Application Brief
ADS7x28 True Root-Mean-Square Module

TEXAS INSTRUMENTS

Overview

The root-mean-square (RMS) value of an AC voltage waveform signifies the effective voltage across a load, that is, the RMS is equal to the DC voltage that can deliver the same power to a load. The RMS value is used to asses the power quality of an AC supply. There are two popular methods of computing RMS, the *Averaging RMS* and *True RMS* methods. The True RMS method is a superset technique that can be used for non-periodic signals, which includes both linear and non-linear loads. This technique is required in electrical grid applications due to the occurrence of sinusoidal and non-sinusoidal voltages and currents in the system. Thus, electrical measuring instruments used for such assessment need to be able to compute RMS of AC signals. This document focuses on the performance of the True RMS module integrated into the ADS7x28 family of ADC devices.

What is True RMS?

The RMS of any signal is the square root of the average of the square of any signal as expressed by Equation 1.

$$e_{RMS} = \sqrt{\frac{1}{T}\int_0^T V(t)^2 dt} \qquad (1)$$

where

- T = time period of the signal
- V = instantaneous voltage of the signal
- t = time

True RMS is a method capable of computing the RMS of sinusoidal signals as well as non-sinusoidal signals. A True RMS measuring circuit first squares the input signal, then performs the average of the result over time. This is followed then by completing the square root of the average to finally compute an accurate RMS value of the input signal.
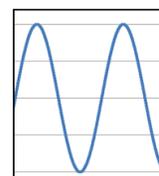
Observation Window

An *observation window* is the time in which the True RMS measurement detects the input signal to compute the result. To accurately calculate True RMS, the *observation window* must include an integer number of half cycles of the input signal. Figure 1 shows an example of a sinusoidal signal with an integer number of 2 half cycles within the *observation window*. If the *observation window* does not include an integer number of half cycles, as shown in Figure 2, the True RMS computation is not accurate.

The *observation window* requires a sufficient number of half cycles to accurately compute the True RMS, though one half-cycle results in a True RMS value. Include a minimum of 32 half cycles to achieve a true RMS with less than 0.5% error. Generally, as the frequency of input signal increases, more cycles are observed within the same *observation window* which results in a decreasing RMS error.

Time

Integral number of half cycles
No error in RMS

Figure 1. Observation Window With Integer Number of Half Cycles

Time

Non integral number of half cycles
Error in RMS

Figure 2. Observation Window Without an Integer Number of Half Cycles

ADS7x28 RMS Module

ADS7x28 is an 8-channel, 12-bit SAR ADC with an integrated True RMS module. Any one analog input channel can be selected for computing the RMS result. The ADS7x28 *observation window* used for the True RMS computation can be configured within the device using Equation 2:

$$\text{observation window} = \frac{\text{RMS\_SAMPLES}}{f_{\text{CYCLE}}} \text{seconds} \tag{2}$$

where

- RMS_SAMPLES is the total number of samples used to calculate the RMS value
- f_{CYCLE} is the sample rate of the ADC

Based on the recommendation of a minimum of 32 half cycles of the input signal within the *observation window*, Table 1 lists the recommended *observation window* with regard to the input signal frequency, and the ADS7x28 configuration to achieve the *observation window*.

Table 1. Recommended Observation Window Length

Input Signal Frequency Cutoff	RMS_SAMPLES	f_{CYCLE}	Minimum Observation Window
≤ 80 Hz	65536	333.3 kSPS	200 ms
≤ 40 Hz	65536	166.7 kSPS	400 ms
≤ 20 Hz	65536	83 kSPS	800 ms
≤ 10 Hz	65536	41.7 kSPS	1600 ms
≤5 Hz	65536	20.8 kSPS	3200 ms

RMS of *AC Only*

The ADS7x28 features the capability of completing the RMS of only the AC component by subtracting the DC input signal component in the True RMS measurement. If True RMS of only the AC component of the input signal is desired, DC subtraction can be enabled by following the configuration setting of the DC_SUB register of the device as shown in Table 2.

Table 2. Configuring True RMS Measurement

True RMS Measurement	DC_SUB Register
AC + DC	0b
AC only	1b

The device implements Equation 3 when the *AC only* input signal component is selected.

$$\text{RMS} = \sqrt{(\text{AC} + \text{DC})^2_{\text{avg}} - \text{DC}_{\text{subtraction}}{}^2} \tag{3}$$

Figure 3 shows the uncalibrated RMS measurement percent error vs input voltage, this means the setting *AC only* was used.
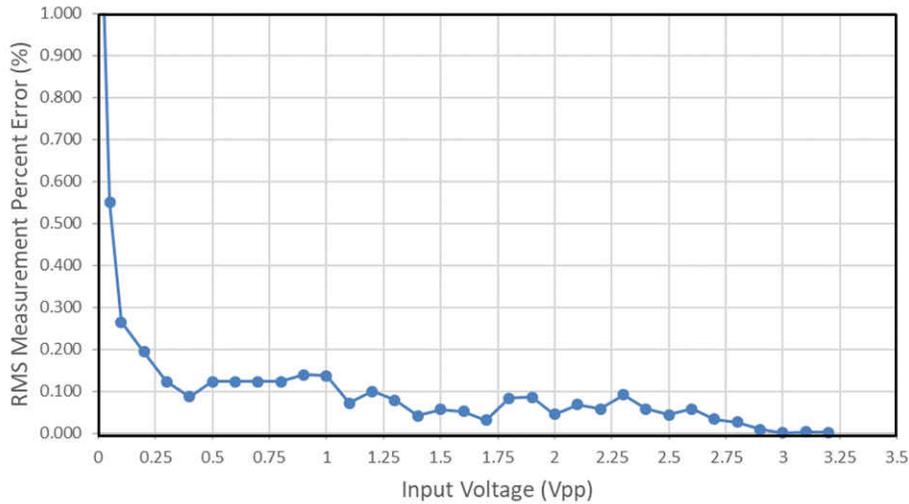

Figure 3. *AC Only* Percentage Error

Improving *AC Only* RMS Results

Implementing a calibration to the RMS calculated can improve the RMS result when using *AC only* using Equation 4.

$$\text{Calibrated RMS} = \text{AC}_{RMS} - \frac{\text{DC}_{RMS}^{2}}{2 \times \text{AC}_{RMS}}$$
(4)

Steps for calibration:

1. Connect unipolar input signal to one channel of ADS7x28
2. Connect the DC offset to another channel
3. Compute *AC only* RMS of the channel with input signal (AC_{RMS})
4. Compute *AC only* RMS of the channel with only DC offset applied (DC_{RMS})
5. Use Equation 4 to solve for the Calibrated RMS value

Figure 4 shows the RMS percent error after calibration plotted against peak-to-peak voltage of the input signal. Calibrating the RMS result reduces the magnitude of RMS error.
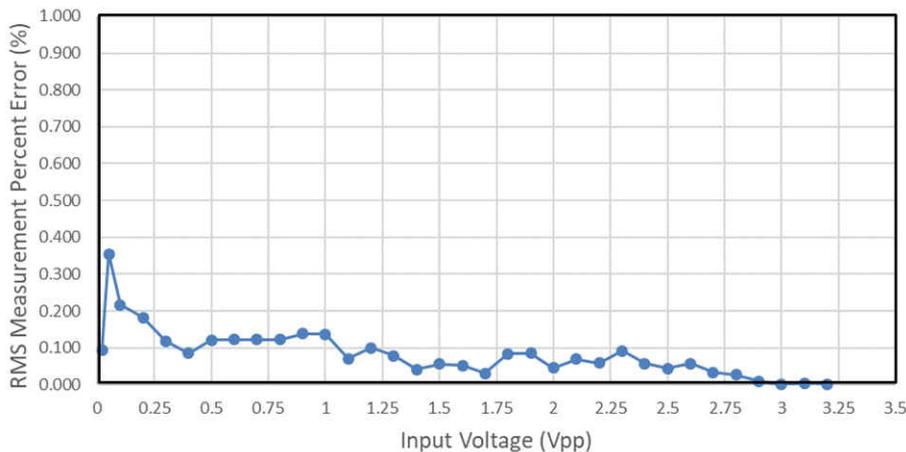
Figure 4. ADS7128 RMS Measurement Percent Error vs Input Voltage (Calibrated)

Conclusion

This brief detailed the merits of RMS computation using ADS7x28 devices.

- **Settings through software**: Select settings through software. No hardware changes required.
- **Simplicity:** Only *observation window* needs to be selected based on the range of input signal frequency through simple software settings. Frequency can be measured by built-in zero crossing detector module. Computation time does not change with crest factor, input signal waveform, amplitude of input signal, and so forth.
- **Calibration:** Error can be improved by calibration using a simple equation.
- **Compact design size:** One-chip design
- **Low power requirement**
- **Unipolar supply**

Table 3. ADCs With RMS Module

Device	Description
ADS7128	Small, 8-channel, 12-bit ADC with I^{2}C interface
ADS7028	Small, 8-channel, 12-bit ADC with SPI

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