RL78 Family

Real-Time-Clock Watch Error Correction function

Introduction

Many RL78 MCUs have a Real-Time-Clock (RTC) timer peripheral with external 32768HZ oscillator usinga crystal or ceramic resonator, but that resonator will not always generate a precise 32768HZ time base. TheRL78 RTC Watch error correction function can be used to correct the RTC count value, so the resulting "Time-of-day" results will be more accurate over a long term period compared to when not using Watch error correction function.

Target Device

RL78 MCUs having Real-Time-Clock (RTC) timer block, not RTC2. The RTC2 timer has somewhat different Watch error correction settings not covered by this application note's software project.

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1. Introduction

Many applications using Real Time Clock (RTC) function have elapsed time accuracy requirements. If we use the example of 1 year of count operation, a Real Time Clock time-of-day value (seconds, minutes, hours) may show significant discrepancy relative to actual elapsed time, due to (1) the resonator time-base not having a precise 32768HZoutput at Room temperature and (2) a frequency drift error varying over environmental ambient temperature range.
RTC Watch error correction function can be used effectively to counteract both the fixed and temperature (variable) frequency errors. The f_{SUB} oscillator frequency itself is not modified, but the resulting elapsed time will be corrected, byautomatically adding or subtracting RTC counts.

In this app note we will refer to the 32768HZ Subclock oscillator as the f_{SUB} oscillator.

1.1   Commercially available 32768HZ ceramic resonator error at room temperature

Resonator vendors rate the 32768HZ resonator manufacturing tolerance in Parts-Per-Million (PPM) offset at room temperature, 25degrees Centigrade. For a 365 day-long year, there are 8760 hours, or 525,600 minutes of elapsed time. For example, a +/-1 PPM resonator clock error in counting 1 year elapsed time results in +/- 0.53 minutes (~32seconds)uncertainty which may be OK in most applications, although achieving +/-1ppm accuracy over temperature is impractical. However, +/-100 PPM error could result in about +/-53 minutes uncertainty after 1 year, which may be unacceptable, for example, if the Time-of-day is being used to keep a personal appointment.

Possible Resonator Frequency error range (+/-)	Resulting RTC Elapsed TimeError (+/- Minutes/year)
1 ppm	0.53
5 ppm	2.63
10 ppm	5.26
50 ppm	26.28
100 ppm	52.56
200 ppm	105.1 2

Figure 1: Results of 32768HZ resonator accuracy on elapsedRTC value after one year (without Watch correction)

Resonator vendors charge more for resonators with a tighter specified, initial (delivered) tolerance. A resonator accuracy of +/-1 PPM or +/-5 PPM @25C temperature may be desired, but cost a lot more than one rated for +/-50 PPMor +/-100 PPM accuracy @25C temperature. However, a cheaper +/-50 PPM, or +/-100 PPM accuracy resonator can still benefit from Watch Error Correction function to possibly reach elapsed time accuracy goals close to +/-5 PPM or better achieved RTC counting accuracy.

The resonator "delivered" tolerance frequency error is relatively constant, except for some slight drift due to resonatoraging, which is usually inconsequential compared to initial PPM error and PPM offset errors over temperature.

Tolerance is the variance in the specified or rated value as delivered from the manufacturer. Changes due to aging, temperature or other environmental variables are referred to as "drift". Changes in value due to power supply or circuit parameters are described as "sensitivities". Offset is used to describe an initial displacement from an ideal specified value, not typically associated with a temperature change. This application note addresses RTC error correction to PPM offset as delivered (due to tolerance) at 25C ambient temperature, and PPM errors due to frequency drift over temperature, but not due to sensitivities that change over time (like power supply voltage variations) nor aging.

1.2   Factory calibration step

Customer factory equipment must be used to measure the RL78 PCLBUZ0 = f_{SUB} output or RTC1HZ output pin to determine the actual resonator frequency at 25C, and calculate the initial PPM offset error. This PPM offset error value then needs to be stored in MCU non-volatile memory (code or data flash) for later retrieval.

Possible initial PPM offset error storage methods:

1.2.1   Storing the PPM offset error in Code/data flash WITHOUT using an RL78 self-programming library

After the initial RL78 MCU code image is programmed into the device, without programming Data flash, the MCU can be started up with PCLBUZ0 = f_{SUB} output enabled and measured by factory equipment. Once the f_{SUB} frequency is captured and PPM calculated, a 2nd RFP (Renesas Flash Programmer SW utility) flash programming operation can be used to store a 2-byte PPM offset value into RL78 Data flash, leaving the original code image intact. RL78 Data flash can be accessed by USER Software without implementing the Data Flash library.

Or else it might possible on RL78 MCUs without Data flash, to re-image the Code flash with the PPM offset value appended to the Code image. The advantage to these methods is not having to implement the RL78 Code or Data flash self-programming libraries and not needing MCU serial port communications with factory measuring equipment. The disadvantage is having to add the initial PPM offset to the code or data flash image (via PC utility?) and performing a second external flash programmer procedure.

1.2.2   Storing the PPM offset error in Code or data flash by using an RL78 self-programming library and serial port communications

If an RL78 Serial port is used with factory test equipment to receive the calculated initial PPM offset value, RL78 Data flash programming library (FDL) can be used to write to Data flash for later retrieval. If an RL78 MCU with extra 1KB of code flash block is available, the PPM data could be stored in code flash instead. The advantage of self- programming is that a 2nd external flash programmer operation is not needed. The disadvantage is that the RL78 code and data flash programming libraries require library code space and some USER code space to implement them. The MCU also needs to have a serial port available to the external factory equipment.

1.3   RTC 32768HZ resonator frequency error due to ambient temperature

Resonators have a well-known characteristic curve of PPM offset error over temperature, and typically the equation is given by:

$$\text{PPM Offset} = 0.035 * (t_{AMBIENT} - 25)^2$$

(Where $t_{AMBIENT}$ is in degrees Centigrade)

As can be seen in **Figure 2** below, there is a pronounced resonator frequency offset to slower frequencies (minus PPM values) at temperature extremes; with approximately -148 PPM frequency drift error at -40C and -126 PPM error at
+85C temperature. Back to the 1 year elapsed time example, a constant -148 ppm error in f_{SUB} would result in an uncertainty of +/-77.8 minutes after one year. Therefore, compensating the f_{SUB} oscillator error due to environmental ambient temperature variations may be more critical than correcting the initial ceramic resonator manufacturing PPM error value, assuming the delivered tolerance at 25C is much tighter than +/- 148 PPM. The RTC Watch error correction function can correct for both errors, if total PPM error is within +/- 189 PPM range from 32768HZ.

Note that this graph shows PPM variation with the ideal 32768HZ frequency as the reference point. Therefore, the PPM error is shown as a minus error from a 25C temperature reference. In the RL78 RTC watch error correction function documentation, the actual f_{SUB} frequency is the reference point. Thus, if actual f_{SUB} frequency is >32768HZ, and needs compensation to achieve effective 32768HZ time base, the drift is considered as minus PPM to be corrected. On the other hand, if actual f_{SUB} frequency is <32768HZ, and needs compensation to achieve effective 32768HZ time base, the drift is considered as positive PPM to be corrected. The application note example software project accounts for these opposite reference points.
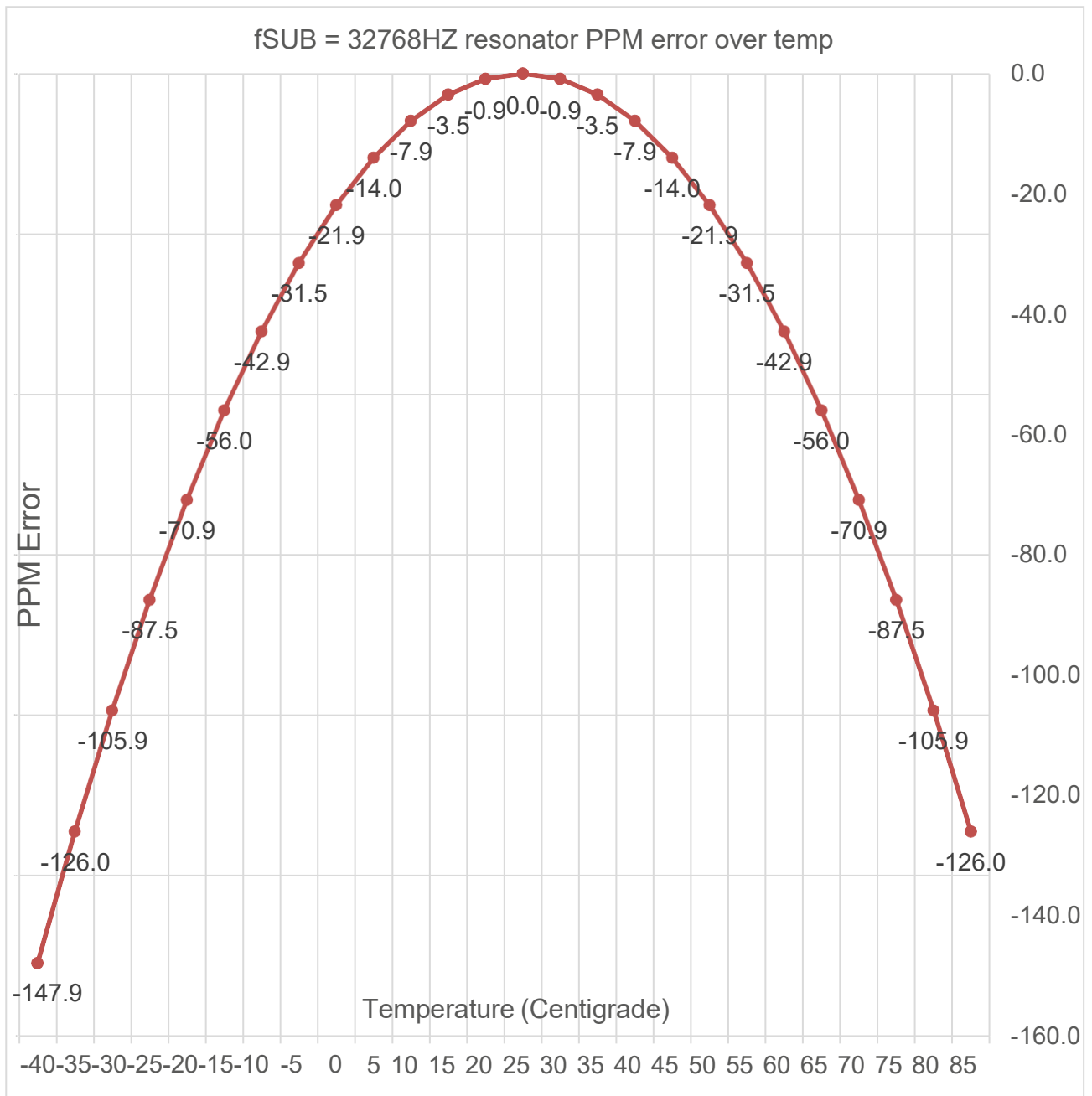
Figure 2: Typical frequency variation (in PPM) with Ambient temperature (-40C to +85C)

2.   Software Project Environment

The accompanying Software project for this app note uses IAR IDE with IAR C/C++ Compiler for Renesas RL78 and e2studio IDE with IAR ICCRL78 compiler v2.21 plug-in, which uses the ILINK-style linker file. The code size is less than 16KB, so either IAR EWRL78 KS16 (free evaluation version, 16KB code size limit) compiler or full license compiler version can be used.

Item	Description
Microcontroller used	RL78/G14(R5F104PJ)
Operating frequency	● High-speed on-chip oscillator (HOCO) clock: 32 MHz ● CPU/peripheral hardware clock: 32 MHz
Operating voltage	5.0 V (can run on a voltage range of 2.9 V to 5.5 V.) LVD operation (VLVD): Reset mode 2.81 V (2.76 V to 2.87 V)
Integrated development environment (IAR)	IAR Systems IAR Embedded Workbench for Renesas RL78 V4.21.3
C compiler (IAR)	IAR Systems IAR C/C++ Compiler for Renesas RL78 V4.21.3.2447

3.   How the RL78 RTC Watch correction works

3.1   The RTC Internal counter

The RTC Internal counter (**Figure 3**) has a 16bit register that counts f_{RTC} (from f_{SUB}, nominally 32768HZ) for 32768 clock periods when there is no Watch error correction. With no Watch correction, this internal counter will start at hex value 0000H and count up to a terminal value of 7FFFH, then reset back to 0000H on the 32768th count. The Internal counter output then increments the Second Count register (If Register RTCC0 bit RTCE = 1 and Register RTCC1 bit RWAIT = 0) every 32768 counts at the 0000H rollover value. That means that a "Second" count duration will have the same PPM magnitude error as $f_{RTC} = f_{SUB}$, from the ceramic resonator when no Watch correction is applied. However, an $f_{SUB} = 32768HZ - 100$ PPM frequency error will result in a 1second +100 PPM period duration, when terminal count = 32768 clock periods are counted (no Watch correction).
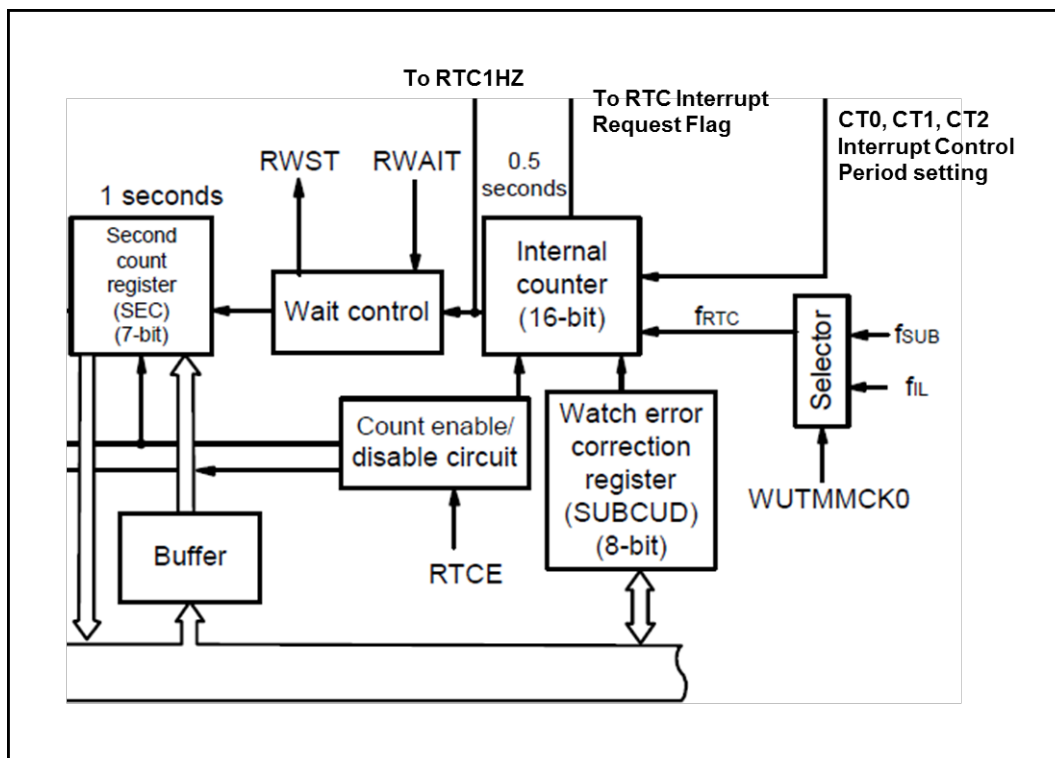

Figure 3 (from RL78/G14 Hardware User's manual, RTC chapter):

3.2   With Watch Correction function turned on

When the Watch error correction is enabled, the number of Internal 16bit counter f_{RTC} clocks counted is either added to or subtracted from 32768 (0 PPM error full count) by changing the terminal count in the Internal timer compare registerto increase or decrease a "1 second" period. To increase the Internal counter period, counts are added to the perfect 32768 terminal count value. For example, using terminal count of 800FH would delay the rollover count (800FH >> 0000H) by 16 f_{RTC} clocks later. Increasing the Internal timer count is done to correct the condition when $f_{RTC} = f_{SUB} > 32768HZ$.

To decrease the Internal 16bit counter period, counts are subtracted from the ideal 32768 terminal count value. Forexample, using 7FF0H would advance the rollover count (7F0FH >> 0000H) by 16 f_{RTC} counts for a shorter time. Decreasing the Internal timer count is done to correct the condition when $f_{RTC} = f_{SUB} < 32768HZ$.

These Watch correction counts are increased or decreased for only one "second" period out of every 20 seconds or 60seconds, depending on the DEV bit setting in SUBCUD Watch error correction register.

3.3 Setting of watch error correction value

For f_{RTC} resonator frequencies > 32768HZ, a minus PPM error is indicated and the Internal counter terminal count needs to be INCREASED (SUBCUD bit F6 = 0 setting) to correct back to elapsed time closer to 0 PPM error. For f_{RTC} resonator frequencies < 32768HZ, a positive PPM error is indicated and the PPM correction needs to be DECREASED(SUBCUD bit F6 = 1 setting) to correct back to elapsed time closer to 0 PPM error.

Examples:

(1) When f_{RTC} = f_{SUB} = 32774.2HZ - 189.2 PPM = 32768HZ (minus PPM error indicated), the optimum Watch error correction is Internal counter set for DEV = 0, F6 = 0, and 32768 + 124 = 32892 counts to increase one "1second"period out of 20 second. A +189 PPM value is corrected by INCREASED count setting, making the resulting elapsed time closer to 0 PPM error by SUBCUD register setting = 0b00111111 = 0x3F.

(2) When f_{RTC} = f_{SUB} = 32761.8HZ + 189.2 PPM = 32768 (positive PPM error indicated), the optimum Watch error correction is Internal counter set for DEV = 0, F6 = 1, and 32768 +124 = 32646 counts to lengthen one "1second"period out of 20 seconds. A positive PPM value is DECREASED closer to 0 PPM error by SUBCUD register setting = 0b0100010 = 0x42.

SUBCUD register setting			RTC Watch Correction Action onInternal counter	If f_{SUB} value is:	PPM Correction Range
bit 7	bit 6	bits 5-0			
DEV	F6	F5, F4, F3, F2, F1, F0			
0	0	62 possible values	RTC Count DECREASE setting: Full count of 32768 decreased by 2, 4, 6, … 122, 124 counts once every 20 seconds	< 32768HZ	+3.05 PPM to +189.2 PPM
0	1	62 possible values	RTC Count INCREASE setting: Full count of 32768 increased by 2, 4, 6, … 122, 124 counts once every 20seconds	> 32768HZ	- 3.05 PPM to - 189.2 PPM
x	x	00000x	No correction if b5-b1 = all zeroes	= 32768HZ	None
1	0	62 possible values	RTC Count DECREASE setting: Full count of 32768 decreased by 2, 4, 6, … 122, 124 counts once every 60seconds	< 32768HZ	+ 1.02 PPM to + 63.1 PPM
1	1	62 possible values	RTC Count INCREASE setting: Full count of 32768 increased by 2, 4, 6, … 122, 124 counts once every 60 seconds	> 32768HZ	- 1.02 PPM to - 63.1 PPM

Figure 4: RTC Watch error correction register SUBCUD settings

4. RTC2 (High accuracy) Watch Error Correction function

The Real-Time-Clock RTC2 has a high accuracy Watch Error Correction function which operates similarly to theoriginal RTC Watch Error Correction function, with these differences:

(a) RTC2 Watch correction has a wider dynamic correction range (correction from -274.6 PPM to +212.6 PPM totaloffset error relative to ideal 32768HZ). By having a wider range on the minus PPM correction direction, RTC2 Watch error correction can correct a resonator frequency having @25C make tolerance range of about -126.6 PPM to +212.6 PPM, whereas the basic RTC watch error correction can only correct for initial PPM offset error of about -41 PPM to +189 PPM.

(b) RTC2 Watch correction has finer PPM correction resolution over the whole correction range (in 0.96 PPM steps)

(c) RTC2 Watch correction corrects the RTC2 elapsed time every 32 seconds, instead of 20 Second or 60 Secondupdate rate on the previous RTC correction function.

Note: the example software project for this app note covers the original RTC watch error correction function only, notthe RTC2 type.

5. Watch Error Correction Application Note sample code operation

In main(), the following code sequence implements RTC Watch Error correction function:

main() flowchart:
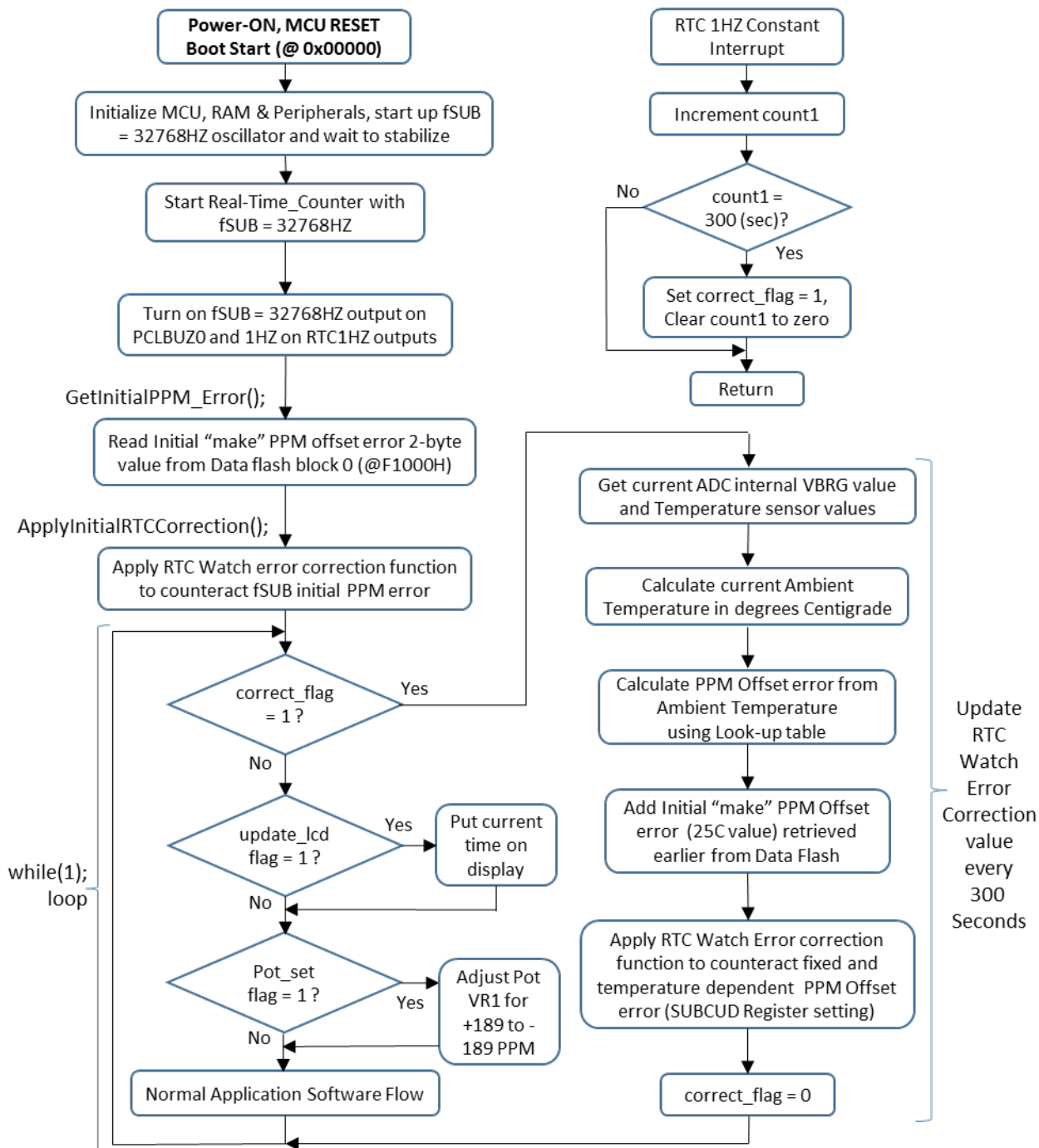
When the resulting PPM error is in +64 to +189 PPM or -64 to -189 PPM range, then SUBCUD register is set for the RTC Watch correction automatically performed once every 20 second counts (SUBCUD DEV bit = 0) and is applied in
3.05 PPM steps. When the resulting PPM error is in -63 to +63 PPM range, then SUBCUD register can be set for the RTC Watch correction automatically performed once every 60 second counts (SUBCUD DEV bit = 1) and is applied in 1.02 PPM steps.

6. Using RTC1HZ and PCLBUZ0 = f_{SUB} outputs to confirm RTC Watch error correction function

6.1 Factory calibration step

The RL78 PCLBUZ0 = f_{SUB} output or RTC1HZ output can be used by customer factory equipment to determine the 32768HZ (nominal) frequency at 25C, and calculate the initial PPM offset error.

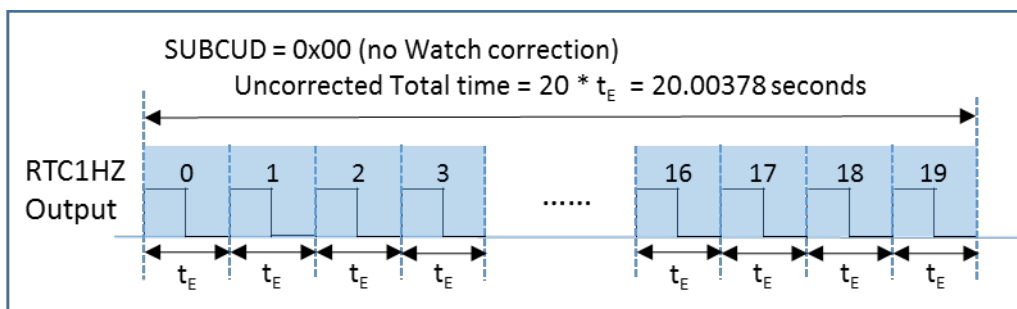### 6.2 Observing RTC Watch error correction in operation

By using an Oscilloscope capture of 1HZ output on RTC1HZ, the Watch error correction function can be verified. When there is no Watch error correction every RTC1HZ interval will have a constant duration with some PPM error from each ideal 1second duration. With Watch error correction enabled, the 1HZ interrupt will still have some error for each 1HZ interval, but total elapsed time can be more nearly correct every 20 or 60 seconds, depending on quantizationerror and how accurately the PPM error due to ambient temperature is estimated and applied.

In both the following examples, it can be seen that no single "1second" interrupt will ever have an actually interval of one second, unless fRTC = fSUB = 32768HZ exactly and no Watch error correction is applied. Otherwise, with somefSUB frequency error, but optimum Watch error correction applied, then over the long term the RTC "time-of-day" (seconds, mins, hours) elapsed time can be corrected to a much smaller elapsed time error.
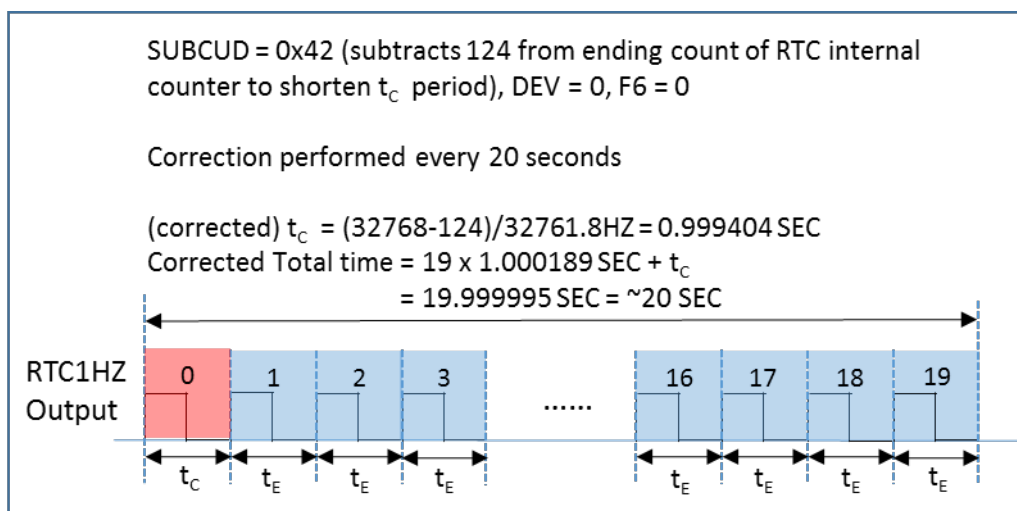
Example 1:

Conditions: Actual fRTC =
32761.8HZt_E = 1.000189 seconds
 Correction needed: 32761.8 HZ + 189 PPM = 32768 HZ

With NO RTC Watch error correction:

With RTC Watch error correction enabled (optimum setting):

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Conclusion: For a large error of -189 PPM the coarse setting of 3.05 PPM correction steps must be used. Watch error correction can be used to get accurate 20 second intervals over the long term. Since the Watch error correction can only be set to 3.05 PPM intervals for PPM error offsets between -64 to -189 PPM and +64 PPM to +189 PPM range, there can be up to 3.05PPM quantization error, even if all other compensation (temperature to PPM offset, etc) is calculatedand applied perfectly.
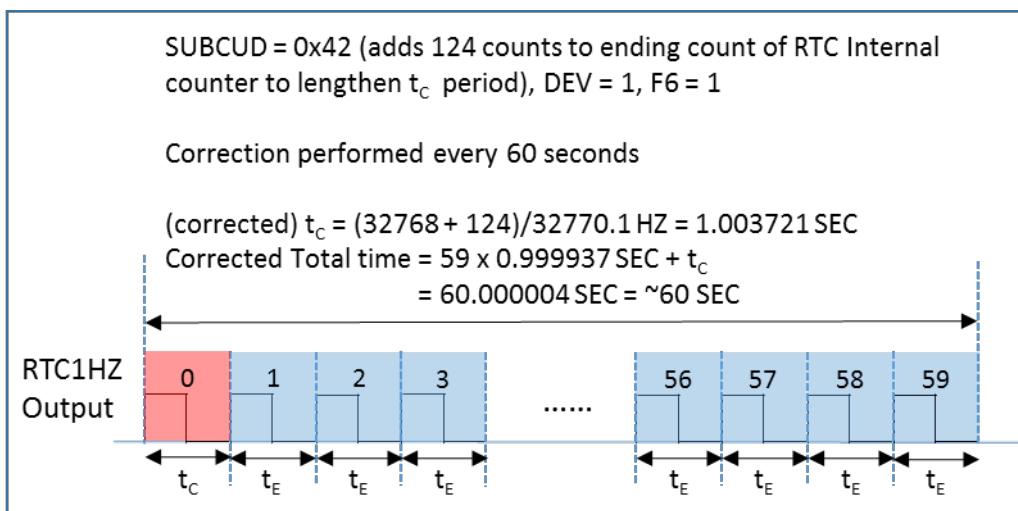
Example 2:

Conditions: actual f_{RTC} = 32770.1
HZt_E = 0.999937 seconds
Correction needed: 32770.1 HZ - 63 PPM = 32768 HZ

With NO RTC Watch error correction:
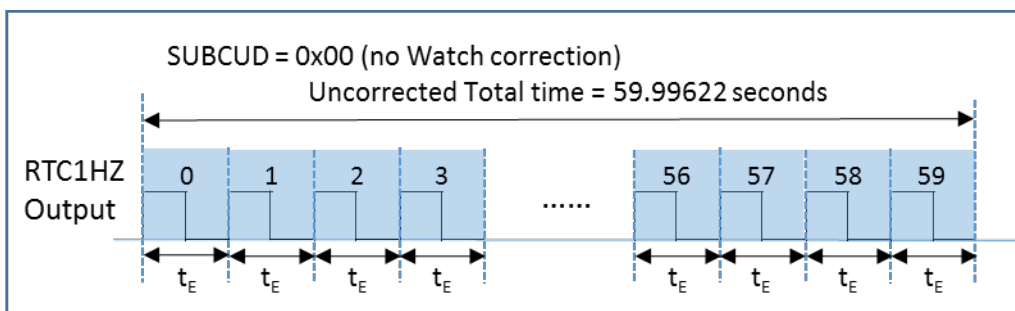
With RTC Watch error correction enabled (optimum setting):

Conclusion: For a smaller error range of +/-63 PPM, the "fine" setting of 1.02 ppm steps can be used. In this mode, Watch error correction can be used to get accurate 60 second intervals over the long term. Using the finer Watch errorcorrection steps of 1.02 PPM allows closer correction to 0 ppm elapsed time error, but there can be up to 1.02 PPM quantization error, even if the initial PPM delivered error and temperature drift errors are offset and applied perfectly.

7. Limitations in using RTC Watch correction Application note software project

There are several areas this Application note does not address or implement.

(1) This application note example software does not include RL78 serial communication to factory board level equipment to obtain, and store the ceramic resonator 25C initial PPM error into RL78 data flash location. Instead,the initial PPM offset value is "hard-coded" into Data flash, compiled and flash-programmed at the same time as code image.

(2) Users should consult the chosen 32768HZ resonator manufacturer specs to analyze the distribution of PPM temperature offset error. In many cases, the 0 ppm offset error may not be exactly at 25C but possibly some otherreference temperature, for example within 25C +/-5C. In the case of wide ambient temperature operation, setting the 0 PPM offset error temperature reference point will greatly affect the PPM offset calculation accuracy at temperature extremes such as -40C and +85 degrees centigrade.

(3) The temperature measurement algorithm using RL78 ADC internal voltage reference (VBRG) and internal Temperature sensor may not be very accurate and itself needs factory calibration. Refer to Renesas Electronics application note r01an0988eu0100, RL78 Internal Temperature Sensor Calibration (Using IAR Toolchain), for more details. It was not in the scope of this Watch error correction app note to provide temperature accuracy, but show how to use RL78 RTC Watch error correction function once an accurate ambient temperature is obtained. Also, there may be a slight temperature difference between the RL78 MCU internal die and the 32,768HZ ceramicresonator on PCB. Therefore, it may be necessary for the user to implement a more accurate ceramic resonator temperature measurement system, especially if desired Watch correction accuracy is tight.

(4) When temperature measurement is referenced to 25C ambient temperature point, it can be seen in Figure 2 that 32768HZ ceramic resonator PPM offset error changes greatly with small temperature changes at extremes of -40Cand at +85C. For example there is about 22 PPM offset difference from -40C to -35C. That means that temperature measurement would need almost +/-0.2C degree accuracy to achieve 1 ppm accuracy in Temperature-to-PPM offset calculation between -40C to -35C. This app note SW project uses a rough calculation for Temperature-to-PPM offset to demonstrate Watch correction implementation in simpler platforms not using floating point math routines.

(5) Since the PPM offset error due to temperature only changes in minus PPM direction, there is non-symmetrical nature to the RTC Watch Error correction. In other words, a 32768 HZ ceramic resonator with an 25C delivered tolerance of +189 PPM (32774.2 HZ @25C) can be corrected close to 0 PPM for any ambient temperature of - 40C to +85C, but a resonator with delivered tolerance of -189 PPM relative to 32768HZ (32761.8 HZ @25C) cannot be corrected to 0 PPM, since the total PPM value needing correction is greater than 189 PPM. In actuality,the maximum allowed minus PPM error value @25C that could be corrected at -40C is about -41 PPM below ideal 32768HZ frequency, since PPM offset error due to -40C is about -148 PPM.

(6) Along with PPM offset calculation errors due to (3) and (4) above, the Watch error correction function is quantified to 1.02 PPM steps within the +/-63PPM range and +3.05 PPM steps outside of +/-63 PPM range. Therefore a careful study should be made to determine the final PPM correction accuracy range, taking all thesevariations into account along with initial 32768HZ ceramic resonator "make" tolerance, and desired ambient temperature range.

8. RTC Watch error correction example software demo and HW platform

8.1   HW Platform used

This demo uses the YRDKRL78G14 Development board with RL78 device number R5F104PJ, and the followingHardware;

- GLYPH LCD panel (64 x 96 pixels) graphics display – **Figure 5**

- 3 pushbuttons (Switch 1, Switch 2, Switch 3) – **Figure 5**

- 3 LEDs (LED4, LED6, LED15) – **Figure 6**

- PCLBUZ0 output = fSUB on MCU pin 3 (port P140)

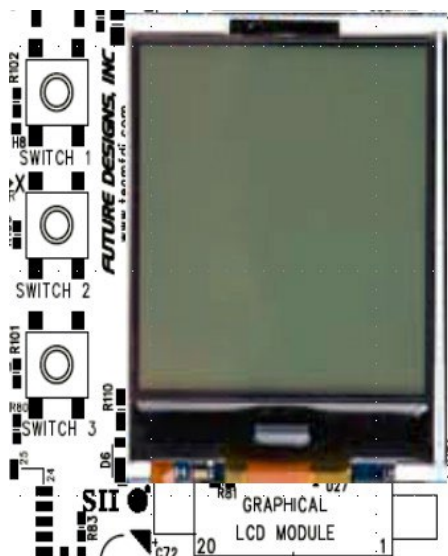- RTC1HZ output on MCU pin 52 (port P30)
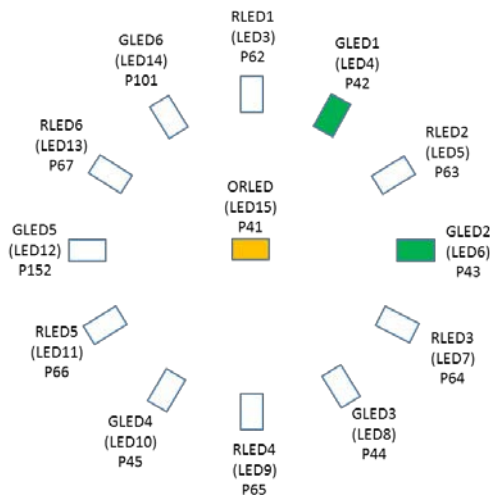
Figure 5: GLYPH display, Pushbutton switches   **Figure 6:** LEDs

8.2   Operation

8.2.1   At power-ON RESET, the GLYPH startup screen shows:

Figure 7: Startup screen

- fSUB is the resonator frequency of 32768HZ +/- ?PPM.

- "Time-of-day" is updated at 1HZ rate on Line 3.

- Initial PPM tolerance (offset) error stored in Data Flash is shown on Line 4.

- The RTC watch error correction register "SUBCUD" is updated using Initial PPM offset value and PPM drifterror due to Ambient temperature, LED4 (green) flashes for 0.5 Sec when SUBCUD correction register is updated.

- RTC correction interval is normally 300 seconds, but can be changed to shorter value (e.g.:10 Sec) for testingby changing to RTC_CORRECTION_UPDATE_TIME_10 constant set in r_cg_rtc_user.c 1HZ RTC interrupt callback function.

- LED15 (orange) flashes at 0.5HZ rate (1 second ON, 1 second OFF).

8.2.2   To modify VR1 POT setting for Initial PPM error of -189 to +189 PPM range

- Press Switch 2 and the display is changed to:

```
Real  Time  Clock          Line1
fSUB  =  32768Hz            Line2
        12:00:54            Line3
DFcalib  =    189  PPM      Line4
POT=        0  PPM          Line5
Press  SW1:   DFcalib       Line6
Press  SW3:   VR1  POT      Line7
SUBCUD=    67               Line8
```

Figure 8: After pressing SW2

- LED6 (green) flashes at 5HZ rate, and VR1 pot value is converted by ADC every 100mSEC, with last readingshown on Line 6 from -189 to +189 PPM.

- LED5 (orange) keeps flashing at 0.5HZ rate.

- When LED6 is flashing, the RTC 1HZ interrupt still occurs in background, but Time-of-day value on GLYPHdisplay Line3 is not updated. Also, RTC correction updates are suspended.

- Adjust VR1 until desired initial PPM offset is shown on Line 5. (-189 PPM indicates an initial PPM offset for32768HZ + 189PPM = 32774.2HZ, and +189PPM indicates an initial PPM offset for 32768HZ – 189PPM = 32761.8HZ.

8.2.3   Locking in the VR1 POT PPM value

- When SW3 is pressed, the VR1 PPM value on GLYPH display Line 5 is set as initial PPM offset, and LED6stops flashing, and Lines 6 and 7 are updated to:

```
Real  Time  Clock          Line1
fSUB  =  32768Hz           Line2
        12:00:54           Line3
DFcalib  =    189  PPM     Line4
POT=  -189  PPM            Line5
Press  SW2:  adj  VR1      Line6
Use  POT  PPM  value       Line7
SUBCUD=    67              Line8
```

Figure 9: After pressing SW2, then SW3

(example: after adjusting POT to -189PPM)

- Time-of-day updates are resumed on Line3, and RTC correction updates resume (with LED4 flashing for0.5seconds when they occur).

- Using the VR1 POT PPM value is a quick method to simulate tests for various Resonator frequency PPMoffsets without having to re-compile and re-program the MCU data flash PPM Offset.

8.2.4   Changing back to original initial PPM offset value in Data Flash

- If the user wants to revert to the original initial PPM offset value stored in data flash, press Switch 2 and then press Switch 1. Then Line 7 will show the message "Use DFcalib value", which the RTC correction algorithmwill then resume using.

Note: the SUBCUD value varies depending on ambient temperature and initial PPM offset value used. The SUBCUD value = 67 is not necessarily correct for all the initial PPM offset values shown in these display examples.

Revision History

Rev.	Date	Description	
		Page	Summary
1.00	Sep 22,2016	-	Initial Release
1.10	June 24,2022	5	Update Software Project Environment

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General Precautions in the Handling of Microprocessing Unit and Microcontroller Unit Products

The following usage notes are applicable to all Microprocessing unit and Microcontroller unit products from Renesas. For detailed usage notes on the products covered by this document, refer to the relevant sections of the document as well as any technical updates that have been issued for the products.

1. Precaution against Electrostatic Discharge (ESD)

   A strong electrical field, when exposed to a CMOS device, can cause destruction of the gate oxide and ultimately degrade the device operation. Steps must be taken to stop the generation of static electricity as much as possible, and quickly dissipate it when it occurs. Environmental control must be adequate. When it is dry, a humidifier should be used. This is recommended to avoid using insulators that can easily build up static electricity. Semiconductor devices must be stored and transported in an anti-static container, static shielding bag or conductive material. All test and measurement tools including work benches and floors must be grounded. The operator must also be grounded using a wrist strap. Semiconductor devices must not be touched with bare hands. Similar precautions must be taken for printed circuit boards with mounted semiconductor devices.

2. Processing at power-on

   The state of the product is undefined at the time when power is supplied. The states of internal circuits in the LSI are indeterminate and the states of register settings and pins are undefined at the time when power is supplied. In a finished product where the reset signal is applied to the external reset pin, the states of pins are not guaranteed from the time when power is supplied until the reset process is completed. In a similar way, the states of pins in a product that is reset by an on-chip power-on reset function are not guaranteed from the time when power is supplied until the power reaches the level at which resetting is specified.

3. Input of signal during power-off state

   Do not input signals or an I/O pull-up power supply while the device is powered off. The current injection that results from input of such a signal or I/O pull-up power supply may cause malfunction and the abnormal current that passes in the device at this time may cause degradation of internal elements. Follow the guideline for input signal during power-off state as described in your product documentation.

4. Handling of unused pins

   Handle unused pins in accordance with the directions given under handling of unused pins in the manual. The input pins of CMOS products are generally in the high-impedance state. In operation with an unused pin in the open-circuit state, extra electromagnetic noise is induced in the vicinity of the LSI, an associated shoot-through current flows internally, and malfunctions occur due to the false recognition of the pin state as an input signal become possible.

5. Clock signals

   After applying a reset, only release the reset line after the operating clock signal becomes stable. When switching the clock signal during program execution, wait until the target clock signal is stabilized. When the clock signal is generated with an external resonator or from an external oscillator during a reset, ensure that the reset line is only released after full stabilization of the clock signal. Additionally, when switching to a clock signal produced with an external resonator or by an external oscillator while program execution is in progress, wait until the target clock signal is stable.

6. Voltage application waveform at input pin

   Waveform distortion due to input noise or a reflected wave may cause malfunction. If the input of the CMOS device stays in the area between V_{IL} (Max.) and V_{IH} (Min.) due to noise, for example, the device may malfunction. Take care to prevent chattering noise from entering the device when the input level is fixed, and also in the transition period when the input level passes through the area between V_{IL} (Max.) and V_{IH} (Min.).

7. Prohibition of access to reserved addresses

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8. Differences between products

   Before changing from one product to another, for example to a product with a different part number, confirm that the change will not lead to problems. The characteristics of a microprocessing unit or microcontroller unit products in the same group but having a different part number might differ in terms of internal memory capacity, layout pattern, and other factors, which can affect the ranges of electrical characteristics, such as characteristic values, operating margins, immunity to noise, and amount of radiated noise. When changing to a product with a different part number, implement a system-evaluation test for the given product.

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