Application Brief

Choosing the Voltage Reference for Your Automotive Application

Introduction

In automotive systems such as ADAS, body electronics, powertrain, etc. there is a need for precise data converters. For every data converter, a precise voltage reference (VREF) is often necessary to reach the lowest possible errors when measuring automotive signals. While many data converters can incorporate internal references, it is difficult to find a internal voltage reference in CMOS technology that can reach the high accuracy, low temperature drift, and low noise of a bipolar process. This is even more complicated in digital processes for MCUs as the internal reference can be noisy due to all the inherit clocking noise. Due to this, it is often desirable to use an external voltage reference to have more precise measurements.

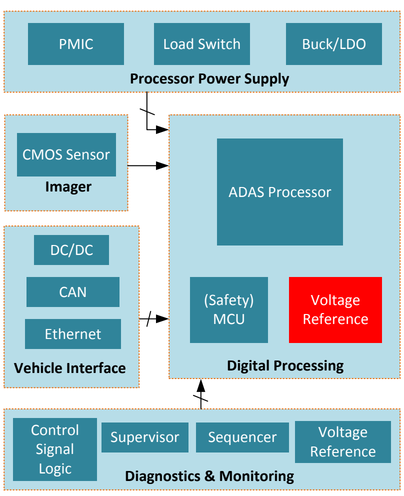

Figure 1. Simplified ADAS Front Camera Diagram

Voltage Reference for Monitoring a 1% 1V Rail

In an automotive advanced driver assistance system (ADAS) it is important to monitor the voltage rails being used in the MCU/DSP/FPGAs. Voltage rails are monitored independently with an ADC and voltage supervisor combination to ensure that the voltage rail does not cross a certain voltage which might cause an undervoltage or overvoltage event which could damage the MCU/DSP/FPGAs. Typically these ADCs are internal to a microcontroller (MCU) that are used to ensure the voltage rails are working correctly.

It is not uncommon to see an external VREF be attached to a MCU for precision and to ensure that the internal ADC has a redundant voltage reference for robustness. With the addition of an external VREF it is possible to have an accurate ADC that does not need calibration for monitoring a 1% 1V rail.

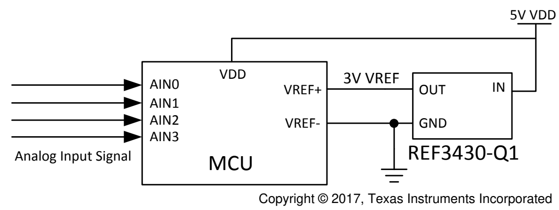

Figure 2. REF3430-Q1 with MCU

In order to ensure that a system meets the error specifications, it is important to characterize the signal chain to understand the errors of the voltage rail. Voltage rail errors have become a more stringent as the total error allowed has been reducing to allow for a more optimized system. An issue with characterizing the signal chain error in a MCU is that typically internal voltage references are not fully characterized as in depth as external voltage references and often lack maximum worst case values. Due to this it is difficult to calculate the worst case error of the system. This challenge can be resolved by using an external voltage reference such as REF3430-Q1 as shown in Figure 2.

Table 1. Typical Core Voltage Rail Monitoring

Specification	Requirement
Voltage Rail	1V
Max Error (-40C to 125C)	1%

Table 1 shows an example of voltage rail monitoring requirements for monitoring a 1V rail for a precision MCU in an ADAS system by a micro. Due to the stringent requirements of some voltage supply rails to be within a certain voltage range, we want to make sure that the total error of the signal chain system is less than 1% so we can measure the deviation which in this case is 10mV.

For a 1V DC measurement it possible to use an external voltage reference to calculate the total error.

There are two ways to calculate error in a system: worst-case and root sum squared (RSS). The main difference between the error calculations is how the individual errors of a system are combined. In worse-case error all the errors are additive of their worst case which results in a conservative to ensure that every device will work but main drawback is that 6+ sigma events are taken into account and this can increase the cost of a system. A common alternative to the worst-case method is the RSS method that is based on statistical tolerance analysis. RSS is used because it provides a more realistic acceptable limit that is based on distributions. In this example we use RSS due to its more realistic presentation of error.

Table 2. REF3430-Q1 3V Specifications

Specification	Requirement
Reference Voltage + Initial Accuracy	3V ± 0.05%
Temperature Drift (-40°C to 125°C)	6 ppm/°C
Temperature Hysteresis (TempCo)	30 ppm
Long-Term Stability	25 ppm
1/f Noise	15 μV_{PP}

The total error for a VREF reference calculation is a culmination of all the errors such as initial accuracy, temperature coefficient, ect. To calculate the total error, all the errors should be in common units such as ppm (parts-per million) as in Equation 1. The VREF total error can be further reduced with calibration, as calibration can eliminate the static errors such as initial accuracy and TempCo. For the purposes of this example, errors such as solder shift, load regulation, line regulation among others have been omitted but they can be included to calculate a more accurate representation of the VREF total error. Equation 1 shows how all the errors are combined using the RSS method.

$$\begin{aligned} \text{Error}_{VREF}\big|_{Total} &= \sqrt{(\text{Accuracy})^2 + (\text{TempCo})^2 + (\text{TempHyst})^2 + (\text{LongTerm Drift})^2 + (1/f\ \text{Noise})^2} \\ &= \sqrt{(500\text{ppm})^2 + (6\text{ppm}/°\text{C} * 165°\text{C})^2 + (30\text{ppm})^2 + (25\text{ppm})^2 + (15\mu V_{PP}/3V)^2} \\ &= 1110\text{ppm} \end{aligned} \quad (1)$$

Table 3. Example of Internal MCU ADC

Specification	Requirement
Resolution	12 Bits
Gain Error	4 LSB
Offset Error	4 LSB
INL Error	4 LSB

When choosing an ADC it is important to find an ADC with the lowest possible errors. Internal MCU ADC with the specifications from Table 3 are used for this example. The ADC total error in this situation is also known as the total unadjusted error and it is calculated similar to the VREF total error by using the RSS method.

$$\begin{aligned} \text{Total Unadjusted Error} &= \text{Error}_{ADC}\big|_{Total} \\ &= \sqrt{(\text{Gain Error})^2 + (\text{Offset Error})^2 + (\text{INL Error})^2} \\ &= \sqrt{(4\ \text{LSB})^2 + (4\ \text{LSB})^2 + (4\ \text{LSB})^2} \\ &= 6.92\ \text{LSB} \end{aligned} \quad (2)$$

When performing error calculations, the error of the ADC is independent but the error of the voltage reference is proportional to the ADC analog input signal. The VREF total error calculated in Equation 2 is only valid when the analog input signal is at full scale. In this example, since the analog input is 1V and not the full scale voltage, only a fraction of the VREF total error affects the analog input can be seen in Equation 3.

$$\begin{aligned} \text{Error}_{VREF@AIN}\big|_{Total} &= \frac{\text{Error}_{VREF@AIN}\big|_{Total} * \text{Analog}_{IN}}{\text{Reference Voltage}} \\ &= \frac{1110\text{ppm} * 1V}{3V} \\ &= 370\text{ppm} \end{aligned} \quad (3)$$

With ADC specifications, the VREF total error is convert into LSB using Equation 4 which makes it possible to combine both VREF and ADC errors using the RSS method in Equation 5.

$$\begin{aligned} \text{Error}_{VREF@AIN}\big|_{Total}(\text{LSB}) &= \text{Error}_{VREF@AIN}\big|_{Total} * 2^{\text{ADC Resolution}} \\ &= 370\ \text{ppm} * 2^{12} \\ &= 1.51\ \text{LSB} \end{aligned} \quad (4)$$

$$\begin{aligned} \text{Error}_{VREF+ADC}\big|_{Total} &= \sqrt{\left(\text{Error}_{VREF@AIN}\big|_{Total}\right)^2 + \left(\text{Error}_{ADC}\big|_{Total}\right)^2} \\ &= \sqrt{(1.51\ \text{LSB})^2 + (6.92\ \text{LSB})^2} \\ &= 7.08\ \text{LSB} \\ &= 2.82\ \text{bits} \end{aligned} \quad (5)$$

$$\begin{aligned} \text{Effective Resolution} &= \text{ADC Resolution} - \text{Error}_{VREF+ADC}\big|_{Total} \\ &= 12\ \text{bits} - 2.82\ \text{bits} \\ &= 9.18\text{bits} \end{aligned} \quad (6)$$

Table 4. Total Error

Specification	Requirement
REF3430-Q1 Total Error for AIN	1.51 LSB
ADC Total Unadjusted Error	7.08 LSB
Percent Error of Vin	0.517%

Table 4 summarizes the final error of the system as an external voltage reference can help in characterizing the error to make sure that the minimum accuracy is met. In practice the measurements will be more precise than the total RSS error but this error can provide a baseline to improve on. The ADC errors of the system can easily be reduced by choosing a more accurate ADC since the dominant error is from the ADC. There are also techniques to improve the voltage reference error such as using a higher voltage external voltage reference. In Table 5 there are alternate voltage reference devices that can help reduce this error or save power.

Table 5. Alternative Device Recommendations

Device	Optimized Parameters
REF3130-Q1	Quiescent current, Temperature drift
REF5025-Q1	Initial accuracy, Temperature Drift, Noise
LM4132-Q1	Quiescent current, Temperature drift
LM4128-Q1	Quiescent current, Temperature drift

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