

# Adjusting the A/D voltage reference to provide gain

By **Russell Anderson** (Email: anderson\_russ@ti.com)

Senior Applications Engineer

The purpose of providing gain in the analog-to-digital converter (ADC) is to boost the signal and thereby improve the signal-to-noise ratio (SNR). Even in ADCs that have internal programmable gain amplifiers (PGAs), some noise also gets amplified so that a doubling of the SNR is not achieved for each doubling of the programmable gain. This article shows how changing the reference voltage can achieve gain even in those ADCs that have no PGA.

The reference voltage defines the range of voltage inputs and therefore the size of the LSB. For an N-bit converter, the LSB is defined as

$$\frac{\text{Full-scale voltage}}{2^N}$$

The full-scale voltage range may not always be  $V_{REF}$ ; depending on the particular ADC, it could be  $2V_{REF}$  or  $\pm V_{REF}$ . But regardless of how the output codes are mapped, they are directly influenced by the value of  $V_{REF}$ . A smaller voltage for  $V_{REF}$  will mean that all the output codes are constrained to a smaller voltage range and that the LSB will be a smaller voltage.

The observed noise in the output codes comes from two sources: (1) analog noise sources (random and synchronous) and (2) quantization noise.

When the bit size is large, as in an 8- or 12-bit ADC, the dominant noise source is expected to be quantization noise. But for high-resolution converters of 24 bits, the quantization noise could be the smallest noise source. Even when quantization noise is not the major source, reducing it to contribute even less to the overall result can still be useful.

If we look at the RMS noise as a function of the reference voltage for the ADS1253 (Figure 1), we notice that, as a percentage of full-scale, the smallest noise is achieved with the largest  $V_{REF}$ . This is because, as we increase  $V_{REF}$ , we are increasing the LSB; therefore, the dominant noise source starts to be influenced more by quantization noise and less by other noise sources. Or at least, the other noise sources do not increase as fast and therefore contribute less to the larger voltage range and larger LSB size.

If we convert the graph in Figure 1 to a graph of the amplitude of the noise in volts (Figure 2), we can see that the total noise is actually increasing as quantization noise becomes a more significant factor.

We can now see that the lowest noise occurs at a  $V_{REF}$  of 1 V. This can be a significant factor as we examine the voltage range of the input signal.

Figure 1. ADS1253 RMS noise vs.  $V_{REF}$  in ppm of full-scale

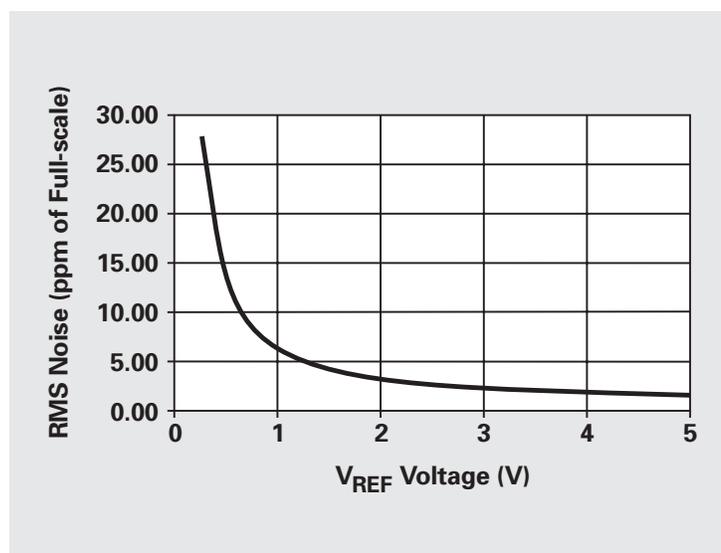
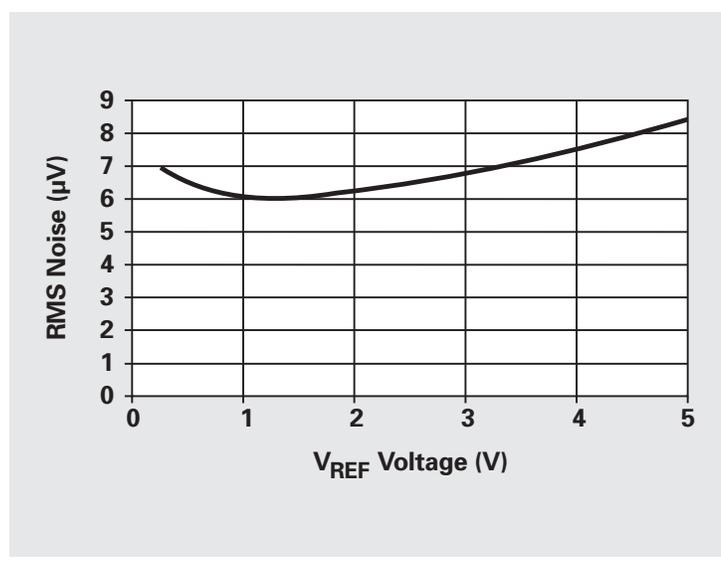


Figure 2. ADS1253 RMS noise vs.  $V_{REF}$  as  $\mu\text{V}$



Let's start by looking at the case of a  $V_{REF}$  of 5 V (Figure 3). If the input signal is smaller than the full-scale range of 10 V (-5 V to +5 V), then it would be more useful to plot the noise versus the signal full-scale value. For example, a noise of 5 ppm with a 5-V full-scale is 10 ppm if the full-scale range is only 2.5 V. It is the magnitude of the noise relative to the signal amplitude that holds our main interest.

The lowest line in Figure 3 is noise versus  $V_{REF}$ . The other lines are noise versus signal voltage.

As can be seen with these different full-scale signals, the best noise performance is achieved when the  $V_{REF}$  matches the full-scale range of the input signal, although there doesn't appear to be any benefit to have a  $V_{REF}$  lower than 1 V.

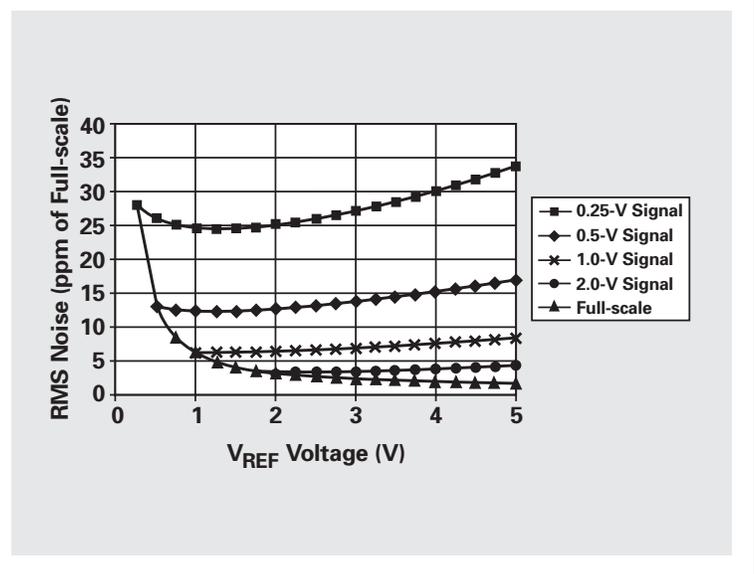
With a lower reference voltage, more of the output codes are used with the smaller range of input voltages. This is the same as providing gain in the ADC. Normally the reference is 5 V; but with a  $V_{REF}$  of 2.5 V the effect is a gain of 2, and a  $V_{REF}$  of 1.25 V would be equivalent to a gain of 4. A gain of 5 seems to be the maximum useful gain, with a  $V_{REF}$  of 1 V.

### Related Web sites

[analog.ti.com](http://analog.ti.com)

[www.ti.com/sc/device/ADS1253](http://www.ti.com/sc/device/ADS1253)

**Figure 3. RMS noise vs. signal and  $V_{REF}$  voltage**



## IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its hardware products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed.

TI assumes no liability for applications assistance or customer product design. Customers are responsible for their products and applications using TI components. To minimize the risks associated with customer products and applications, customers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any TI patent right, copyright, mask work right, or other TI intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information published by TI regarding third-party products or services does not constitute a license from TI to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. Reproduction of this information with alteration is an unfair and deceptive business practice. TI is not responsible or liable for such altered documentation.

Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

### Products

|                  |  |
|------------------|--|
| Amplifiers       | <a href="http://amplifier.ti.com">amplifier.ti.com</a>             |
| Data Converters  | <a href="http://dataconverter.ti.com">dataconverter.ti.com</a>     |
| DSP              | <a href="http://dsp.ti.com">dsp.ti.com</a>                         |
| Interface        | <a href="http://interface.ti.com">interface.ti.com</a>             |
| Logic            | <a href="http://logic.ti.com">logic.ti.com</a>                     |
| Power Mgmt       | <a href="http://power.ti.com">power.ti.com</a>                     |
| Microcontrollers | <a href="http://microcontroller.ti.com">microcontroller.ti.com</a> |

### Applications

|                    |  |
|--------------------|--|
| Audio              | <a href="http://www.ti.com/audio">www.ti.com/audio</a>                   |
| Automotive         | <a href="http://www.ti.com/automotive">www.ti.com/automotive</a>         |
| Broadband          | <a href="http://www.ti.com/broadband">www.ti.com/broadband</a>           |
| Digital control    | <a href="http://www.ti.com/digitalcontrol">www.ti.com/digitalcontrol</a> |
| Military           | <a href="http://www.ti.com/military">www.ti.com/military</a>             |
| Optical Networking | <a href="http://www.ti.com/opticalnetwork">www.ti.com/opticalnetwork</a> |
| Security           | <a href="http://www.ti.com/security">www.ti.com/security</a>             |
| Telephony          | <a href="http://www.ti.com/telephony">www.ti.com/telephony</a>           |
| Video & Imaging    | <a href="http://www.ti.com/video">www.ti.com/video</a>                   |
| Wireless           | <a href="http://www.ti.com/wireless">www.ti.com/wireless</a>             |

## TI Worldwide Technical Support

### Internet

**TI Semiconductor Product Information Center Home Page**  
[support.ti.com](http://support.ti.com)

**TI Semiconductor KnowledgeBase Home Page**  
[support.ti.com/sc/knowledgebase](http://support.ti.com/sc/knowledgebase)

### Product Information Centers

#### Americas

|                |  |     |                  |
|----------------|--|-----|------------------|
| Phone          | +1(972) 644-5580   | Fax | +1(972) 927-6377 |
| Internet/Email | <a href="http://support.ti.com/sc/pic/americas.htm">support.ti.com/sc/pic/americas.htm</a> |     |                  |

#### Europe, Middle East, and Africa

|                   |  |                       |                       |
|-------------------|--|-----------------------|-----------------------|
| Phone             |  |                       |                       |
| Belgium (English) | +32 (0) 27 45 54 32  | Netherlands (English) | +31 (0) 546 87 95 45  |
| Finland (English) | +358 (0) 9 25173948  | Russia                | +7 (0) 95 7850415     |
| France            | +33 (0) 1 30 70 11 64  | Spain                 | +34 902 35 40 28      |
| Germany           | +49 (0) 8161 80 33 11  | Sweden (English)      | +46 (0) 8587 555 22   |
| Israel (English)  | 1800 949 0107  | United Kingdom        | +44 (0) 1604 66 33 99 |
| Italy             | 800 79 11 37   |                       |                       |
| Fax               | +(49) (0) 8161 80 2045   |                       |                       |
| Internet          | <a href="http://support.ti.com/sc/pic/euro.htm">support.ti.com/sc/pic/euro.htm</a> |                       |                       |

#### Japan

|                |  |          |              |
|----------------|--|----------|--------------|
| Fax            |  |          |              |
| International  | +81-3-3344-5317  | Domestic | 0120-81-0036 |
| Internet/Email |  |          |              |
| International  | <a href="http://support.ti.com/sc/pic/japan.htm">support.ti.com/sc/pic/japan.htm</a> |          |              |
| Domestic       | <a href="http://www.tij.co.jp/pic">www.tij.co.jp/pic</a>                             |          |              |

#### Asia

|               |  |             |  |
|---------------|--|-------------|--|
| Phone         |  |             |  |
| International | +886-2-23786800  |             |  |
| Domestic      | Toll-Free Number   |             |  |
| Australia     | 1-800-999-084  | New Zealand | 0800-446-934   |
| China         | 800-820-8682   | Philippines | 1-800-765-7404                                       |
| Hong Kong     | 800-96-5941  | Singapore   | 800-886-1028   |
| Indonesia     | 001-803-8861-1006  | Taiwan      | 0800-006800  |
| Korea         | 080-551-2804   | Thailand    | 001-800-886-0010                                     |
| Malaysia      | 1-800-80-3973  |             |  |
| Fax           | 886-2-2378-6808  | Email       | <a href="mailto:tiasia@ti.com">tiasia@ti.com</a>     |
| Internet      | <a href="http://support.ti.com/sc/pic/asia.htm">support.ti.com/sc/pic/asia.htm</a> |             | <a href="mailto:ti-china@ti.com">ti-china@ti.com</a> |

**C011905**

**Safe Harbor Statement:** This publication may contain forward-looking statements that involve a number of risks and uncertainties. These "forward-looking statements" are intended to qualify for the safe harbor from liability established by the Private Securities Litigation Reform Act of 1995. These forward-looking statements generally can be identified by phrases such as "TI or its management believes," "expects," "anticipates," "foresees," "forecasts," "estimates" or other words or phrases of similar import. Similarly, such statements herein that describe the company's products, business strategy, outlook, objectives, plans, intentions or goals also are forward-looking statements. All such forward-looking statements are subject to certain risks and uncertainties that could cause actual results to differ materially from those in forward-looking statements. Please refer to TI's most recent Form 10-K for more information on the risks and uncertainties that could materially affect future results of operations. We disclaim any intention or obligation to update any forward-looking statements as a result of developments occurring after the date of this publication.

**Trademarks:** All trademarks are the property of their respective owners.

Mailing Address: Texas Instruments  
Post Office Box 655303  
Dallas, Texas 75265

© 2005 Texas Instruments Incorporated

SLYT109