design of the external adjustable voltage reference circuit and describe in detail the design of the circuit and temperature measurements over the commercial and industrial temperature ranges. In particular, this practical circuit allows the designer to precisely set the V_{ref+} and V_{ref-} used to determine the full-scale setting for the A-to-D (analog-to-digital) and D-to-A (digital-to-analog) converters.

High-resolution A-to-D and D-to-A converters rely on an external precision voltage reference to establish absolute measurement accuracy. Any reference error undermines the overall system accuracy; thus, the external voltage reference must provide accurately set constant voltage, independent of load changes, temperature, input supply voltage, and time.

The circuitry

The complete external voltage reference circuit is shown in Figure 1. Designed for simplicity, the circuit is comprised of a 2× charge pump (MAX1682), a precision voltage reference (VRE3050), and an adjustable resistor divider. The circuit was evaluated on the THS1265 evaluation board.

The MAX1682 is suitable for use in low-voltage, low-current applications where power management is a concern. The MAX1682 can deliver 30 mA of output current with a voltage drop of only 600 mV. The device output appears at pin 2 of U1 (see Figure 1). For an input of +5 VDC the chip's output is +10 VDC. Capacitors C1 and C2 need some consideration inasmuch as the values need to be large enough to reduce noise at both the input and output of the device. A 10-µF capacitor was used in the circuit. Capacitor C2 must be rated for >10 V. The MAX1682 output is used to supply the DC input voltage required by the VRE3050. Component C3, connected to U2 pin 8, is recommended for high-frequency (10-Hz to 10-kHz) noise reduction. The VRE3050 has a low 3-μV_{p-p} noise from 0.1 to 10 Hz. Capacitor C4 was added to the VRE3050 output pin to reduce the high-frequency system noise at the input to the THS1265.

The new generation of A-to-D and D-to-A converters requires an external ΔV_{ref} that ranges from 1.2 V to 3.5 V. The common voltage references available on the market are 1.2 V, 2.5 V, 4.096 V, and 5 V. Intermediate voltages are often generated from a standard reference voltage using resistor networks. The resistors used are the surface-mount chip type (CR1206-8W) that have a 1% tolerance and a TC of 100 ppm/°C. This design uses potentiometers to make the V_{ref} adjustable.

Figure 1. A practical adjustable voltage reference circuit for 12-bit, 14-bit, and 16-bit data converters

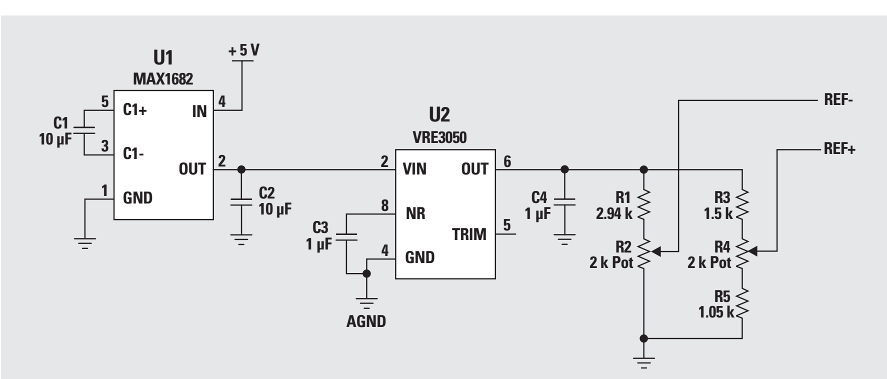
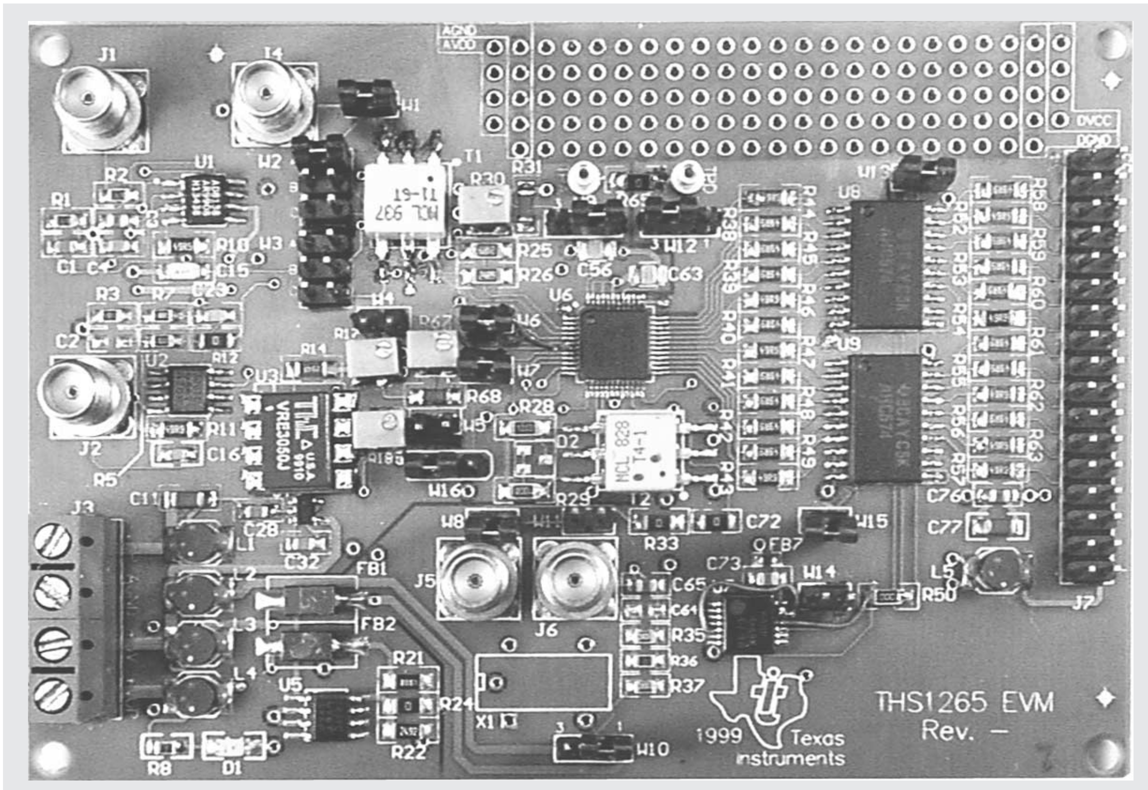


Figure 2. THS1265 evaluation module



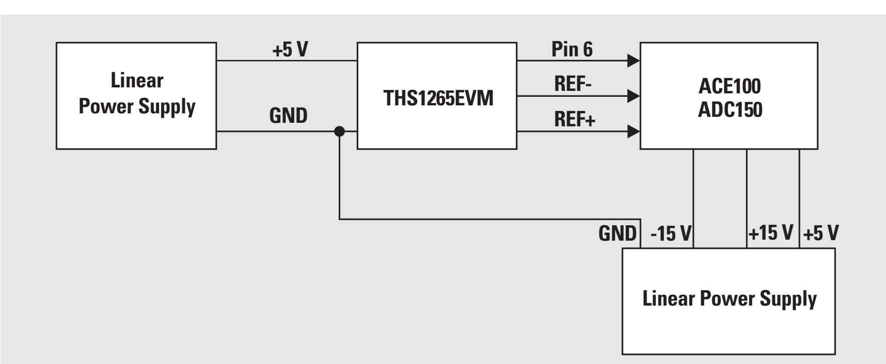
Potentiometers R2 and R4 are used to set REF– and REF+ voltages, respectively. The potentiometer's temperature coefficient (TC) will affect the value of both REF+ and REF– ; therefore, the potentiometers must be chosen from the same series and manufacturer. The TC for the Bourns 3214 series potentiometers used in this circuit is specified at 100 ppm/°C max.

Test setup

The printed circuit board (PCB) used to evaluate the reference circuit is shown in Figure 2. It is the THS1265 evaluation module (EVM) PCB populated with the reference circuit components and a 2-pin power supply connector used for connecting +5 VDC directly to the MAX1682. The PCB is constructed from FR4 material with separate layers for power and ground planes. The power plane layer is split into an analog and a digital power section and the ground plane layer is also split into an analog and a digital ground section. Both analog and digital grounds are tied together at one single point on the ground plane layer. This helps to minimize switching noise interactions between the digital and analog circuits on the THS1265 EVM.

The measurement circuit for the voltages, setup, and adaptation of the THS1265 evaluation module PCB is shown in Figure 3.

Figure 3. Test setup



The THS1265 evaluation board was connected to a DC power supply, then placed in a temperature-controlled oven (±0.5°C). A Thaler ACE100/ADC150 24-bit A/D evaluation board was used to monitor the voltage on pin 6 of the VRE3050 reference and pins REF– and REF+ on the THS1265 board. The grounds were tied to a common point to minimize ground loops. The oven was programmed for the commercial temperature range with data collection points

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at 70°C, 25°C, and 0°C and the industrial temperature range with data collection points at 85°C, 25°C, and –40°C. The data was collected and stored to a file for analysis.

PCB layout

Poor printed circuit board layout (i.e., ground loops) can adversely affect the performance of the reference as well as the output voltage, noise, and thermal performance of the device. Inherent stress in the PCB can also be transferred to the components and can affect the performance of the reference and the overall accuracy of the system.

Results

The output voltages, associated temperatures, and temperature coefficients are summarized in Tables 1 and 2. The temperature coefficient is calculated using the box method.

$$TC = \left[\frac{V_{max} - V_{min}}{V_{nominal} \times (T_{max} - T_{min})} \right] \times 10^6$$

Nominal values of 5 V for the Thaler reference and 2 V for the THS1265 EVM outputs were used. The VRE3050 reference has a TC of 0.5 ppm/°C, which is within the datasheet specification for a J grade device. The output voltage at REF– and REF+ includes the TC error from the trim pot and the resistors, which are each rated at 100 ppm/°C max. The actual drift was ~20 ppm/°C for each of the THS1265 EVM outputs with respect to 2 V. The 2-V differential voltage has a TC of only 5 to 6 ppm/°C. For a 12-bit converter over the commercial temperature range, that equates to ~1 LSB and ~4 LSB over the industrial temperature range.

The thermal hysteresis of the reference circuit design was also evaluated, and the results are summarized in Table 3. Thermal hysteresis was calculated on the room readings after a temperature excursion to 85°C. The VRE3050J had 2.4 ppm of hysteresis over the 60°C temperature excursion, and the ΔV between V+ and V– had 14 ppm of hysteresis.

Summary

An external precision voltage reference is the best way to obtain a very stable and adjustable precise V_{ref} for high-resolution A-to-D or D-to-A converters. The proposed circuit with a variable voltage reference is adequate for circuits that require a variable reference over the commercial operating temperature range. When higher than 12-bit accuracy is required in a system over the industrial temperature range, the trim potentiometers and resistor dividers should be removed from the system. Thaler Corporation offers custom output voltages on their high-precision references.

References

For more information related to this article, visit the TI Web site at www.ti.com/ and look for the following materials by entering the TI literature number into the quick-search box. References without a TI literature number should be available through traditional publishing outlets.

Document Title	TI Lit. #
1. Maxim Corp., MAX1682/1683 Switched-Capacitor Voltage Doubler Datasheet.	—
2. THS1265, 12-bit, 65-MSPS, IF Sampling Communications A/D Converter Datasheet	XXX000
3. Thaler Corp., Evaluation Board ACE100 Datasheet.	—
4. Thaler Corp., Precision Reference VRE3050 Datasheet.	—

Related Web site

www.ti.com/sc/docs/apps/analog/data_converters.html

Table 1. Test results for commercial output voltages

OUTPUT VOLTAGE	0°C	25°C	70°C	TC 0 to 70°C
Thaler reference—VRE3050	4.999763 V	4.999587 V	4.999769 V	0.5 ppm/°C
REF+ from THS1265 EVM	2.996484 V	2.995324 V	2.994505 V	14 ppm/°C
REF– from THS1265 EVM	0.992623 V	0.991307 V	0.989975 V	19 ppm/°C
ΔV_{ref} (REF+ to REF–)	2.003861 V	2.004017 V	2.004530 V	5 ppm/°C

Table 2. Test results for industrial output voltages

OUTPUT VOLTAGE	–40°C	25°C	85°C	TC –40 to 85°C
Thaler reference—VRE3050	4.999922 V	4.999610 V	4.999808 V	0.5 ppm/°C
REF+ from THS1265 EVM	2.998485 V	2.995123 V	2.993548 V	20 ppm/°C
REF– from THS1265 EVM	0.998929 V	0.996100 V	0.992546 V	26 ppm/°C
ΔV_{ref} (REF+ to REF–)	1.999556 V	1.999023 V	2.001002 V	6 ppm/°C

Table 3. Thermal hysteresis

OUTPUT VOLTAGE	25°C	85°C	25°C	HYSTERESIS
Thaler reference—VRE3050	4.999610 V	4.999808 V	4.999622 V	2.4 ppm
ΔV_{ref} (REF+ to REF–)	1.999023 V	2.001002 V	1.999051 V	14 ppm