AN-949
APPLICATION NOTE

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Compensating the ADE71xx/ADE75xx Family RTC for Accurate Timekeeping

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INTRODUCTION

This application note describes how to calibrate and keep accurate time with the ADE71xx/ADE75xx RTC at 25°C and over temperature. It details the hardware compensation provided in the real time clock (RTC) peripheral and provides an algorithm to adjust the compensation over temperature.

The ADE75xx/ADE71xx integrates the analog front end and fixed function DSP of the Analog Devices, Inc., energy (ADE) metering ICs with an enhanced 8052 MCU core. The integrated RTC, LCD driver, and peripherals comprise a fully integrated metering solution.

DESIGN GOALS

Many energy meters offer time-of-use billing where customers are charged a different rate for peak usage and off-peak usage. Because these meters are installed for 10 to 20 years, having an accurate clock to determine the time-of-use bins is essential.

Once calibrated the RTC is accurate to within 0.5 sec/day at a constant temperature and within 0.15 sec/day°C over temperature. This results in an RTC that should not gain or lose more than 30 seconds per month over the temperature range of −40°C to +85°C.

THEORY

Crystals, like other common electrical components, such as resistors and capacitors, have certain tolerances associated with them. A crystal that is specified to have a nominal frequency of 32.768 kHz at 25°C may actually have a frequency ±20 ppm from the nominal. The crystal frequency also changes over temperature. For these reasons, it is important to be able to compensate the crystal frequency variation to keep accurate time. The ADE71xx/ADE75xx makes it easy to achieve this with automatic periodic hardware compensation of the RTC and an on-board temperature ADC.

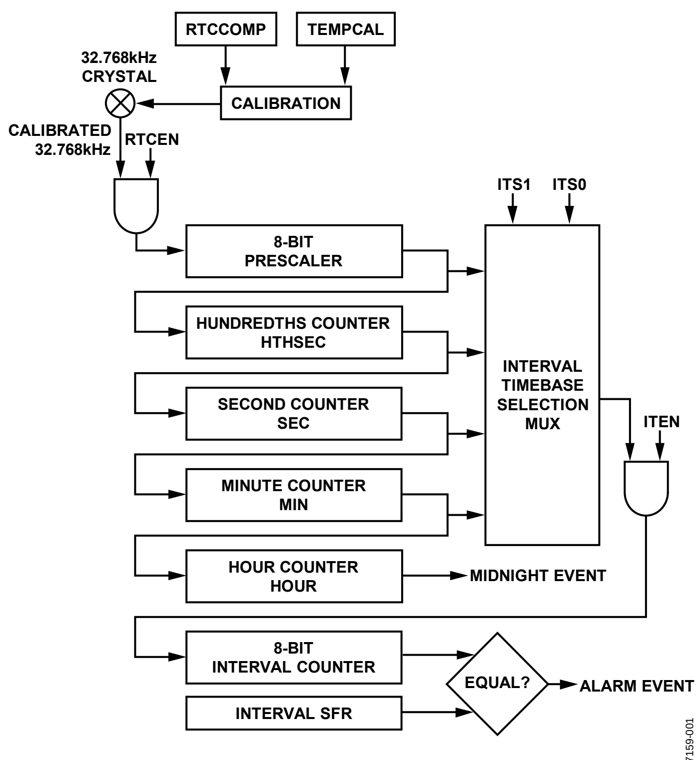

Figure 1. RTC Implementation

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IMPLEMENTATION

The ADE71xx/ADE75xx RTC contains timekeeping registers from hundredths of a second up to hours (see Figure 1). An interrupt is generated once a day for the user to update a software calendar.

The ADE71xx/ADE75xx calibrates the 32.768 kHz input signal using the automatic periodic hardware compensation scheme. Calibration is achieved by adding or removing pulses out of a stream of one million clock pulses. This results in a window of 30.5 seconds in normal mode. A calibration mode is also available with a shorter calibration window of 0.244 seconds. A pulse output proportional to the compensated RTC is provided on P0.2 in both normal mode and calibration mode, with the frequency options shown in Table 1.

The INTPR register is used to select the output frequency for calibration (see Table 1). The RTCCAL bit, also located in the INTPR register, enables the calibration output. Note that the RTC calibration output modes are not recommended for normal use. See the ADE71xx/ADE75xx data sheet for more information.

Table 1. RTC Frequency Options

INTPR Register FSEL [1:0]	Calibration Window(sec)	f_{CAL} (Hz)
Normal Mode 0	30.5	1
Normal Mode 1	30.5	512
Calibration Mode 0	0.244	500
Calibration Mode 1	0.244	16,384

The nominal frequency calibration is performed with the RTCCOMP special function register (SFR) while the TEMPCAL SFR is used to adjust the compensation over temperature. The compensation has a resolution of 2 ppm/LSB, or 0.17 sec/day. Up to 248 ppm of compensation can be adjusted by writing to the RTCCOMP and TEMPCAL SFRs.

Calibrating the Nominal 32 kHz Frequency

An RTC reference or a frequency counter is used to determine the error in the frequency output. An example of an RTC reference, the ITP02 made by Infotec Electronics Co., Ltd., is shown in Figure 2. This reference meter determines the sec/day error between f_{CAL} and the expected frequency, over a configurable gate time of 1 sec, 5 sec, or 10 sec.

Figure 2. ITP02 RTC Reference from Infotec

The required compensation can be determined by calculating the percentage error in the single pulse frequency output. Once the error from the crystal is known, a calibration value is loaded into the internal RTCCOMP register. The ADE71xx/ADE75xx automatically compensates the RTC frequency by the value loaded into the RTCCOMP register. This compensation occurs within a time window defined by the RTC mode (see Table 1). In normal mode, this window is 30.5 seconds.

The required RTC adjustment is determined from the output pulse created in firmware. The RTC calibration pulse is output on P0.2. From the output pulse the percentage error in the frequency can be determined and the compensation factor derived. The RTCCOMP register represents 2 ppm of correction where 1 sec/ day is equal to 11.57 ppm.

$$RTCCOMP = \frac{1}{2 \times 11.57} \times \left(\text{sec}/\,day\ \ error\right)$$

$$RTCCOMP = 5000 \times \left(\%\ \ error\right)$$

Assuming that the calibration is performed in normal mode and given that the actual RTC calibration pulse is 1.000063 Hz, the RTCCOMP value can be calculated as follows:

$$RTCCOMP = \frac{1\ \text{Hz}_{\text{actual}} - 1\ \text{Hz}}{1\ \text{Hz}} \times 5000$$

$$RTCCOMP = \frac{1.000063\ \ \text{Hz} - 1\ \text{Hz}}{1\ \text{Hz}} \times 5000 = -31$$

To verify the calibration after the RTCCOMP or TEMPCAL registers are adjusted to a nonzero value, the calibration must be checked over the calibration window. This means that with a RTC reference or frequency counter, the gate time should be set to 30 seconds or some multiple of 0.244 seconds, depending on the frequency output mode. Alternatively, if a 30 sec gate time is not available, the error from three 10 sec gated measurements could be averaged to get the final error.

Determining Crystal Variation Over Temperature

Crystal variation over temperature is dictated by the physics of the mechanical crystal, resulting in the parabolic curve shown in Figure 3. If no temperature compensation is applied to compensate for this behavior, the RTC could quickly lose its accuracy in an outdoor environment.

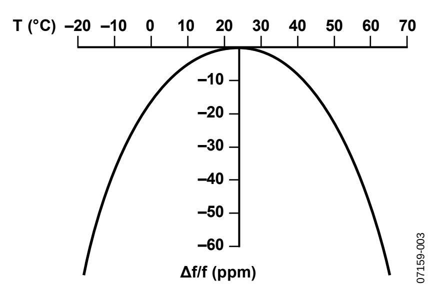

Figure 3. Parabolic Temperature Curve of a Crystal

The curve is typically specified by the crystal manufacturer in terms of the inflexion point (T_o) and the curvature (k). The frequency variation can then be mathematically described as a function of these parameters as shown in Equation 1.

$$f - f_o = -k \times \left(T - T_o\right)^2 \quad (1)$$

The curvature, k, is intrinsic to the mechanical properties of the crystal and can vary from manufacturer to manufacturer. Because it is undesirable to perform a temperature calibration in production, the curvature should be fixed in the design. The crystal data sheet gives a typical specification for the curvature. This value can be used if the error is acceptable. Alternatively, this parameter can be determined empirically, by testing the change in frequency output across several meters.

Once the crystal coefficient has been determined, an algorithm is developed to add in the appropriate correction based on the temperature of the meter. Obtaining a temperature reading is easily achieved in the ADE71xx/ADE75xx by using the on-board temperature ADC.

ADE71xx/ADE75xx Temperature ADC

The ADE71xx/ADE75xx temperature ADC is accurate to 0.78°C per LSB. The ADE71xx/ADE75xx provides two ways to obtain temperature measurements. In one method, a temperature measurement is requested and then read from a register. In the second method, temperature measurements take place in the background and, once the change in temperature exceeds a user defined threshold, an interrupt is generated. For example, an interrupt could be generated after the temperature ADC changes by one or more LSBs, in increments of 0.78°C .This provides an unobtrusive way for the user code to keep track of the temperature. Refer to the ADE71xx/ADE75xx data sheet for more information on the temperature ADC measurement.

Temperature Compensation Algorithm

The easiest way to perform the temperature compensation is to update the TEMPCOMP SFR when the temperature ADC result changes. The crystal used in the ADE71xx/ADE75xx reference design has a curvature of −0.0306 ppm/°C^2 and an inflection point of 25°C. From this, the relationship between the TEMPADC code and the appropriate TEMPCOMP is derived and finally given in Equation 2.

Equation 1 and the intrinsic properties of this crystal give the change in crystal frequency as a function of temperature.

$$\Delta f = -0.0306 \text{ ppm} \times \left(\Delta T\right)^2$$

The TEMPADC in the ADE71xx/ADE75xx has a resolution of 0.78°C/LSB so that

$$\Delta T = 0.78°\text{ C/ LSB} \times TEMPADC$$

Substituting this in, the change in crystal frequency as a function of the TEMPADC register is determined:

$$\Delta f = -0.0306 \text{ ppm} \times (0.78)^2 \left(\Delta TEMPADC\right)^2$$

Because the RTC compensation given by the TEMPCOMP register has a weight of 2 ppm/LSB

$$\Delta TEMPCOMP = \frac{-0.0306 \text{ ppm}}{-2} \times (0.78)^2 \left(\Delta TEMPADC\right)^2$$

$$\Delta TEMPCOMP = 0.0093 \times \left(\Delta TEMPADC\right)^2 \quad (2)$$

Equation 2 can be rearranged, as shown in Equation 3, to simplify the math required for the 8052 core processor.

$$\Delta TEMPCOMP = 38 \times 2^{-12} \times \left(\Delta TEMPADC\right)^2 \quad (3)$$

This requires two 8 × 8 multiplications and some shifting. However this is not code or time intensive since the 8052 core includes a multiply instruction.

Alternatively, the compensation could be implemented with a simple look up table. Because the change in crystal frequency is parabolic, and hence symmetrical around the y-axis, only half of the compensations need to be stored.

The resulting lookup table is shown in Table 2. The index and thus the compensation value can be determined by reading the temperature ADC and subtracting the value at 25ºC, 139. For example, at 70ºC the TEMPADC value is 207 resulting in an index of 207 − 139 = 68. Therefore, the required TEMPCOMP value at 70ºC is 37. Because of the symmetrical nature of the crystal temperature response, the index can be defined as the absolute value of the difference between the ADC reading at temperature and 25°C.

$$Table\ Index = \left| TEMPADC - TEMPADC_{25°C} \right|$$

Table 2. RTC Temperature Compensation Lookup

Index	Temp (°C)	TEMPADC Code	TEMPCOMP Value
0	25.12863	139	0
1	25.79268	140	0
2	26.45674	141	0
3	27.12079	142	0
4	27.78485	143	0
5	28.4489	144	0
6	29.11296	145	0
7	29.77701	146	0
8	30.44107	147	0
9	31.10512	148	1
10	31.76917	149	1
11	32.43323	150	1
12	33.09728	151	1
13	33.76134	152	1
14	34.42539	153	1
15	35.08945	154	2
16	35.7535	155	2
17	36.41756	156	2
18	37.08161	157	2
19	37.74567	158	3
20	38.40972	159	3
21	39.07378	160	3
22	39.73783	161	4
23	40.40189	162	4
24	41.06594	163	4
25	41.73	164	5
26	42.39405	165	5
27	43.0581	166	5
28	43.72216	167	6
29	44.38621	168	6
30	45.05027	169	7
31	45.71432	170	7
32	46.37838	171	8
33	47.04243	172	8
34	47.70649	173	9
35	48.37054	174	9
36	49.0346	175	10
37	49.69865	176	10
38	50.36271	177	11
39	51.02676	178	11
40	51.69082	179	12
41	52.35487	180	13
42	53.01893	181	13
43	53.68298	182	14
44	54.34703	183	15
45	55.01109	184	15
46	55.67514	185	16
47	56.3392	186	17
48	57.00325	187	17
49	57.66731	188	18
50	58.33136	189	19
51	58.99542	190	20
52	59.65947	191	20
53	60.32353	192	21
54	60.98758	193	22
55	61.65164	194	23
56	62.31569	195	24
57	62.97975	196	24
58	63.6438	197	25
59	64.30786	198	26
60	64.97191	199	27
61	65.63597	200	28
62	66.30002	201	29
63	66.96407	202	30
64	67.62813	203	31
65	68.29218	204	32
66	68.95624	205	33
67	69.62029	206	34
68	70.28435	207	35
69	70.9484	208	36
70	71.61246	209	37
71	72.27651	210	38
72	72.94057	211	39
73	73.60462	212	40
74	74.26868	213	41
75	74.93273	214	42
76	75.59679	215	44
77	76.26084	216	45
78	76.9249	217	46
79	77.58895	218	47
80	78.253	219	48
81	78.91706	220	49
82	79.58111	221	51
83	80.24517	222	52
84	80.90922	223	53
85	81.57328	224	54
86	82.23733	225	56
87	82.90139	226	57
88	83.56544	227	58
89	84.2295	228	60
90	84.89355	229	61
91	85.55761	230	62

RESULTS

The nominal crystal frequency is calibrated to be within 2 ppm, or 0.17 sec/day with a design goal of 0.5 sec/day. Using Table 2, a worst-case error over temperature of 0.085 sec/day°C is obtained. The calibrated error over temperature is shown in Figure 5. Both Table 2 and the direct calculation approach result in the same error, well within the 0.15 sec/day target. Note that some part-to-part variation in the crystal variation over temperature results in a small increase in the error for the compensated plot shown in Figure 5.

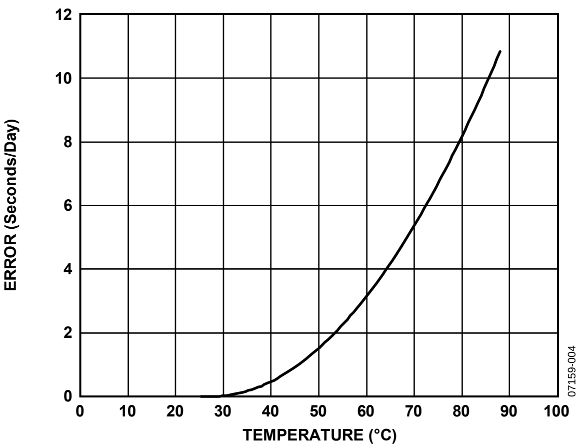

Figure 4. Sec/day Error with No Temperature Compensation

Without temperature compensation, a 10 sec/day error occurs at 85°C (see Figure 4). This is close to the design goal of 0.15 sec/day°C, since 10 sec/day/(85°C – 25°C) = 0.167 sec/day°C. However, the additional overall specification of 30 sec/month could easily be violated by a meter that does not perform temperature compensation in an outdoor environment.

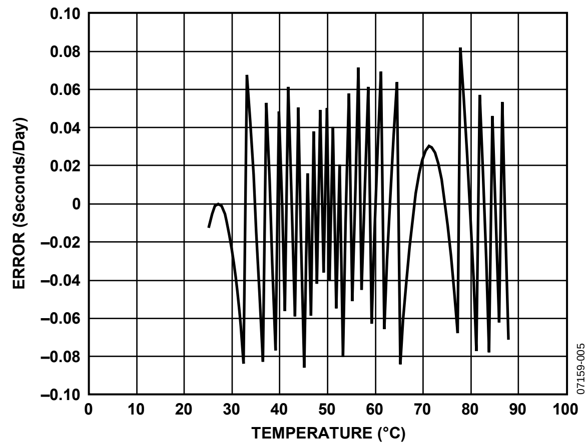

Figure 5. Sec/day Error with Temperature Compensation

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