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TN1461

Technical note

How to calibrate the ADC120 and ADC1283 using a voltage reference

Introduction

The ADC120 and ADC1283 analog-to-digital converters have the same architecture and require a known analog supply voltage to perform voltage conversion in the microcontroller.

This technical note describes the hardware needed to manage software calibration. The software must be able to measure a dedicated channel and compare the results with the expected values. Any differences indicate that the voltage is not appropriate, and this difference should be treated inside the microcontroller to ensure proper conversion.

1 ADC coding and maximum scaling value

The converted input voltage appears on the SPI interface in a 12-bit natural binary code format. The LSB (quantum) of the conversion is directly linked to the analog voltage that supplies the ADC (AVCC).

$$LSB = \frac{AVCC}{2^{12}} = \frac{AVCC}{4096} \quad (1)$$

Typically, the LSB for 3.3V analog supply is rounded to 0.806 mV.

2 Potential error due to imprecise voltage supply

The ADC120 and ADC1283 are SAR ADCs with 12-bit resolution. The AVCC input supply voltage is used in the following ways:

- For supplying the analog part of the ADC.
- As the measurement reference.

If all power supply errors are not known, the microcontroller software may generate a conversion error, even if the hexadecimal conversion result on the output of the ADC represents the analog input voltage correctly. This mismatch can occur in the customer software if the AVCC is over or underestimate, and lead to inaccurate results.

Consider the example of the ADC providing a decimal code of 3526. If the supply voltage is 3.3 V, the measured voltage should be 2.035 V. But if the supply voltage is only 3.25 V, the software must have this new value for reference, or an error may be introduced on the output. For a supply voltage of 3.25 V, the final calculated voltage should be 2.004 V. The user may notice an error of around 0.03 V (30 mV).

3 How to remove the potential error

The real voltage used for the measurement must be reflected by the value used by the microcontroller to perform calculations. As the device uses an analog supply voltage to obtain the digital output of the channel voltage, channel measurement through a resistive bridge supplied by the AVCC is not sufficient.

A reference voltage device can be used as a dedicated channel with a well-known voltage. Measuring this voltage, the software can correct the supply value by performing a comparison with the expected reference voltage.

For example, a reference voltage of 1.8123 V can be used on a dedicated channel. Measurement of this channel can be performed and compared with the recorded value in the software to determine whether the measurement is being performed in a different power supply condition.

The software should implement the correction to obtain the proper conversion voltage, so it can provide the correct voltage after the digitalization of the input analog voltage.

4 ST device able to perform the calibration

Among the various ST reference voltage devices available, we chose the TS3431 adjustable shunt voltage reference buffered by a TSX711 operational amplifier.

The chosen output voltage is 1.8123 V, and appropriate measurement performed with a correct power supply should provide this voltage.

If the measurement returns a different value, the software should adjust the voltage used to calculate the digitalized output voltage.

5 Proposed circuit to perform ADC calibration

The following schematics are designed to ensure proper ADC calibration. A voltage reference with a known value is connected to an input.

Input 0 is used in this case, but all the inputs can be used for this operation.

Figure 1. Proposed block diagram

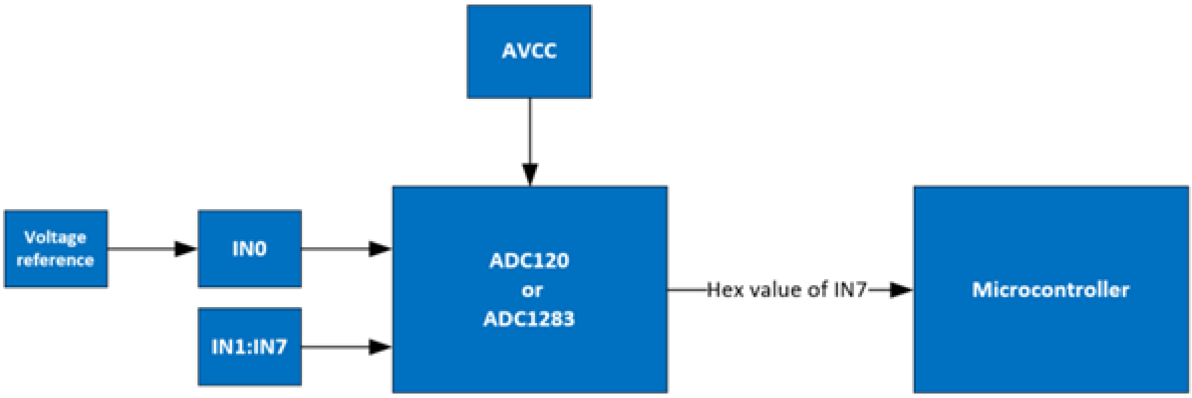
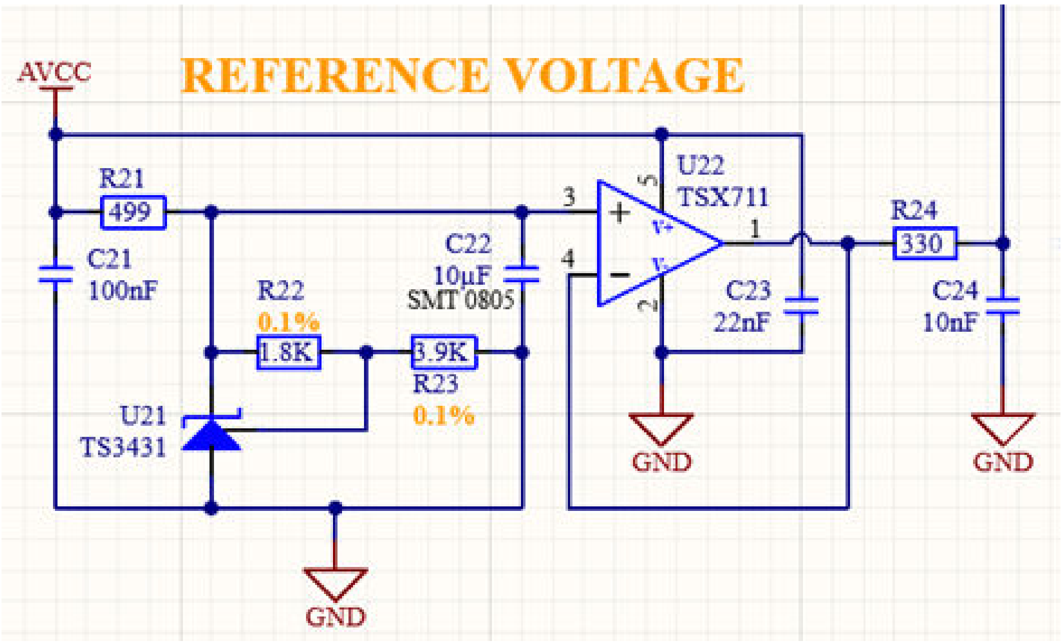


Figure 2. Schematics of the VREF circuit



6 Uncertainty calculations

6.1 Uncertainty calculation example with the TS3431C

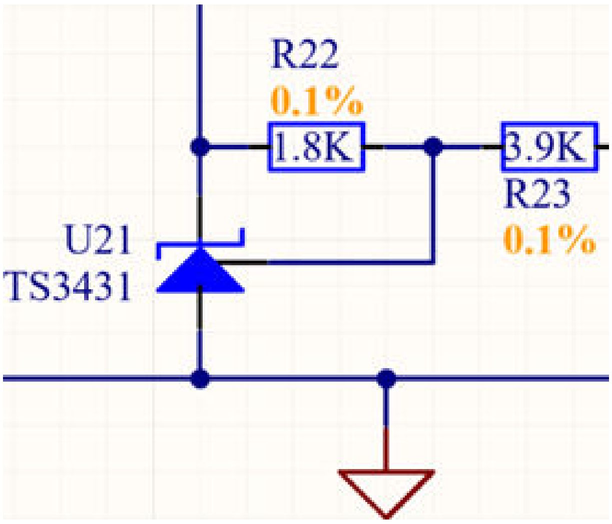
The TS3431 is an adjustable shunt voltage reference with guaranteed temperature stability over the entire operating temperature range (-40°C to +125°C). The output voltage can be set to any value between 1.24 V and 24 V with an external resistor bridge.

The version of the reference voltage mounted on the STEVAL-AKI002V1 is the TS3431C, with ±0.25% precision.

The value of the reference voltage is known and should deliver a constant voltage to the selected ADC input. To determine the uncertainty of the voltage reference, the following calculations were performed with this device at a constant temperature of 25°C.

Using the reference voltage and the schematic presented in Figure 3. Reference voltage set to 1.8123 V, the following calculations determine the error on the reference voltage presented on the ADC input.

Figure 3. Reference voltage set to 1.8123 V



$$V_{\text{ref}} = V_{refTS3431}{}^{*}\left(1 + \frac{R22}{R23}\right) + I_{\text{ref}}{}^{*}R22 \tag{2}$$

With:

- I_{ref} = input current in the TS3431 from the resistor bridge
- From the datasheet: $I_{ref} \in \left[0.5\mu A, 3\mu A\right]$
- V_{ref} = output reference applied on one of the ADC channels current in the TS3431 from the resistor bridge
- $V_{refTS3431} = 1.24V \pm 0.003V$
- R22 & R23 forming the resistor bridge
- Including the uncertainty on resistor values:
  - $I_{refmin} = 0.5\mu A$
  - $I_{refmax} = 3\mu A$

$$V_{ref} = \begin{bmatrix} 0.9975{}^{*}V_{refTS3431}{}^{*}\left(1 + \frac{0.999{}^{*}R22}{1.001{}^{*}R23}\right) + I_{refmin}{}^{*}0.999{}^{*}R22; \\ 1.0025{}^{*}V_{refTS3431}{}^{*}\left(1 + \frac{1.001{}^{*}R22}{0.999{}^{*}R23}\right) + I_{refmax}{}^{*}1.001{}^{*}R22 \end{bmatrix} \tag{3}$$

$$V_{ref} = \left[1.237{}^{*}\left(1 + \frac{1798.2}{3903.9}\right) + 0.0009; 1.243{}^{*}\left(1 + \frac{1801.8}{3896.1}\right) + 0.0054\right]$$

$$V_{ref} = [1.80768V; 1.82324V]$$

$$V_{refmin} = 1.80768V$$

$$V_{refmax} = 1.82324V$$

This reference value is buffered by a TSX711 op amp, which also introduces some uncertainty, but is far lower than the uncertainty from the voltage reference or the ADC1283 and ADC120 devices.

The static characteristics of the ADC120 and ADC1283 give an offset error of ±2 LSB. The LSB value represents the smaller step between two converted values. ADC120 and ADC1283 are both 12-bit converters, hence the LSB depends on the analog voltage applied to the component. As the ADC120 or ADC1283 has an offset error of ±2 LSB on the calculated value, the converted values are precise to ±2 LSB.

The following calculation returns the estimated supply voltage. Val_{in0} is the decimal value read on INput 0 of the ADC (reference input).

$$LSB = Quantum \in \left[\frac{V_{refmin}}{Val_{In0}+2};\frac{V_{refmax}}{Val_{In0}-2}\right] \tag{4}$$

$$LSB_{min} = \frac{V_{refmin}}{Val_{In0}+2} = \frac{1.80768V}{Val_{In0}+2} \tag{5}$$

$$LSB_{max} = \frac{V_{refmax}}{Val_{In0}-2} = \frac{1.82324V}{Val_{In0}-2} \tag{6}$$

$$V_{supply} \in \left[LSB_{min}{}^*(2^{12}-1); LSB_{max}{}^*(2^{12}-1)\right]$$

For example, if the value given by the reference is Val_{In0} = 0x8CC :

$$0\text{x}8\text{CC(h)} = 2252\text{(d)}$$

$$LSB_{min} = \frac{V_{refmin}}{Val_{In0}+2} = \frac{1.80768V}{2252+2} = 0.000802V \tag{7}$$

$$LSB_{max} = \frac{V_{refmax}}{Val_{In0}-2} = \frac{1.82324V}{2252-2} = 0.000810V \tag{8}$$

$$V_{supply} \in \left[LSB_{min}{}^*(2^{12}-1); LSB_{max}{}^*(2^{12}-1)\right]$$

$$V_{supply} \in \left[0.000802V{}^*(2^{12}-1); 0.000810V{}^*(2^{12}-1)\right]$$

$$\boldsymbol{V_{supply}} \in \left[3.284\boldsymbol{V}; 3.317\boldsymbol{V}\right]$$

For a decoded value of 0x8CC, the analog voltage supply applied on the ADC120 or ADC1283 is therefore between 3.284 V and 3.317 V.

6.2 Impact of Vref accuracy

An important thing to consider is the reference voltage precision. For example, if you use a 0.05% reference voltage (accuracy given at the entry of the ADC, see Figure 1. Proposed block diagram) of 1.8123 V, then the following calculations are performed:

$$V_{ref} = 1.8123V \pm 0.05\%$$

$$V_{ref} = \left[1.8114; 1.8132\right]$$

$$V_{refmin} = 1.8114V$$

$$V_{refmax} = 1.8132V$$

Val_{In0} is the decimal value read on INput 0 of the ADC (reference input).

$$LSB = Quantum \in \left[\frac{V_{refmin}}{Val_{In0}+2}; \frac{V_{refmax}}{Val_{In0}-2}\right] \quad (9)$$

$$LSB_{min} = \frac{V_{refmin}}{Val_{In0}+2} = \frac{1.8114V}{Val_{In0}+2} \quad (10)$$

$$LSB_{max} = \frac{V_{refmax}}{Val_{In0}-2} = \frac{1.8132V}{Val_{In0}-2} \quad (11)$$

$$V_{supply} \in \left[LSB_{min}{}^{*}\left(2^{12}-1\right); LSB_{max}{}^{*}\left(2^{12}-1\right)\right]$$

For example, if the value given by the reference is Val_{In0} = 0x8CC :

$$0\text{x8CC(h)} = 2252\text{(d)}$$

$$LSB_{min} = \frac{V_{refmin}}{Val_{In0}+2} = \frac{1.8114V}{2252+2} = 0.000804V \quad (12)$$

$$LSB_{max} = \frac{V_{refmax}}{Val_{In0}-2} = \frac{1.8132V}{2252-2} = 0.000806V \quad (13)$$

$$V_{supply} \in \left[LSB_{min}{}^{*}\left(2^{12}-1\right); LSB_{max}{}^{*}\left(2^{12}-1\right)\right]$$

$$V_{supply} \in \left[0.000804V^{*}\left(2^{12}-1\right); 0.000806V^{*}\left(2^{12}-1\right)\right]$$

$$\boldsymbol{V_{supply}} \in \left[3.292\boldsymbol{V}; 3.301\boldsymbol{V}\right]$$

For a decoded value of 0x8CC, the analog voltage supply applied on the ADC120 or ADC1283 is therefore between 3.292 V and 3.301 V.

7 Conclusion

The measurement on an ADC1283 or ADC120 board using a ST reference voltage on one of the eight channels can provide very useful information to ensure that the software can perform appropriate calibration.

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Revision history

Table 1. **Document revision history**

Date	Version	Changes
06-Mar-2023	1	Initial release.

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