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RENESAS

H8/300L

Hardware Interface Technique to Oscillator (HWosc)

Introduction

This application note is to assist the product design engineers in selecting the correct crystal oscillator and external capacitors required for H8/300L Super Low Power (SLP) series microcomputer.

The product design engineer should also consult with the crystal manufacturer about the needs of their product design.

For product success, it is important that the designer understand how an oscillator operates in order to select the correct crystal.

Target Device

H8/300L Super Low Power series – H8/38024F microcomputer

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1. About Crystal

The oscillator circuit is often overlooked and selection of components is based largely on the manufacturer's table. If the circuit starts up and works, then further thoughts would not be given to it, right?

However, many conditions can negatively affect the performance of our design. Conditions such as higher temperatures and lower supply voltages can lower the loop gain in the oscillator circuit, causing poor, or slow or no startup; colder temperatures and higher supply voltages can increase the loop gain of the oscillator circuit, causing the crystal to be overdriven, and potentially damaged; or the circuit can be forced to another harmonic and throw off the timing or cease functioning altogether. It is also possible to waste power through the improper selection of components.

We shall now look at how a quartz crystal operates internally.

Quartz or piezoelectric (quartz) crystal oscillators appear most often in high-quality digital equipment. Designer appreciates their highly accurate frequency output. In addition, the resonance has a very high Q ranging from 10,000 to several hundred thousand. It is possible in some cases, to achieve 2 millions. However, with this merits, it also contributes to its limitation: difficulty to tune a crystal oscillator. The practical frequency for fundamental mode AT-cut crystals is 600KHz to 30MHz. The fundamental frequency of the crystal ranges as high as 40MHz. This application note shall focus on fundamental frequency mode.

2. Equivalent Circuit

The schematic symbol for a quartz crystal and the equivalent circuit are shown in Figure 1.1.

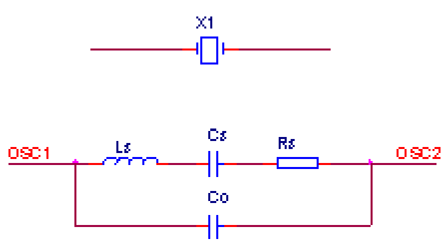


Figure 1.1 Equivalent Circuit

The equivalent circuit is an electrical representation of the quartz crystal's mechanical and electrical behavior. The crystal is after all a vibrating piece of quartz. The components Cs, Ls and Rs are called the motional arm and represent the mechanical behavior of the crystal element. **Co** represents the electrical behavior of the crystal element and holder.

Cs represents the motional arm capacitance measured in Farads. It represents the elasticity of the quartz, the area of the electrodes on the face, thickness and shape of the quartz wafer.

Ls represents motional arm inductance measured in Henrys. It represents the vibrating mechanical mass of the quartz in motion.

Rs represents the resistance measured in ohms. It represents the real resistive losses within the crystal.

Co represents the shunt capacitance measured in Farads. It is the sum of the capacitance due to the electrodes on the crystal plate plus stray capacitance due to the crystal holder and enclosure.

Let's look at the following example crystal's electrical specification that you would find in a crystal data sheet. See Table 1.

Parameter	Value
Frequency (MHz)	4.193
Rs (ohm)	100 (max.)
Co (pF)	16 (max.)

Table 1 Electrical Specification of Crystal

When purchasing a crystal, the designer specifies a particular frequency along with load capacitance as well as mode of operation. Notice that the motional parameters, Cs, Ls, Rs are not typically given in data sheet. You must get them from the crystal manufacturer or measured yourself.

3. Types of Connection

3.1 Connection to Crystal Oscillator

Figure 3.1 shows a typical method of connecting a crystal oscillator.

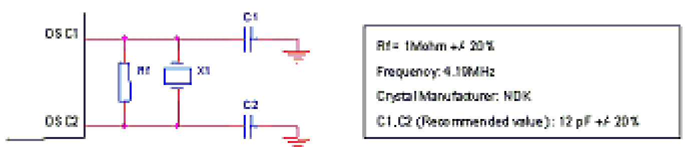


Figure 3.1 Connection to Crystal Oscillator

3.2 Connection to Ceramic Oscillator

Figure 3.2 shows a typical method of connecting a ceramic oscillator.

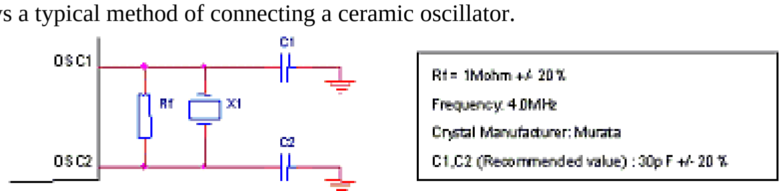


Figure 3.2 Connection to Ceramic Oscillator

4. Selection of Components

There are several factors that go into the selection and arrangement of these external components. Some of these are: Amplifier Gain, Desired Frequency, Resonant Frequency(s) of the crystal, Temperature of Operation, Supply Voltage and its range, Start Up Time, Stability, Crystal Life, Power Consumption, Simplification of the Circuit, Use of the Standard Components (as few as possible).

5. Determining Best Values for Crystal, C1, C2, Rf and Rd

Crystals are usually selected by their parallel resonant frequency only. The H8/300L SLP series microcomputer utilizes a parallel oscillator circuit that requires a parallel resonant crystal. A specific range of load capacitance would need to be used in order to oscillate the crystal closest to the desired frequency. However, it may be necessary to juggle these values in order to achieve other benefits.

C1 & C2 are the load capacitance and they provide the phase lag of 180°. They should also be initially selected based on the load capacitance as suggested by the crystal manufacturer and also the values suggested in the specific device hardware manual. However, this can only be used as a starting point for your fine-tuning.

Ideally, the lowest capacitance is chosen (within the range of the recommended crystal load preferably) that will oscillate at the highest temperature and lowest VCC that the circuit will be expected to perform. High temperature and low VCC both have a limiting effect on the loop gain, such that if the circuit functions all these extremes the designer can be more assured of proper operation at other temperatures and supply voltages.

Besides loading the crystal for proper frequency response, these capacitors can also have the affect of lowering loop gain if their value is increased. C2 can be selected to affect the overall loop gain of the circuit.

However, C values that are too high can store and dump too much current through the crystal so C1 & C2 should not become too large.

Rf is the feedback resistance, and it provides negative feedback around the inverter in order to put it in the linear region, so the oscillation will start when power is applied. If the value of Rf is too large, and if the insulation resistance of the input inverter is accidentally decreased, oscillation will stop due to the loss of loop gain. Also, with large Rf, noise from other circuits can be introduced into the oscillation circuit. Obviously, if Rf is too small, loop gain will be low. An Rf of 1MΩ is generally used with crystal or ceramic oscillator.

Rd is a series resistor for damping purpose, it is selected to prevent overdriving the crystal. It is often not needed if C1 & C2 are selected properly.

6. Specification of a Crystal

In addition to what has been mentioned above, there are three main specifications we would use to characterize crystals:

- Frequency Tolerance
- Motional Parameter
- Temperature Performance

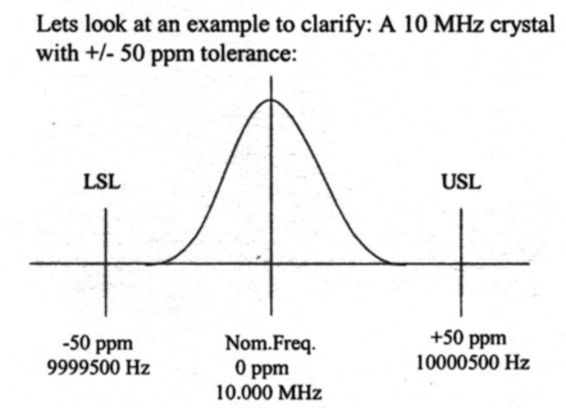
In this application note, it would proceed to describe about frequency tolerance and how to calculate the tolerance.

As mentioned before, the quartz crystal exhibits a stable performance and the standard frequency tolerance is in units of parts per million (ppm).

Since 1ppm = 0.0001%, a ppm is less cumbersome to use. Most other electronic parts tolerances are given as +/- % of the mean (or nominal) value.

A ppm is 1 unit referenced to 1 million units, and it also refers to 1Hz in a 1.0MHz for a crystal.

Just an example to clarify: A 10MHz crystal with +/-50ppm tolerance:



6.1 How to calculate a "ppm to Hz" tolerance

The equation for calculating from PPM to Hz:

Tolerance in ppm X nominal frequency in MHz = Result in Hz

Example: What is the minimum and maximum frequency of a 10MHz crystal with +/-10 ppm tolerance?

Max = 10ppm X 10MHz = 100Hz: 10000000Hz + 100Hz = 10000100Hz

Min = 10ppm X 10MHz = 100Hz: 10000000Hz – 100Hz = 9999900Hz

6.2 How to calculate a "Hz to ppm" tolerance

The equation for calculating from Hz to ppm :

Tolerance in Hz/Frequency in MHz = Result in ppm

Example: How many ppm is +/- 200Hz for a 20.0MHz crystal?

Max = +200ppm / 20MHz = +10ppm, or 20000000Hz + 200Hz = 20000200Hz

Min = -200ppm / 20MHz = -10ppm, or 20000000 Hz – 200Hz = 19999800Hz

7. Notes on Oscillator Stabilization Time

The following description is based on the H8/38024/F microcomputer.

Oscillator stabilization time is defined as the time from the point at which the system clock oscillator oscillation waveform starts to change when an interrupt is generated, until the amplitude of the oscillation waveform increases and the oscillation frequency stabilizes.

Wait time is defined as the time required for the CPU and peripheral functions to begin operating after the oscillation waveform frequency and system clock have stabilized. To give an example on how to set this wait time, we refer to the H8/38024/F microcomputer; simply set the standby timer select bits 2 to 0 [STS2 to STS0] [bits 6 or 4 in the system control register (SYSCR1)].

[1] – When standby mode, watch mode, or sub-active mode is cleared by an interrupt or reset, and a transition is made to active (high-speed/medium-speed) mode, the oscillation waveform begins to change at the point when the interrupt is accepted. Therefore, when an oscillator element is connected in standby mode, watch mode, or sub-active mode, since the system clock oscillator is halted, the time from the point at which this oscillation waveform starts to change till the amplitude of the oscillator waveform increases and the oscillation frequency stabilizes, this refer to the oscillation stabilization time required. Please refer to Figure 6.1.

[2] – The oscillation stabilization time in the case of these state transitions is the same as the oscillation time at power-on where the power supply voltage reaches the prescribed level until the oscillation stabilizes. This is specified in the AC characteristics by Oscillation Stabilization time *trc*.

[4] – A wait time of at least 8-states is necessary in order for the CPU and peripheral functions to operate normally.

Thus the time required from interrupt generation until operation of CPU and peripheral functions is the sum of the oscillation stabilization time and wait time. This total time is called oscillation stabilization wait time and expressed by following equation:

Oscillation Stabilization Wait Time = [trc + (8 to 16,384 states)]

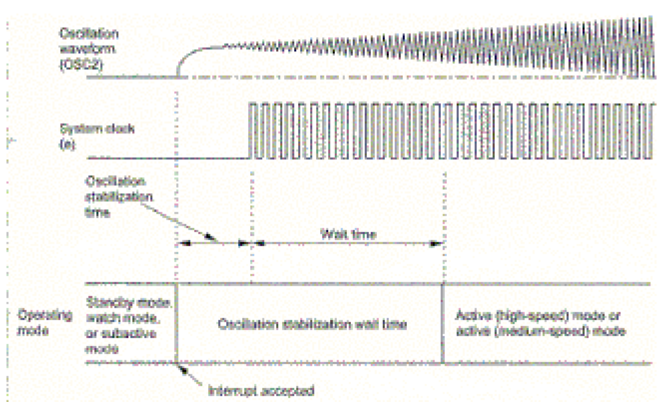


Figure 6.1 Oscillation Stablization Time

8. Notes on Crystal Oscillator Element

This section highlights the various concerns for crystal oscillator element but excludes ceramic oscillator element.

When a microcomputer operates, the internal power supply potential fluctuates slightly in synchronization with the system clock.

Depending on the individual crystal oscillator element characteristics, the oscillator waveform amplitude may not be sufficiently large immediately after the oscillation stabilization wait time, making the oscillation waveform susceptible to influence by fluctuation in the power supply potential.

In this state, the oscillation waveform may be disrupted, leading to an unstable system clock and erroneous operation of the microcomputer.

If erroneous operation occurs, change the setting of standby timer select bits 2 to 0 (STS2 to STS0) (bits 6 to 4 in system control system register) to give a longer wait time.

If the same kind of erroneous operation occurs after a reset as after a state transition, hold the RESET(_RES) pin low for a longer period.

9. Arrangement of Crystals & Board Design

9.1 Arrangement of Crystals

Oscillator characteristics are closely related to board design and should be carefully evaluated by the user. Figure8.1 provide an example of the arrangement of the components. Oscillator circuit constants will differ depending on the oscillator element, stray capacitance in the interconnecting circuits, and other factors.

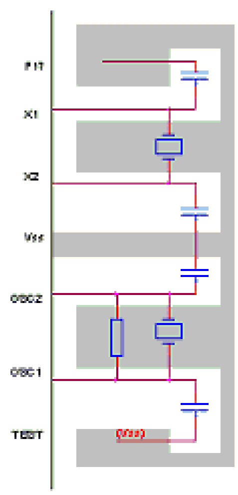


Figure 8.1 Arrangement of Components

9.2 Board Design

When generating clock pulses by connecting a crystal or ceramic oscillator, one needs to take note of the following points:

- Avoid running signal lines close to the oscillator circuit, since the oscillator may be adversely affected by induction current. [See Figure 8.2]
- The board should be designed so that the oscillator and load capacitors are located as close as possible to pins OSC1 and OSC2.

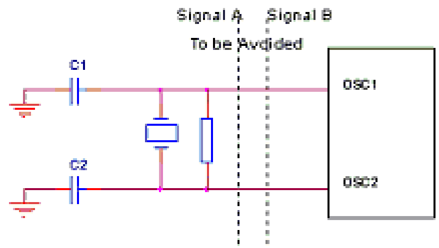


Figure 8.2 Signal Lines

10. Notes on Unused Clock Pins

For unused clock pins such as the sub-clock pins, X1 & X2, connect X1 pin to Ground and leave X2 pin open.

11. Notes on External Clock Input

For external clock connection to system (main) clock, connect an external clock to pin OSC1 and leave OSC2 open. For external clock connection to sub-clock, connect an external clock to pin X1 and leave X2 open. Ensure that the duty cycle is between 45% ~ 55% for proper operation.

12. Final Notes

The most difficult time for the oscillator to start up is waking up from a halted state. This is because the load capacitance has partially charged to some quiescent value and phase differential at wake up is minimal. Thus more time is required for stable oscillation. Also remembers that low voltage, high temperature imposes limitations on loop gain, which in turn affects start up.

An oscillator circuit depends on some stray noise to start up. Usually the power up process will provide this, but if the processor is halted, the oscillator will have to start up on wake up without power up ramp (although some noise is created internally by the wake up logic).

Some suggestions to help start up are using of a cheap Rs resistor which made of carbon film or carbon composition resistor, as it generate some amount of white noise which when placed in the crystal oscillator path can assist start up; Increase C2 over C1 to increase phase shift and help start up, especially at low frequencies.

However, it is also possible for a circuit with too much gain not being able to start up. This usually occurs when using a low frequency crystal, like 32KHz, since at high frequencies; the high gain is dissipated more easily by the load capacitance.

Lastly, if you would like to have the circuit oscillate at resonant frequency to be as accurate as possible, you may better served by adding a Rs to the circuit as needed and keep the capacitor values closer to the load capacitance suggested by the crystal manufacturer.

Reference

1. H8/38024 Series, H8/38024F-ZTAT™ Hardware Manual
2. www.embedded.com

Revision Record

Rev.	Date	Description	
		Page	Summary
1.00	Sep.03	-	First edition issued

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