

Optimizing Sensor Measurement: Driving a SAR ADC Input Without a Driver Amplifier



A Successive Approximation Register (SAR) Analog to Digital Converter (ADC) is an excellent choice when it comes to measurement systems that require low latency. Most of the SAR ADCs have an analog input structure which is the combination of a sampling switch, switch resistance and sampling capacitor. In the sampling phase, a sampling switch is closed and the sampling capacitor is charged to the input voltage. To achieve the desired precision and full throughput performance for an ADC, an ADC driver amplifier is frequently used. But do SAR ADCs always need a driver amplifier? Not really! Many sensors can be directly connected to the input of a SAR ADC.

Figure 1 shows a typical application diagram for interfacing a sensor directly to a SAR ADC input without the use of a driver amplifier. The Sensor block highlights the Thevenin equivalent of a sensor output. Voltage source V_{TH} is the Thevenin equivalent voltage and source resistance R_{TH} is the Thevenin equivalent impedance. Most sensor data sheets provide the Thevenin model of the sensor from which the value of the series impedance can be easily calculated.

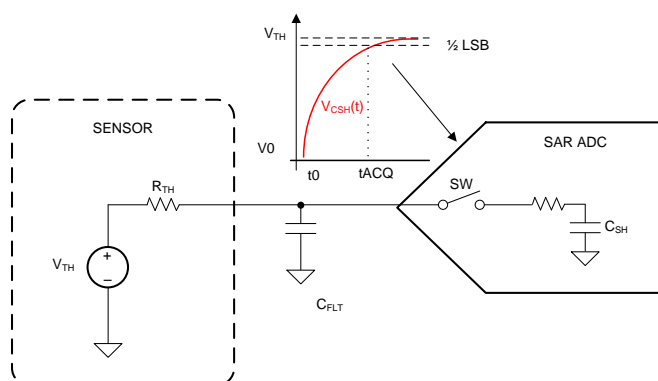


Figure 1. Interfacing SAR ADC Directly With Sensor Output

SAR ADCs can be directly interfaced with sensors when the analog input source is capable of driving the switched capacitor load of a SAR ADC and settling the analog input signal to within $\frac{1}{2}$ of an LSB within the acquisition time of the SAR ADC. This is because $\frac{1}{2}$ of

an LSB is the maximum amount of voltage that an ADC can resolve due to its inherent quantization noise. To achieve this, the external RC filter (R_{TH} and C_{FLT}) must settle within the acquisition time (t_{ACQ}) of ADC. The relationship between the ADC acquisition time and RC time constant of the external filter is given by Equation 1.

$$t_{ACQ} > k \times \tau_{FLT}$$

where

- $\tau_{FLT} = R_{TH} \times C_{FLT}$
- k is the single pole time constant for N bit ADC which can be found on page 96 and page 97 of the [Analog Engineer's Pocket Reference](#)

(1)

For more information on SAR ADCs and front end design for SAR ADCs, refer to SAR ADC Precision Labs [training video series](#).

The output impedance of the sensor must be taken into account when interfacing a SAR ADC directly with sensors. The input signal requires more acquisition time to settle to the desired accuracy if the output impedance of the sensor is higher. One way of interfacing high output impedance sensors directly with SAR ADC is to increase the acquisition time to allow the input signal to settle.

In applications such as environmental sensors, gas detectors and smoke or fire detectors where the input is very slow-moving, the sensor can be connected directly to the SAR ADC. The data acquisition circuit can be designed without the input driver because the ADC can run at a lower throughput rate which lengthens the acquisition period allowing the input signal to settle within $\frac{1}{2}$ of an LSB. This direct interface of sensor to the SAR ADC enables lowest power, smallest size and lowest cost solution.

shows the timing diagram for the ADS7056 ADC. This device requires 18 clock falling edges to complete its conversion process and a minimum of 6 clocks for the acquisition of the input signal.

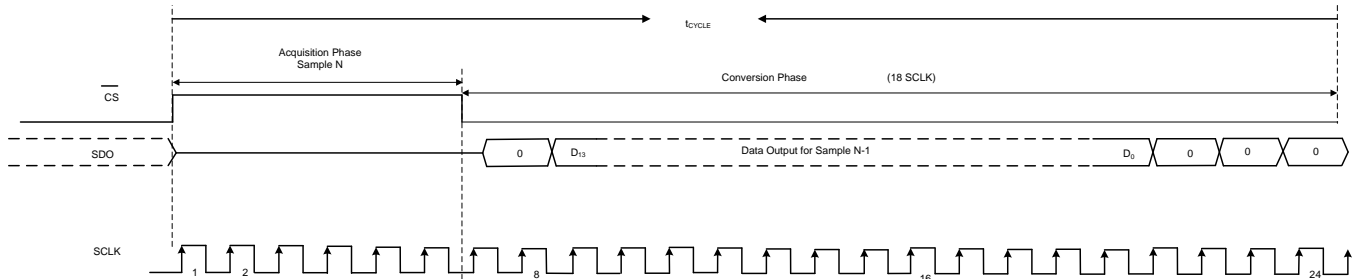


Figure 2. ADS7056 Timing Diagram for 1 Acquisition and Conversion Cycle

The acquisition time of a SAR ADC can be increased by reducing throughput in the following ways:

1. Reducing the SCLK frequency to reduce the throughput
2. Keeping the SCLK fixed at the highest permissible value (that is, 60 MHz for the device) and increasing the CS high time.

Table 1 lists the acquisition time for the above two cases for the ADS7056 SAR ADC operating at 100 kSPS throughput ($t_{\text{CYCLE}} = 10 \mu\text{s}$). We can see that Case 2 provides a longer acquisition time for the input signal to settle.

Table 1. ADS7056 Acquisition Time With Different Clock Speeds

CASE	SCLK	t_{CYCLE}	CONVERSION TIME ($18 \times t_{\text{SCLK}}$)	ACQUISITION TIME ($t_{\text{CYCLE}} - t_{\text{CONV}}$)
1	2.4 MHz	$10 \mu\text{s}$	$7.488 \mu\text{s}$	$2.512 \mu\text{s}$
2	60 MHz	$10 \mu\text{s}$	$0.3 \mu\text{s}$	$9.7 \mu\text{s}$

Figure 3 provides the results for the Effective Number of Bits (ENOB) achieved from the ADS7056 for case 2 at different throughput with different input impedances. Note that all the results for Figure 3 were taken without an ADC driver amplifier.

For this example, you can see that optimal performance is achieved for sampling speeds less than 22 kSPS for a wide range of sensor impedances. Most of the slow-moving (DC to 100 Hz) environmental sensors mentioned earlier such as smoke, gas, chemical, and temperature can be directly interfaced with low-resolution SAR ADCs operating at lower throughputs.

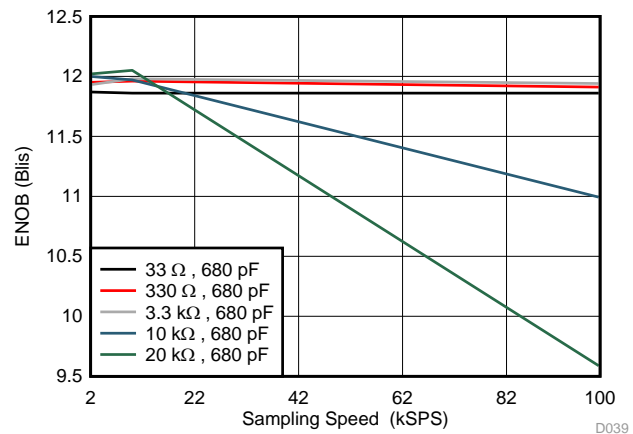


Figure 3. Performance Achieved at Different Throughput Rates of the ADS7056 Under Different Loading Conditions

Table 2 lists performance comparison between an 8-bit, 10-bit, 12-bit and 14-bit ADC with respect to sampling speed and ENOB when a sensor output with an output impedance of 10 kΩ is directly interfaced with the ADC input.

The ADS7042 and ADS7056 families of ultra-low-power, small-size SAR ADCs were especially designed to address system requirements of reducing cost, size and power and are well-suited for low-power sensing applications like the one described here.

Table 2. Sampling Speed and ENOB Performance Comparison Between ADCs

SAMPLING SPEED (kSPS)	ADS7040 (8-BIT ADC) ENOB ($R_{\text{TH}} = 10 \text{ k}\Omega$, $C_{\text{FLT}} = 1.5 \text{ nF}$)	ADS7041 (10-BIT ADC) ENOB ($R_{\text{TH}} = 10 \text{ k}\Omega$, $C_{\text{FLT}} = 1.5 \text{ nF}$)	ADS7042 (12-BIT ADC) ENOB ($R_{\text{TH}} = 10 \text{ k}\Omega$, $C_{\text{FLT}} = 1.5 \text{ nF}$)	ADS7056 (14-BIT ADC) ENOB ($R_{\text{TH}} = 10 \text{ k}\Omega$, $C_{\text{FLT}} = 680 \text{ pF}$)
10	7.93	9.87	10	12.05
100	7.92	9.85	9.97	10.99
500	7.88	9.68	9.95	8

IMPORTANT NOTICE FOR TI DESIGN INFORMATION AND RESOURCES

Texas Instruments Incorporated ("TI") technical, application or other design advice, services or information, including, but not limited to, reference designs and materials relating to evaluation modules, (collectively, "TI Resources") are intended to assist designers who are developing applications that incorporate TI products; by downloading, accessing or using any particular TI Resource in any way, you (individually or, if you are acting on behalf of a company, your company) agree to use it solely for this purpose and subject to the terms of this Notice.

TI's provision of TI Resources does not expand or otherwise alter TI's applicable published warranties or warranty disclaimers for TI products, and no additional obligations or liabilities arise from TI providing such TI Resources. TI reserves the right to make corrections, enhancements, improvements and other changes to its TI Resources.

You understand and agree that you remain responsible for using your independent analysis, evaluation and judgment in designing your applications and that you have full and exclusive responsibility to assure the safety of your applications and compliance of your applications (and of all TI products used in or for your applications) with all applicable regulations, laws and other applicable requirements. You represent that, with respect to your applications, you have all the necessary expertise to create and implement safeguards that (1) anticipate dangerous consequences of failures, (2) monitor failures and their consequences, and (3) lessen the likelihood of failures that might cause harm and take appropriate actions. You agree that prior to using or distributing any applications that include TI products, you will thoroughly test such applications and the functionality of such TI products as used in such applications. TI has not conducted any testing other than that specifically described in the published documentation for a particular TI Resource.

You are authorized to use, copy and modify any individual TI Resource only in connection with the development of applications that include the TI product(s) identified in such TI Resource. NO OTHER LICENSE, EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE TO ANY OTHER TI INTELLECTUAL PROPERTY RIGHT, AND NO LICENSE TO ANY TECHNOLOGY OR INTELLECTUAL PROPERTY RIGHT OF TI OR ANY THIRD PARTY IS GRANTED HEREIN, including but not limited to any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information regarding or referencing third-party products or services does not constitute a license to use such products or services, or a warranty or endorsement thereof. Use of TI Resources 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.

TI RESOURCES ARE PROVIDED "AS IS" AND WITH ALL FAULTS. TI DISCLAIMS ALL OTHER WARRANTIES OR REPRESENTATIONS, EXPRESS OR IMPLIED, REGARDING TI RESOURCES OR USE THEREOF, INCLUDING BUT NOT LIMITED TO ACCURACY OR COMPLETENESS, TITLE, ANY EPIDEMIC FAILURE WARRANTY AND ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, AND NON-INFRINGEMENT OF ANY THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

TI SHALL NOT BE LIABLE FOR AND SHALL NOT DEFEND OR INDEMNIFY YOU AGAINST ANY CLAIM, INCLUDING BUT NOT LIMITED TO ANY INFRINGEMENT CLAIM THAT RELATES TO OR IS BASED ON ANY COMBINATION OF PRODUCTS EVEN IF DESCRIBED IN TI RESOURCES OR OTHERWISE. IN NO EVENT SHALL TI BE LIABLE FOR ANY ACTUAL, DIRECT, SPECIAL, COLLATERAL, INDIRECT, PUNITIVE, INCIDENTAL, CONSEQUENTIAL OR EXEMPLARY DAMAGES IN CONNECTION WITH OR ARISING OUT OF TI RESOURCES OR USE THEREOF, AND REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

You agree to fully indemnify TI and its representatives against any damages, costs, losses, and/or liabilities arising out of your non-compliance with the terms and provisions of this Notice.

This Notice applies to TI Resources. Additional terms apply to the use and purchase of certain types of materials, TI products and services. These include; without limitation, TI's standard terms for semiconductor products (<http://www.ti.com/sc/docs/stdterms.htm>), [evaluation modules](#), and [samples](http://www.ti.com/sc/docs/sampterm.htm) (<http://www.ti.com/sc/docs/sampterm.htm>).

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2017, Texas Instruments Incorporated