Application Report
SNAA074B–August 2011–Revised May 2013

LMP90100 True Continuous Background Calibration

ABSTRACT

To achieve the desired low offset and gain errors over time and temperature, the Texas Instruments LMP90100 employs a technique called true continuous background calibration. This technique essentially eliminates the device's gain and offset errors at all gains and output data rates. This application report discusses how this technique works as well as summarize the numerous background calibration modes offered by the LMP90100. In addition, this application report also explains the advantages of LMP90100's background calibration technique compared to the competitor's background calibration and offer a method to validate background calibration using the Sensor AFE development platform.

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1 Introduction

Many sensor applications require very high absolute accuracy and linearity, and very low noise, offset, and gain errors over time and temperature. Historically, a sensor analog front end (AFE) can be designed using discrete components such as differential amplifiers and ADC. Nowadays, the AFE can be incorporated into one single IC, making the system design compact and less complicated for the system designer. Having an integrated solution means the job to correct for the signal path errors falls into the hands of the IC designer, not the system designer. Texas Instruments LMP90100, a highly integrated, multi-channel, low-power, 24-bit Sensor AFE, is one integrated solution that can do the job.

2 The Background Calibration Offered by the LMP90100

The LMP90100 offers two methods for offset and gain calibration.

- The first method is the Correction method (Method 1) in which the LMP90100 continuously determines the gain and/or offset coefficient and applies this coefficient to the output code. This method continuously keeps track of changes in the LMP90100's gain and offset errors due to changes in the operating conditions such as voltage, temperature, and time. Using this method, however, will create a small impact to the output data rate. The impact depends on the number of channels selected and the output data rates of the selected channels. The impact is least when the number of channels is more and/or their data rates are lower.
- The second method is the Estimation method (Method 2) in which the LMP90100 continuously applies the last known offset and/or gain calibration coefficient to the output code. The last known offset and gain calibration coefficients can come from two sources. The first source is the default coefficient which is pre-determined and burnt in the device's non-volatile memory. The second source is from a previous calibration run of Method 1. Using Method 2 does not create an impact to the output data rate.

The LMP90100 allows a combination of Method 1 and Method 2 in different calibration modes. These calibration modes, as seen in Figure 1, are selected by programming the BGCALCN register. BgCalMode2 is the most accurate mode because it allows both offset and gain correction. BgCalMode1 and BgCalMode3 offer a mixture of correction and estimation methods to correct for the offset and gain errors. Operating in these modes, compared to BgCalMode2, will yield a higher output data rate, lower power consumption, and slightly better noise. The exact savings will depend on the number of channels being scanned and the output date rate and gain of each channel.

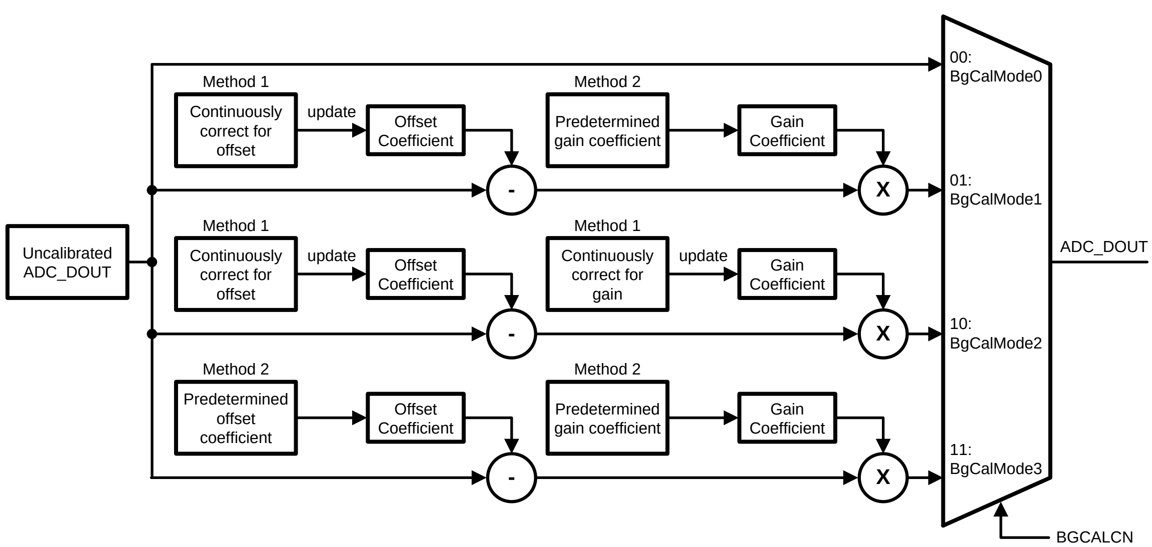

Figure 1. Background Calibration Modes

3 How the Correction Method (Method 1) Background Calibration Works

In the conventional method for offset calibration, differential inputs to the ADC are internally disconnected from the input pins and then shorted with each other. The offset coefficient is calculated and stored in a register, and the offset error from each conversion can be removed by subtracting this coefficient from the digital output code.

Similarly, the conventional method for gain calibration starts with applying a positive full-scale reference voltage to the differential inputs of the ADC. The gain coefficient is calculated and stored in a register, and then the offset corrected digital output code is multiplied by this factor to perform gain calibration. However, in these calibration techniques, the ADC input has to be interrupted while the ADC is calculating the offset or gain coefficient. This effectively reduces the output data rate of the ADC by up to a factor of 6.

LMP90100's background calibration technique has been designed to create minimal impact on the output data rate of the ADC. An important assumption behind this offset calibration technique is that the input is approximately DC so that any two consecutive samples can be considered to be the same. For offset correction, the polarity of the alternate input samples is internally reversed at the FGA (fixed gain amplifier) input, as shown in Figure 2. The offset calibration coefficient can be obtained by averaging any two consecutive digital output codes. This coefficient can be subtracted from the digital output code to remove the offset error.

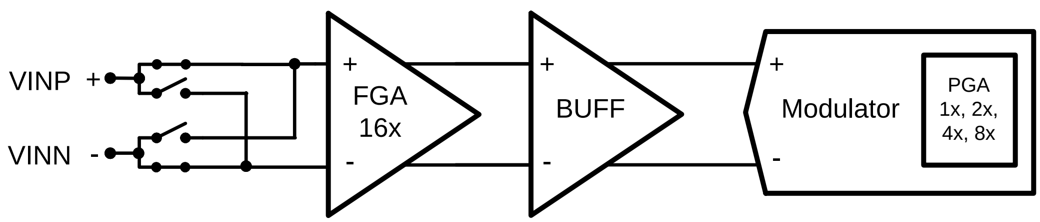

Figure 2. Offset Calibration Technique Diagram

The gain error for the FGA is eliminated by taking a ratio of two gains, first with FGA OFF at alternate input samples, then with FGA ON at alternate input samples, as shown in Figure 3. The gain calibration coefficient is calculated by dividing the ideal gain of the FGA, which is 16, by the actual gain. Afterwards, the offset corrected digital output code is multiplied by this gain correction factor to calibrate for the FGA error.

Gain calibration for the PGA (programmable gain amplifier, 1x to 8x) in the modulator is done by obtaining the output at alternate input samples with the FGA and buffer OFF. The PGA gain coefficient is obtained by dividing the difference of these outputs by the difference of these alternate input samples. The digital output code is multiplied by the PGA gain factor to correct for the PGA error.

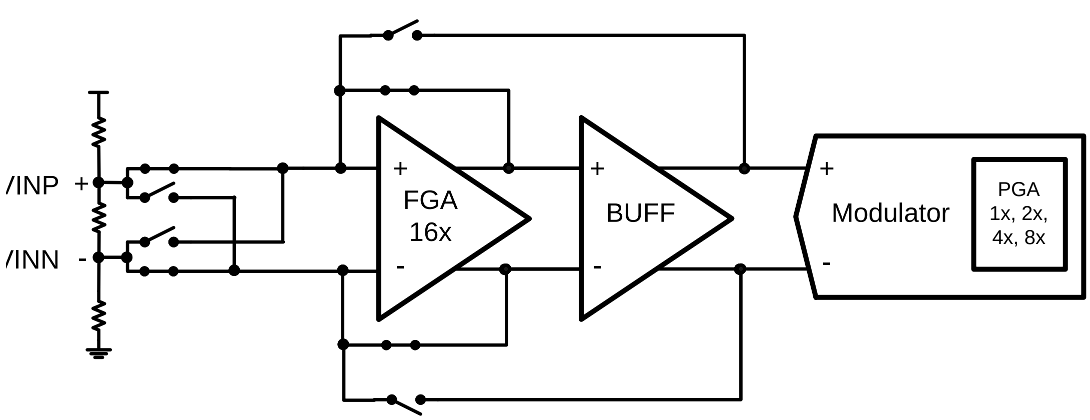

Figure 3. Gain Calibration Technique

4 How Texas Instruments Background Calibration Differs from Competitors

The mentioned calibration techniques allow the LMP90100 to calibrate for its offset and gain errors at all gain and data rate settings with minimal impact to its output data rate. This technique is what separates Texas Instruments background calibration from competitors. In addition, the LMP90100 calibration technique also allows for positive as well as negative gain calibration. This technique also corrects for even-order harmonics and is possible at all gains and for multiple channels with different gain or output data rate settings. Lastly, the LMP90100 calibration technique yields lower noise and higher accuracy because its gain and offset are averaged over several conversions, not just a single conversion.

5 Validating Background Calibration

To validate for offset background calibration, use the LMP9100 Development Platform to capture and compare the sensor signal path data with and without calibration. The LMP90100 Sensor AFE Development Platform consists of the LMP90100 evaluation board, the SPIO-4 digital controller board, and the Sensor AFE Development Platform Software. More information on this collateral can be found on the TI website.

A simple method to validate the offset background calibration is to perform a shorted input test. Internally shorting the LMP90100 means that the positive input voltage is the same as the negative input voltage. For example, since a channel is defined as VINP – VINN, then CH0 = VIN2 – VIN2 is a valid shorted input channel. A shorted input test is a good method to showcase the offset error because it eliminates the possibility of any external errors and the ideal input voltage is a known 0V.

However, due to errors in the signal path, the measured output voltage with a gain of 1 and with calibration OFF is shown in Figure 4.

With calibration ON, the offset error is effectively reduced closer to 0V as shown in Figure 5. This shorted input test is a simple technique that can be done with the LMP90100 Development Platform to showcase the LMP90100 offset calibration.

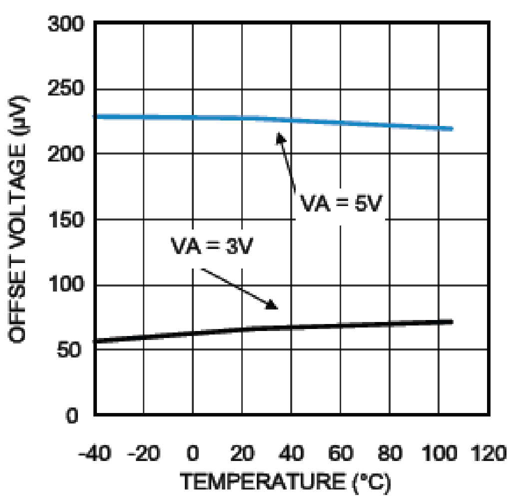

Figure 4. Offset Error at Gain = 1 Without Calibration

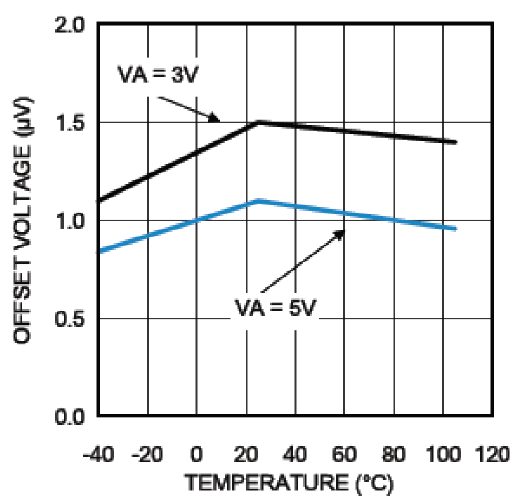

Figure 5. Offset Error at Gain = 1 With Calibration

The gain calibration, however, is harder to prove because it requires careful and accurate measurement of the input voltage. This requires a high precision and accurate multimeter. Nevertheless, it can be done, and typical results for gain error with and without calibration can be seen in Figure 6 and Figure 7.

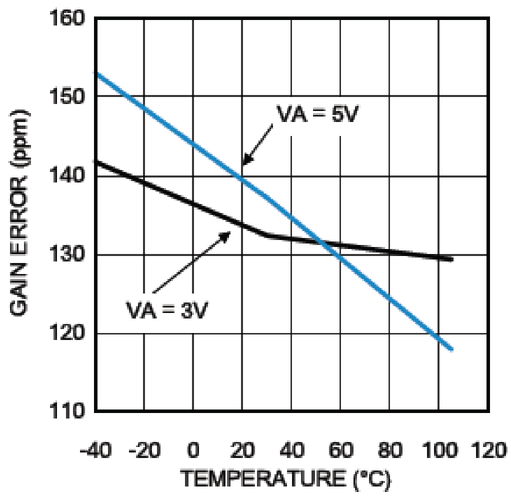

Figure 6. Gain Error at Gain = 1 Without Calibration

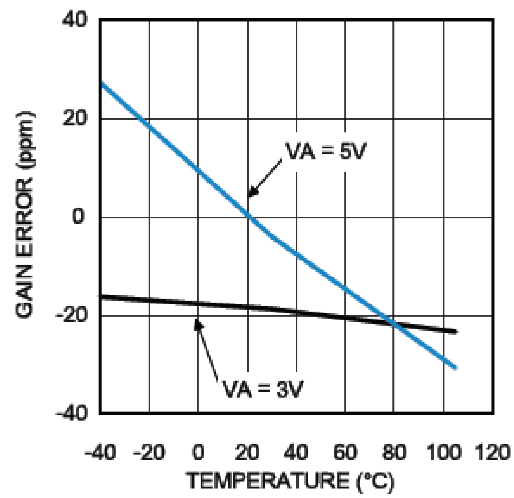

Figure 7. Gain Error at Gain = 1 With Calibration

6 Conclusion

To meet the needs of many sensor applications that require very low offset and gain errors over time and temperature, the LMP90100 employs a true continuous background calibration technique. This technique corrects for higher order nonlinear errors and for positive as well as negative gain. With this technique, the device also retains its output data rate because the input signal is not interrupted, and lower noise and higher accuracy are also possible because the gain and offset are averaged over several conversions.

The background calibration technique has two methods. The Correction method (Method 1) is the most accurate method in which the LMP90100 continuously determines the coefficients and applies these coefficients to the output code to correct for the offset and gain errors. Detailed description of this method was thoroughly discussed in this application report. The second method is the Estimation method (Method 2) in which the coefficient that was previously determined is continuously applied to the output code. Operating in this method will yield a higher output data rate, lower power, and slightly better noise. To choose the appropriate method to correct for the offset and gain errors, program the BGCALCN register.

Background calibration can also be verified using the shorted input test for the offset correction, and the gain error can be verified using an accurate multimeter. With calibration ON, the offset error can be reduced to a typical 1.22 uV, and the gain error can be reduced to a typical 7 ppm, making the LMP90100 an ideal sensor AFE for many sensor applications.

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