ANALOG DEVICES

APPLICATION NOTE

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Adjusting the Calibration Coefficients on the AD771X Family of Sigma Delta Converters

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INTRODUCTION

The AD771X family of sigma delta converters provides the complete analog front end for a variety of low frequency measurement applications. These 24-Bit Signal Conditioning A/D converters utilise sigma delta techniques to offer 16-bit accuracy and no missing codes to 24 bits. They contain a programmable gain front end, a programmable low-pass digital filter and a bidirectional serial interface. The parts feature differential capability on the analog inputs and on the reference input. They can operate from either single or dual supplies and accept analog inputs as low as 20 mV full-scale or as high as ±10 V full scale. Full data on each member of the AD771X family, which includes the AD7710, AD7711, AD7712, AD7713 and AD7714 converters, is available in the respective datasheet available from Analog Devices and the datasheet should be consulted in conjunction with this Application Note.

CALIBRATION

The parts feature a number of different calibration modes which can be used to take out gain and offset errors in either the part or in the part plus the system. These modes include a self-calibration mode, which removes internal offset and gain errors, a system calibration mode, which can remove both internal and external offset and gain errors, and a background calibration mode which automatically removes internal offset and gain errors. In all of these modes, the part performs the calibration and updates internal 24-bit calibration registers with new calibration coefficients.

The parts contain a pair of calibration registers per channel, one for the zero scale calibration coefficient and one for the full scale calibration coefficient. The zero scale calibration register contains a 24-bit word which is used to take out the offset component (either internal or internal plus external) from the word coming out of the AD771X's digital filter. The full scale calibration register also contains a 24-bit word and this is used to take out the gain component (again either internal or external) from the word coming out of the AD771X's digital filter. The zero scale calibration coefficient is first subtracted from the filter output and the resultant word is then multiplied by a scaled version of the full scale coefficient before being loaded to the part's output register.

The range in values for the calibration registers is quite large. This takes into account the different gains and filter cut-offs which can be programmed on the part and it also takes into account power supply tolerances and on-chip parameter variations due to the fabrication process. The nominal values for these coefficients are generally quite large. For example, the default values for the coefficients after power-on reset are 210A7D Hex (2,163,373 Decimal) for the Zero Scale Coefficient and 52A513 Hex (5,416,211 Decimal) for the Full Scale Coefficient. These default coefficients are the nominal coefficients associated with the default conditions in the Control Register at power-up.

The AD771X provides read/write access to these calibration registers. This can be achieved by writing the appropriate word to the Control Register on the AD771X (consult datasheet). Generally, the part's calibration options are sufficient to remove offset and gain errors and the user requires access to the calibration coefficients either for calibration verification or for systems where the calibration coefficients are stored off-chip in E²PROM during a calibration cycle and then downloaded to the part at a later date.

ADJUSTING THE CALIBRATION COEFFICIENTS

There are, however, applications where the user may wish to change the calibration coefficients of the part to tailor the code from the AD7710 to satisfy particular application requirements. A number of situations arise where the user may wish to change the calibration coefficients and these are discussed in this application note.

Scaling System Full Scale Coefficients

The first situation is where the user has an input voltage available for system calibration which is not the upper limit of the analog input range but is a known ratio of the upper limit. In this case, the user can perform the full scale portion of the system calibration with the AD771X on this available input voltage rather than perform the calibration on the upper limit of the input voltage range as would normally be the case for system calibration cycles. The user then reads back the full scale calibration coefficient and divides it by the ratio of the known input voltage to the upper limit of the analog input range to derive a new full scale calibration coefficient. The user reloads the full scale calibration register with this new coefficient to adjust for the actual input voltage range. In this system, the user should end up with a full scale calibration coefficient which is equivalent to the calibration coeffient which the part would have calculated itself if it were to do a normal system calibration on the upper limit of the analog input range.

For example, if the system full scale voltage is 2.5 V but the user has only 1 V available for a system full scale calibration cycle, then the user can apply the 1 V to the AD771X input during the system full scale calibration cycle. The full scale calibration coefficient can then be read back, multiplied by 2.5 and reloaded to the full scale calibration register. This scheme is only useful if the user knows the exact ratio of the input voltage which is applied during calibration to the upper limit of the actual input voltage range.

Scaling Coefficients as a Means of System Calibration

The second situation in which the user may wish to alter the calibration coefficients, is where the requirement is for a system calibration to an input voltage range other than nominal but the user does not have the upper and lower limits of this input range available during a system calibration cycle. Therefore, the user cannot get the part to provide the calibration coefficients via a system calibration. In this case, the user must perform a self calibration on the device, with appropriate gain, filter setting and unipolar/bipolar range selected and condition the coefficients from the self-calibration cycle to cater for the actual input range. Note, that self-calibration must be performed first and the new coefficients are calculated based on the coefficients after the self calibration. It is not possible to calculate the coefficients without first doing a self calibration under the required operating conditions and then using the part's self calibration coefficients to calculate new coefficients.

Assuming that the nominal analog input range for the part is 0 to V_{REF}, then the part's own self calibration calculates its coefficients with respect to 0 V (shorted inputs) and V_{REF}. Assuming the analog input range which the part is required to work with is not the nominal range and that the system has an offset voltage which is no longer 0 but equals B and an input span which is no longer V_{REF} but $A.V_{REF}$, then the actual input voltage range, V_X, can be described as

$$V_X = A.V_{REF} + B$$

After performing self calibration the zero scale calibration register will contain the self calibration zero scale coefficient, Z_0, and the full scale calibration register will contain the self calibration full scale coefficient, F_0. These coefficients need to be read back and modified to provide a new zero scale coefficient, Z_X, and a new full scale coefficient, F_X. The following formulae can be used to calculate the new coefficients based on the self calibration coefficients:

$$Z_X = Z_0 + \frac{B * 2^{20}}{SPAN * F_0/2^{24}}$$

and

$$F_X = F_0/A$$

where

SPAN is the full scale voltage span under nominal conditions, i.e. V_{REF}/GAIN for unipolar input ranges and $2*V_{REF}$/GAIN for bipolar input ranges.

B is the offset voltage in volts

A is a scaling factor applied to the nominal span and is between 0.8 and 1.05 to obey the datasheet limits for the system calibration range

and 2^{20} and 2^{24} are scaling numbers to cater for on-chip scaling of the coefficients.

Working through an example, assuming the calibration coefficients for the AD771X are 2, 164, 978 for zero scale and 10, 841, 618 for full scale. These are typical coefficients for a nominal unipolar input span of 0 V to +2.5 V at a 60 Hz update rate when V_{REF} = +2.5 V. To calculate new coefficients for an input range of +0.2 V to +2.6 V, the numbers are entered into the above formulae. In this case, Z_0 is 2, 164, 978 and F_0 is 10, 841, 618; B is 0.2 and A is (2.6-0.2)/2.5 which equals 0.96. The new zero scale coefficient, Z_X, then becomes

$$Z_X = 2,164,978 \quad + \quad \frac{0.2 * 2^{20}}{2.5 * (10,841,618/2^{24})}$$

therefore

$$Z_X = 2,164,978 + 129,812 = 2,294,790$$

and

$$F_X = 10,841,618/0.96 = 11,293,352$$

These coefficients are then reloaded to the part to cater for the +0.2 V to +2.6 V input range.

The example above is for a unipolar input range with a gain of 1. If the input range had been bipolar, then SPAN for the above example would equal 5 V. If the gain had been 128 for a unipolar input range, then SPAN would equal 19.53 mV.

The scheme just outlined here is only useful if the user knows the exact upper and lower limits of the desired input range and the ratio of the actual input span to the nominal input span.

Coefficient Alteration for AD7710/AD7711/AD7712/AD7713/7714

The following are recommendations for altering the full-scale and zero-scale coefficients to compensate for conditional variations of the sensor being used.

Assume the following conditions:

Voltage from sensor under nominal conditions $= V_0$

Voltage from sensor under condition $X = V_X = A_X V_0 + B_X$

Zero Scale Coefficient under nominal conditions (as above) $= Z_0$

Full Scale Coefficient under nominal conditions (as above) $= F_0$

Zero Scale Coefficient under condition $X = Z_X$

Full Scale Coefficient under condition $X = F_X$

$$Z_X = Z_0 + \frac{B_X * 2^{20}}{SPAN * F_0/2^{24}}$$

$$F_X = F_0/A_X$$

where,

SPAN is the fullscale voltage span under nominal conditions.

N.B. This equation is applicable to both UNIPOLAR and BIPOLAR modes, however, the calculation of SPAN must take into account either UNIPOLAR or BIPOLAR opeartion,

i.e. for a FULL SCALE of 2.5V and a ZERO SCALE of 0.0V

BIPOLAR SPAN = 5V and

UNIPOLAR SPAN = 2.5V

To calculate a new set of calibration coefficients based on the old set of coefficients and the old readings to give new desired output readings, then the following formulae should be used:

$$NFSC = OFSC \frac{(DFSR - DZSR)}{(OFSR - OZSR)}$$

old full scale cal.

$$NZSC = OZSC - \frac{(DZSR.OFSR - OZSR.DFSR)}{(OFSC/2^{21}).(DFSR - DZSR)}$$

old zero scale cal.

where

NFSC is the new Full Scale Calibration Coefficient which needs to be loaded to the Full Scale Cal Register

NZSC is the new Zero Scale Calibration Coefficient which needs to be loaded to the Zero Scale Cal Register

OFSC is the old Full Scale Calibration Coefficient in the Full Scale Cal Register after calibration

OZSC is the old Zero Scale Calibration Coefficient in the Zero Scale Cal Register after calibration

DFSR is the desired full scale output reading (code) from the part for the full scale input voltage

DZSR is the desired zero scale output reading (code) from the part for the zero scale input voltage

OFSR is the old full scale output reading (code) from the part after calibration

OZSR is the old zero scale output reading (code) from the part after calibration