



Alexander Smolyakov and Mihail Gurevich

ABSTRACT

This application note describes the additional ways of using the REF50xx. The application described in this note creates a reliable device with unique characteristics, which allows voltage references to be connected serially.

Table of Contents

1 Description	2
2 1000-V Reference Voltage Source Characteristics	7
2.1 Conclusion.....	9
3 Revision History	9

List of Figures

Figure 1-1. REF5010 in Zener Diode Mode.....	2
Figure 1-2. REF5010 Connected Serially as Usual Zener Diodes.....	3
Figure 1-3. Schematic of 1000-V Reference Voltage Source.....	5
Figure 1-4. 1000-V Reference Voltage Source, Interior View.....	6
Figure 2-1. 100-kV Reference Voltage Using a REF5010 as the Base Element.....	7
Figure 2-2. Common View of a 100-kV Reference Voltage Source.....	8

1 Description

One of the authors is working in a Mars-Energy high-voltage measurement laboratory, which has a high need for precision voltage sources (such as 1000 V, 5000 V, and 10000 V). One method to build these kinds of voltage sources is to use serially-connected Zener diodes. However, Zener diodes have low precision and stability. The REF50xx reference sources have high stability, but in the [official data sheet](#) there is no recommendation on how to connect devices serially.

The precision and stability characteristics of the REF5010 are so intriguing that they have forced the authors to perform some experimentation. As a result, it was discovered that by connecting the Vin and Vout pins together, the REF50xx is converted to an *ideal Zener diode* without any negative side effects, as shown in the schematic of [Figure 1-1](#).

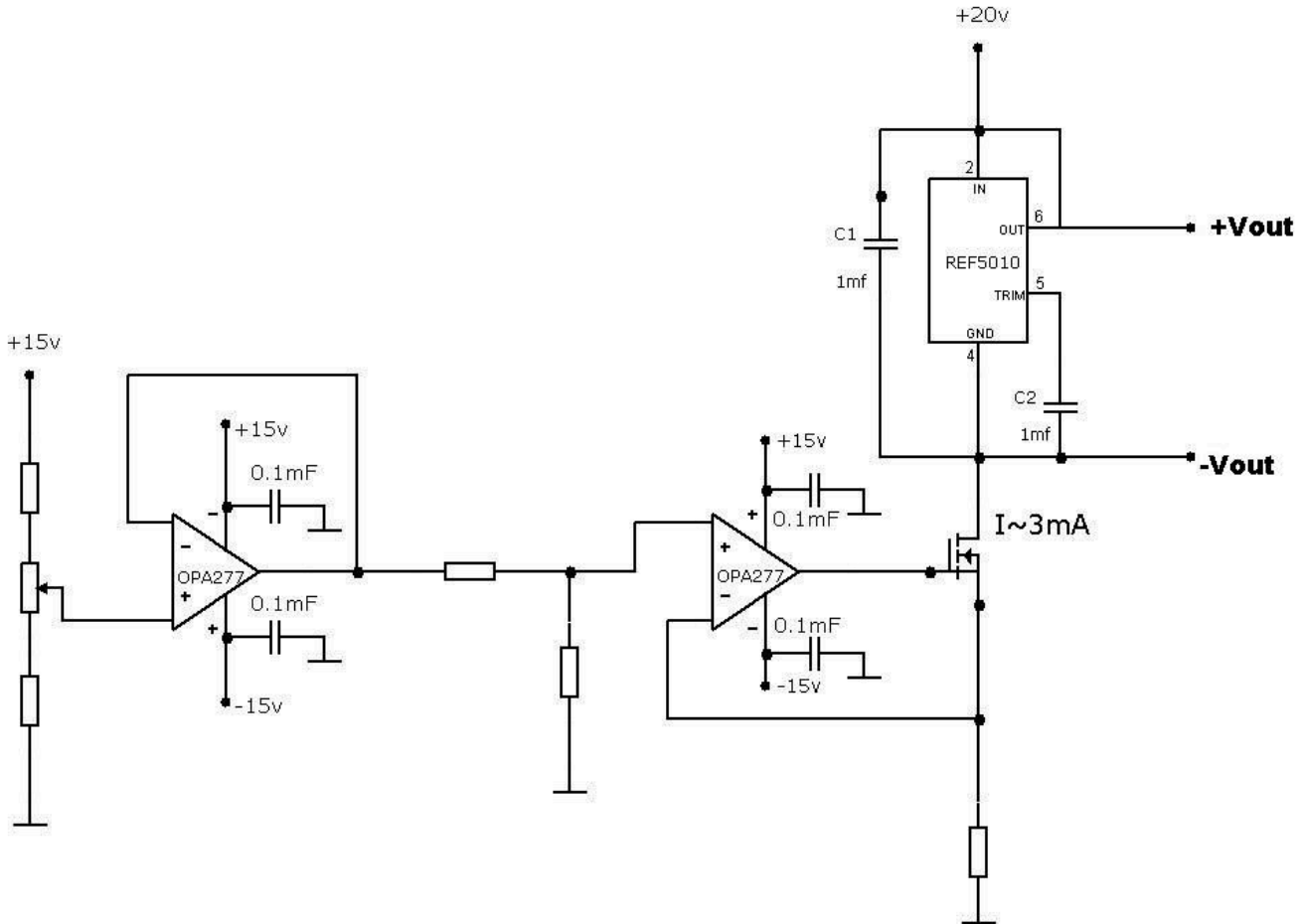


Figure 1-1. REF5010 in Zener Diode Mode

There is only one data sheet operating condition violation in [Figure 1-1](#). REF50xx performance is only ensured when Vin is at least 200 mV greater than the +Vout voltage. The REF50xx ground pin current is set in [Figure 1-1](#) to 3 mA, where 0.8 mA (according the data sheet) is the device quiescent current and 2.2 mA is the +Vout pin sinking current. Likewise, the Vout pin has an input current that is stabilized within the ± 10 mA specified +Iout range. Experiments made with this schematic demonstrated that if a device ground pin current is within the range of 3 mA to 8 mA, the voltage difference between the +Vout and -Vout pins is very precise and stable. However, a significant difference between the standard device application and [Figure 1-1](#) is that in [Figure 1-1](#) there is a two-terminal precision device, which can be easily connected serially (see [Figure 1-2](#)).

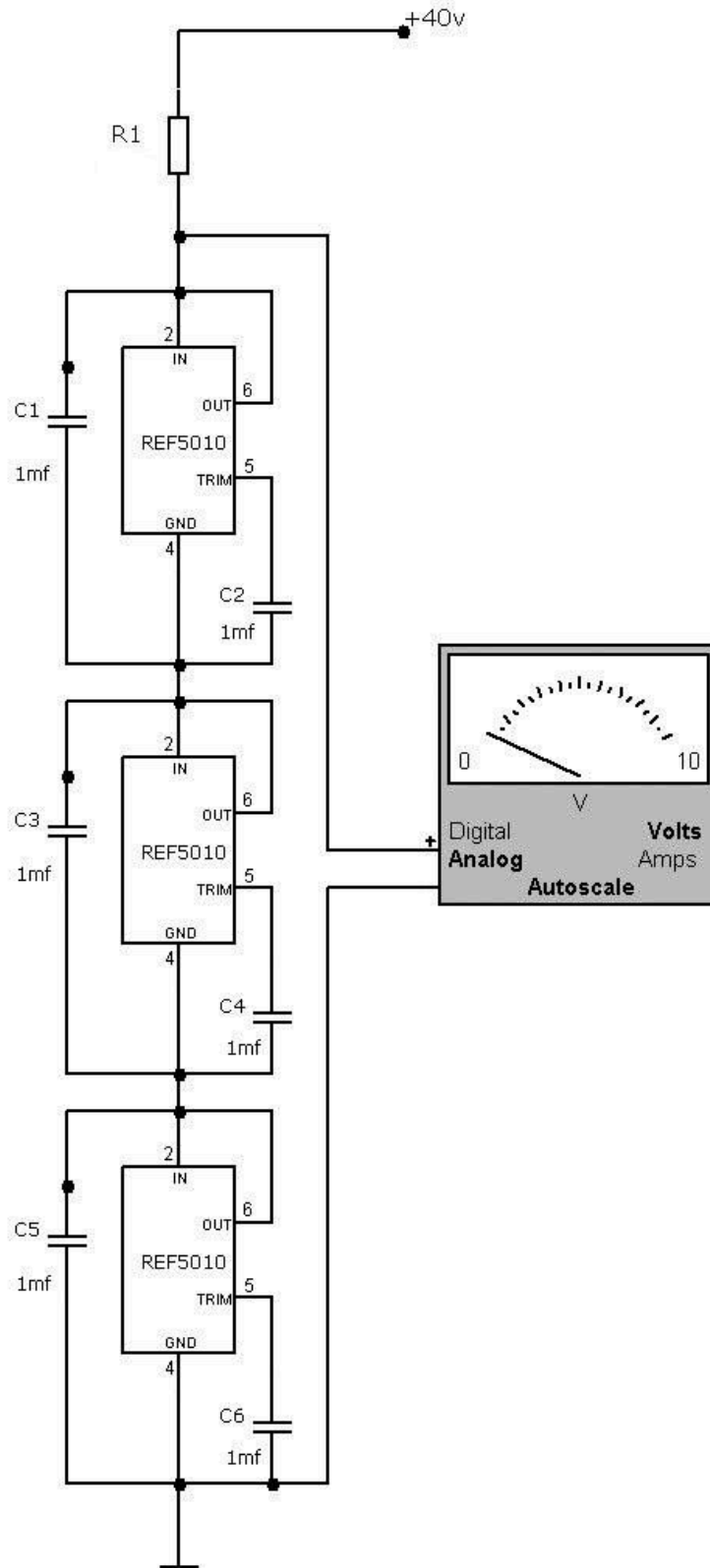
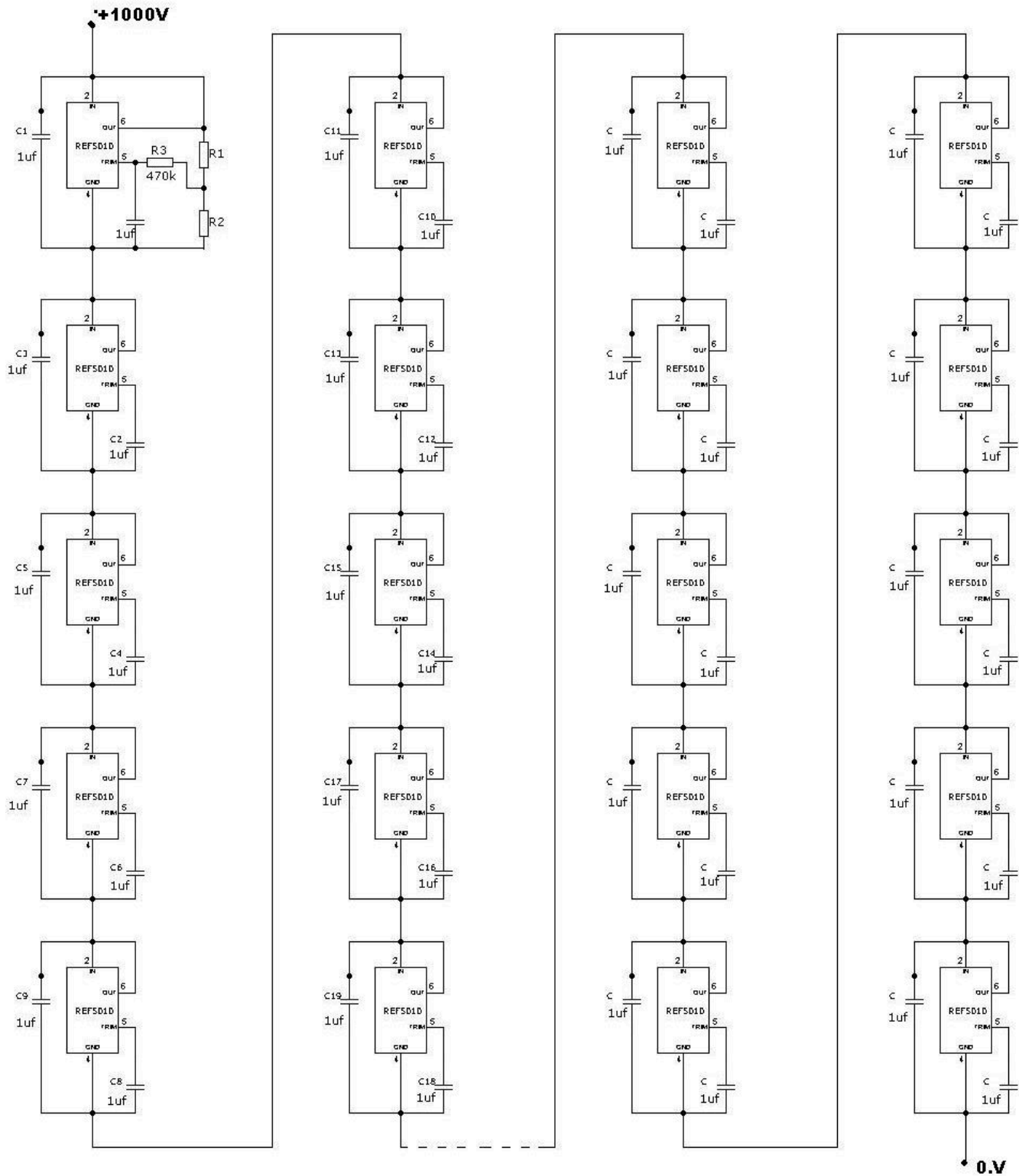


Figure 1-2. REF5010 Connected Serially as Usual Zener Diodes

Experiments performed with the schematic of [Figure 1-2](#) demonstrated the same results as the experiments from [Figure 1-1](#). If the current regulated by R1 stays within the range of 3 mA to 8 mA, the output voltage

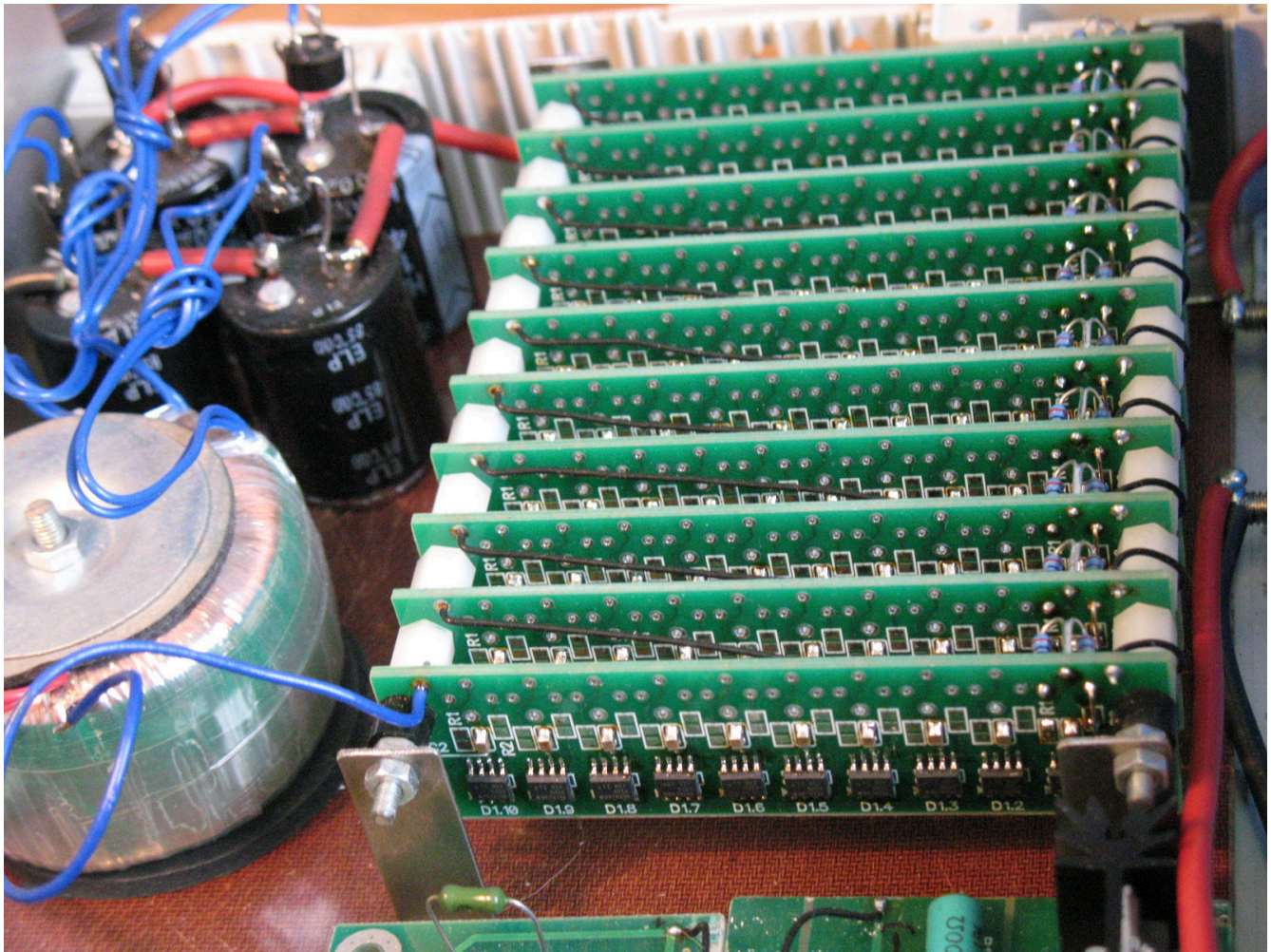
remains stable and is equal to three times the specified voltage of the REF5010 data sheet. The same results are confirmed with other REF50xx device family members.

The precision 1000-V reference voltage source is designed by serially connecting 100 REF5010 devices. Each REF5010 is configured as a two-terminal device. Together, the devices create a 1000-V precision reference source. The top left REF5010 device functions as a voltage adjuster that allows the targeted 1000-V to be set more precisely. However, there is little need for fine tuning because the 100-part averaged value is very close to the ideal 10 V despite some part-to-part variation. The small range of adjustment needed only confirms the statement that if normal distribution is present, a precision device can be built without using precision components. Refer to [Figure 1-3](#). [Figure 1-4](#) illustrates the interior view of the 1000-V voltage source.



NOTE: 100 REF5010 devices are used.

Figure 1-3. Schematic of 1000-V Reference Voltage Source



NOTE: Each board creates a 100-V reference.

Figure 1-4. 1000-V Reference Voltage Source, Interior View

2 1000-V Reference Voltage Source Characteristics

Ten 1000-V reference voltage sources were made. Before the PC boards are installed into the final device, each board goes through thermo training and thermo cycling for 120 hours, according to ISO 9000. The precision and stability of the voltage sources are regularly checked during 3.5 months using the HP3458A digital voltmeter.

The conclusions are:

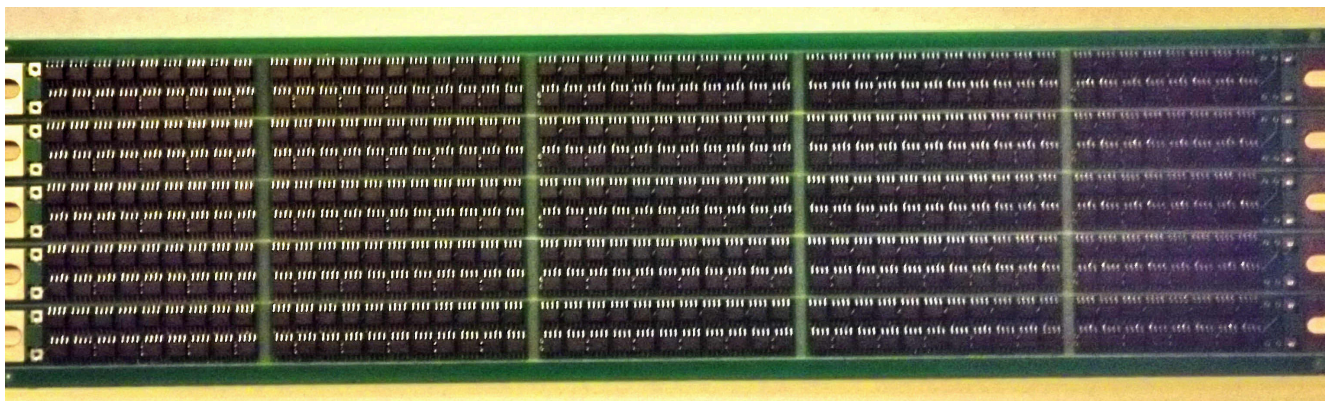
1. Two hours are required to achieve the declared precision corridor of ± 5 ppm.
2. 24 hours are required for the output voltage to stabilize in the precision corridor of ± 2.5 ppm.
3. After stabilizing, the 24-hours change is within ± 3 ppm. The most significant voltage difference between 10 devices after 48 hours is 7 ppm. The most significant voltage difference between devices after 72 hours is 3 ppm to 4 ppm.
4. The average voltage sources output value after 3.5 months is 1000.022 V.

Using the REF50xx two-terminal schemes allows building high-voltage reference sources for any voltage, including sources for tenths of kilovolts.

Currently, the voltage source for 100 kV is built using this method. 10000 REF5010 devices are used to build this device. This design probably hits the record of simultaneous use of TI parts in a single device. Its electrical parameters are under characterization.

Figure 2-1 shows the board that contains 500 serially connected REF5010 devices. The board is later cut into five 100-V strips to obtain better isolation. Together, these strips produce a 5-kV voltage stage.

A 100-kV reference voltage source is depicted in Figure 2-2.



NOTE: Full board view before being cut into 100-V strips.

Figure 2-1. 100-kV Reference Voltage Using a REF5010 as the Base Element



NOTE: The boards are located inside the cylinder.

Figure 2-2. Common View of a 100-kV Reference Voltage Source

2.1 Conclusion

The two-terminal application scheme of the REF50xx has excellent characteristics and features that are closely related to an ideal Zener diode. Serial connections of these blocks allow high voltage reference sources to be built for any voltage with very high precision and stability. Unfortunately, the requirement for additional pins used for package-level trim during device production trimming prevents this ideal two-terminal Zener diode from being offered as a standard device.

3 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision * (May 2013) to Revision A (April 2023)	Page
• Updated the numbering format for tables, figures, and cross-references throughout the document.....	1

IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATA SHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES "AS IS" AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI's products are provided subject to [TI's Terms of Sale](#) or other applicable terms available either on [ti.com](https://www.ti.com) or provided in conjunction with such TI products. TI's provision of these resources does not expand or otherwise alter TI's applicable warranties or warranty disclaimers for TI products.

TI objects to and rejects any additional or different terms you may have proposed.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2023, Texas Instruments Incorporated