Hitachi America, Ltd.

Application Note

H8/5XX

Anthony Mendiola

Microcontroller Crystal Oscillator Tutorial

INTRODUCTION

Every member of Hitachi's H8/500 family requires a stable clock source (meeting the device's specifications) to operate properly. To aid in the design of a clock oscillator, Hitachi has included an on-chip oscillator circuit that requires only the addition of an **AT-cut parallel resonating crystal** and two capacitors to form a simple, economical, reliable and stable clock source. With proper component selection, the clocked oscillator will out perform most available clock oscillators at a fraction of the cost.

Using the on-chip oscillator circuit to form the required clock source is recommended for most applications. However, there are some instances (applications requiring devices to be in synch) that require an external clock signal. Supplying an external clock signal to any member of the H8/500 family is allowed. Please refer to the appropriate device hardware manual for the clock specifications and external clock input circuit configuration.

The scope of this Tutorial is to provide assistance in the design of the on-chip oscillator. We will begin by examining crystal properties and characteristics in some detail and progress towards the design of a practical clock oscillator. Component selection and crystal layout rules will be among the topics discussed.

Crystal Properties

Crystals obtain their mechanical and electrical properties by the angle of cut from a quartz blank. An AT cut (31 deg. 15 min.) crystal is by far the most popular cut, because of its permanence, low temperature coefficient, high mechanical Q, and its wide range of frequencies. The AT cut is available from crystal manufactures for frequencies in the 800 KHz to 25 MHz range in the fundamental mode and up to 200 MHz with overtone operation. This type of cut is the most commonly used in microcontroller oscillator circuit design.

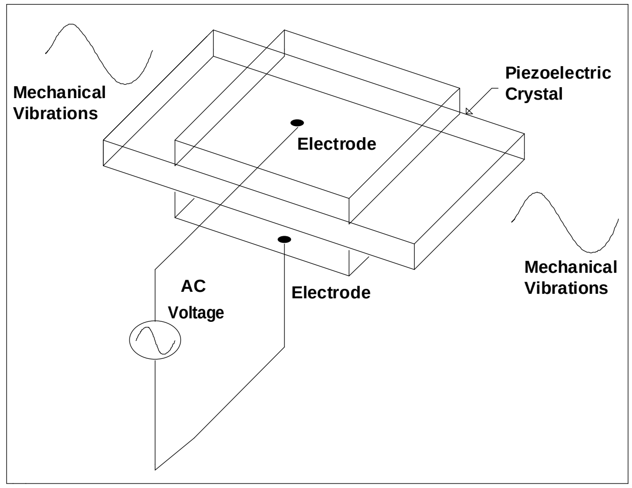

Figure 1: Piezoelectric Effect

Piezoelectric Effect

In figure 1, the crystal undergoes a mechanical deformation by the application of a voltage on the electrodes across the opposite faces of the crystal. The degree of deformation will depend on the characteristics of the drive signal as well as those of the crystal cut. The application of the AC signal will produce longitudinal, shearing or flexural motion.

Referring to figure 1, the electrode plates make the electrical connections to an external drive or output circuit. This is very similar to a ceramic-disc capacitor.

The piezoelectric effect is exhibited by many natural and man-made crystals; the most important natural crystals being Rochelle salt, and tourmaline. While quartz is still the most widely used synthetic material for oscillator frequency control.

Practical Crystal Resonance

Referring to figure 2, a simple test can be run to determine the resonant frequency of an unknown crystal. One merely needs to apply an alternating voltage from a signal generator across the crystal leads and increase the frequency until an amplitude peak representing mechanical resonance is seen on the oscilloscope.

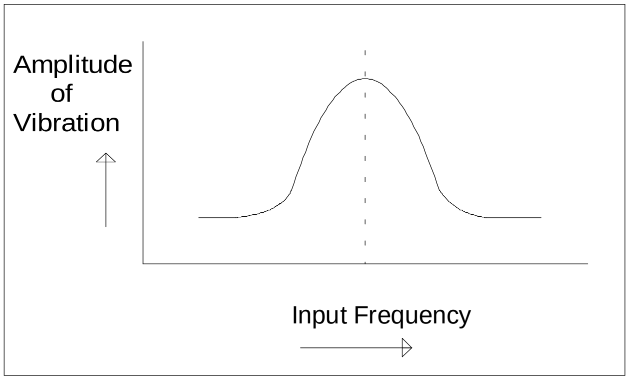

Figure 2: A Crystal's Resonant Frequency can be determined by sweeping the input frequency until a maximum peak is observed on an oscilloscope.

The mechanical vibrations within a crystal slice are called bulk acoustic waves. In general, the thinner the crystal slice, the greater the mechanical vibrations and consequently the higher the resonant frequency. The relationship between a quarts crystal's thickness and resonant frequency (Fr) is given by h=65.5/Fr, where h is the thickness in inches and Fr is the resonant frequency in kilohertz.

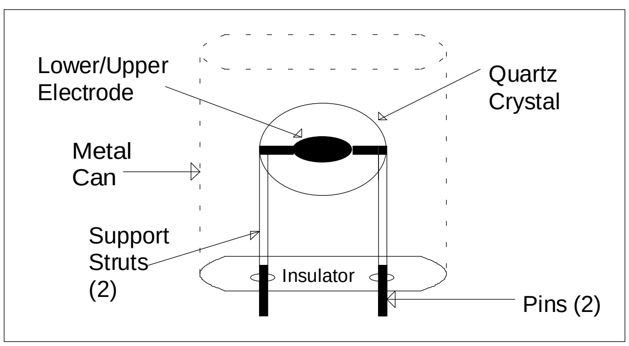

Figure 3: Typical Quartz Crystal Resonator

Figure 3 is a drawing of a typical quartz crystal resonator with its protective case removed. Please refer to this figure in the following discussion.

The Crystal Manufacturing Process

A number of steps are involved in the creation of the a quarts crystal resonator. It is important that the designer be familiar with this process in order to better understand the importance of certain crystal specifications required by the manufacturer.

Step 1: Quarts Etching Process

Manufacturers of crystals use an etching procedure to remove qurts material from the crystal blank until the device is at the specified frequency. After completion of the etching process, the quarts crystal is cleaned and dried to ensure removal of any contamination and moisture prior to the application of the base plate electrodes.

Step 2: Base Plate Process

The metalized electrodes are attached to the crystal during this process. By applying the proper amount of metalization on the electrodes, the desired coarse frequency setting can be achieved. By this stage the crystal is not designated as "series" or "parallel".

Step 3: Mount and Curing Process

The crystal along with the attached electrodes are then mounted onto the crystal base with the use of conductive epoxy. This epoxy provides both mechanical and electrical contact of the crystal electrodes.

Step 4: Final Plate Process

It is at this stage in the process that the crystal is finally designated as "series" or "parallel". The manufacturer will take your specifications and fine tune the unsealed device by applying a controlled amount of vaporized silver or other conducting material at the center of the base plate. This step is accomplished with the aid of a state-of-the-art computer controlled system.

Step 5: Holder Assembly Process

It is at this stage of the process that the final assembly takes place. A protective holder is placed over the crystal and attached electrodes and sealed air tight to avoid contamination of the electrodes. In addition, air is removed from the holder to reduce the crystals mechanical load and thus increase the resonant frequency.

Understanding "Series" vs "Parallel" Specifications

A common misunderstanding made by a number of design engineers is the misuse of phrases such as "series cut" and "parallel cut" crystals. There are different cuts having to do with the motional arm electrical parameters at various frequencies, but there is no special cut for a series or parallel operation. The crystal is finally designated "series" or "parallel" at step 4 of the manufacturing process.

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Equivalent Electrical Circuit

The electrical circuit representation is useful in explaining the operation of a crystal near its fundamental resonant frequency. See figure 4 below.

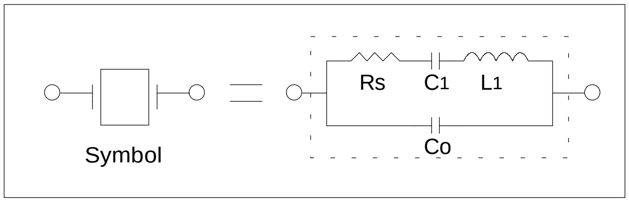

Figure 4: Equivalent Crystal Circuit

C_o - static capacitance, it's the capacitance measured from pin to pin which includes the crystal electrode, mounting structure and holder.

C_1 - represents the motional capacitance of the quartz

L_1 - Motional inductance, it's a function of mass

Rs - Series resistance, it represents the equivalent motional arm resistance.

The series combination of Rs, C1, and L1 represent the electrical equivalent of the vibrational characteristics of the crystal.

Quality Factor (Q)

The "Q" of a crystal is the quality factor of the motional arm at resonance. The stability of the crystal is dependent on the Q. For a High Q crystal, external reactance value changes have a less effect than a low Q crystal.

Series Resonance

At series resonance, the reactance's of C1 and L1 cancel out, leaving Rs in parallel with C0. The reactance of C0 cancels out and the crystal looks purely resistive at a frequency slightly above resonance. Manufacturers refer to this resistance as equivalent series resistance (ESR). Crystal manufacturers normally specify max values of (ESR) because precise values are seldom needed in an oscillator design.

The oscillator circuit using a crystal is capacitive when its tuned below its series resonant frequency and inductive above it.

The series-resonant frequency is given by:

$$Fs = \frac{1}{2\Pi\sqrt{L_1 \times C_1}}$$

Manufacturers make crystals to operate at series or parallel resonance. Make sure that a series resonant crystal **isn't** used in a parallel-resonant circuit if you desire the oscillator circuit to oscillate at or near the stamped value on the crystal holder. This discussion is merely provided for completeness.

Parallel Resonance

Crystal resonators made to oscillate above series resonance (fs) are called parallel-resonance crystals. The parallel resonant frequency is:

$$Fp = \frac{1}{2\Pi\sqrt{L_1 \times C}} \quad \text{where,}$$

$$C = \frac{C_1 \times C_0}{C_1 + C_0}$$

At parallel resonance, the crystals impedance will look inductive to the load. If the crystal is to be used at parallel resonance, the load capacity should always be specified. The load capacity is the dynamic capacity of the circuit across the crystal terminals. In the design of a parallel oscillator circuit, the load capacity should be selected to operate the crystal at a stable point on the reactance curve as close to fs as possible.

For AT-cut parallel resonant cystals, the value of ESR is given by:

$$ESR = Rs(1 + \frac{C_0}{C_l})\wedge 2$$

In Hitachi's H8/500 Family of microcontrollers, an on-chip parallel oscillator circuit is completed with the connection of a crystal across terminals EXTAL and XTAL and the addition of a 10 to 22 pf capacitor attached to each lead of the crystal. This is the load capacitance that the crystal sees. Refer to figure 5 for circuit connection.

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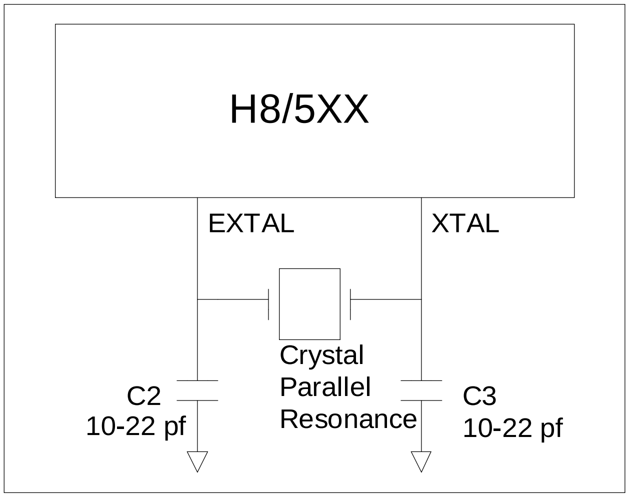

Figure 5: Connection of Crystal Oscillator

The load capacitance can be calculated by the following formula:

$$C_L = \frac{C_2 \times C_3}{C_2 + C_3} + C_{stray}$$

Cstray includes pin to pin, input and output capacitance of the CPU at pins EXTAL and XTAL plus any additional parasitic capacitance. A rule of thumb figure for Cstray is 5 pf; therefore, if C2= C3= 22 pf max, CL would be 16pf. Therefore the crystal operating in the parallel resonant mode should be able to handle **at least** a load of 16pf.

Temperature/ Frequency stability

The frequency imprint found on the crystal is its resonant frequency which changes with temperature. Crystal manufacturers express temperature-related changes in parts per million per degree Celsius (ppm/deg C).

To find the maximum frequency change at a given temperature, look at specifications or read it off a graph. Next multiply the ppm by the nominal operating frequency(in mega-hertz). The formula is given below:

$$F_{\text{max deviation (at given Temp.)}} = F_{\text{crystal}} \times F_{\text{stability}}$$

For example, lets assume the crystal has a frequency stability of +/- 200 ppm for temperatures in the range of -55 to 125 deg C. If the crystal has an imprint on the holder of fcr=20 MHz than this is its resonant frequency. Multiply fcr, 20 X 10 exp 6, by 200 X 10 exp -6. The result indicates a frequency shift from the actual resonant frequency by about +/- 4000 Hz. This is approximately a .02% deviation from the actual value. This deviation is insignificant for most applications. However, for timing applications that use the internal clock as its time base, a .02 % drift in frequency over time will occur. This **may** be unacceptable. If strict frequency control is required in any application, a crystal oven or temperature-compensated oscillator (TCXO) should be used.

Start-up Time

The start-up time and frequency stability tend to pull each other in opposite directions and as a result both are hard to control. For example, if C2 and C3 are increased in value, the start-up time will increase while the frequency stability decreases. Likewise, decreasing the value of C2 and C3 will decrease the start-up time and increase the frequency stability of the oscillator circuit. It is important to mention that very large or small values of C2 and C3 will prevent the oscillator from starting up.

If start-up times is of primary concern in your application, then we recommend you choose a ceramic resonator if an appropriate start-up time can't be arrived at with a quartz crystal.

Aging

Quartz crystal's resonant frequency will change with respect to time. The manufacturer will specify the amount of change in parts per million per year (ppm/year). Typical values range from 3 to 10 ppm/year. For example, a 20-MHz crystal with an aging rate of 5ppm/year will change by 100 Hz per year. The frequency will deviate from the value stamped on its case by .0005% at most each year.

There are many factors involved in the aging of a crystal. Some of the most **common** factors that effect aging include: internal contamination, excessive drive level, surface change of the crystal, various thermal effects, wire fatigue, and frictional wear.

Power dissipation

The crystal when connected to an oscillator circuit will need a certain drive level to begin vibrating at the resonant frequency. If a drive level greater than the recommended max value is applied, the crystal resonator will be permanently damaged. Typical drive levels range from 5.0 mW to 0.1 mW. Drive level values will be

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lower for high frequency crystals because of the thinner cut.

Holder

The holder, also called case, is chosen based upon the physical size and is constrained by the frequency of operation and mode of vibration.

Practical Clock Oscillator Design Considerations

The on-chip oscillator circuit is nothing more than a inverting amplifier that's used as part of a feedback oscillator. The complete clock oscillator design and the electrical equivalent circuit representation are shown in figures 6 and 7, respectively.

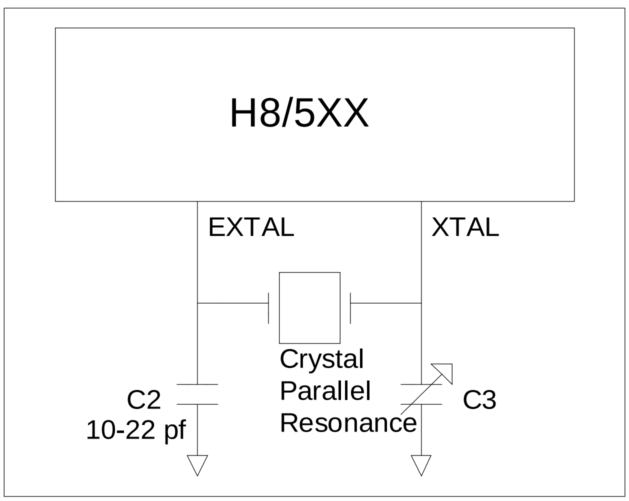

Figure 6: Clock Oscillator Design

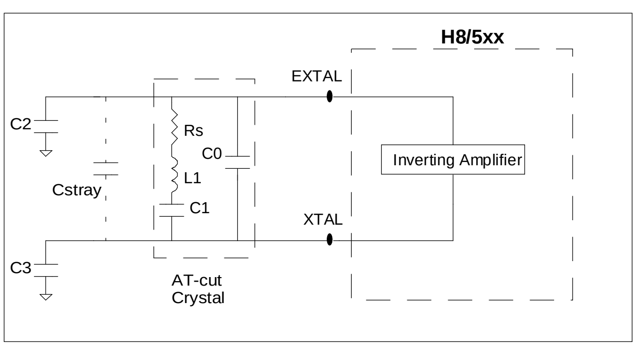

Figure7: Electrical Equivalent Circuit for Crystal Oscillator

Capacitor C3 can be adjusted to fine tune the crystal Oscillator frequency. For time sensitive applications that use the system clock as a time base, it may be necessary to fine tune the oscillator frequency. The following procedure should be carried out when tuning the oscillator circuit:

1) Connect a scope probe to the "phi" pin and monitor the system clock. The system clock is half that of the selected crystals resonating frequency.

2) Adjust C3 to fine tune the system clock to the desired frequency.

In the lab, the H8/534 evaluation board was used to determine the effects of varying capacitor C3 while maintaining C2 fixed at 22pf. In addition, we chose to examine the behavior of the circuit when using various AT-cut series resonant quarts crystals. The theory indicates that the circuit will oscillate at a frequency slightly above the value stamped on the holder with the proper selection of load capacitance. This was verified in the lab.

Because the oscillator circuit was designed to operate in the parallel resonant mode, we **can not recommend** the use of AT-cut series resonant quarts crystals.

Please refer to the following tables below for the experimental results.

Test conditions: Room temperature, H8/534 MCU rated at 10 MHz.

Measurement equipment: Hitachi V-1150 (150 MHz) Oscilloscope with an AT-10AN Hitachi Denshi, Ltd. 10X scope probe.

Test board: Hitachi H8/534 evaluation board (US538EVB21H).

Component specification: C2 = 22pF +/- 10%, 50V ceramic capacitor, C3 was varied with fixed ceramic capacitor values.

Crystal manufacturer: Fox Electronics
Part number: FOX200-20
Special note: AT-cut;quarts crystal value = 20.000 MHz;designed for parallel resonant operation

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Capacitor Values (C3)	Frequency "phi"	Crystal Frequency
100 pF	9.999 MHz	20.000 MHz
33pF	9.999 MHz	20.000 MHz
15 pF	10.000 MHz	20.000 MHz
8 pF	10.001 MHz	20.000 MHz
1 pF	10.002 MHz	20.000 MHz
22 nF	0 MHz	20.000 MHz
0.1 uF	0 MHz	20.000 MHz

Table 1: Loading effects on internal crystal oscillator circuit when using a parallel resonant crystal.

Crystal manufacturer: Fox Electronics
Part number: FOX160-20
Special note: AT-cut;quarts crystal value = 16.000 MHz;designed for parallel resonant operation

Capacitor Values (C3)	Frequency "phi"	Crystal Frequency
100 pF	7.9994 MHz	16.000 MHz
33pF	8.0000 MHz	16.000 MHz
15 pF	8.0007 MHz	16.000 MHz
8 pF	8.0013 MHz	16.000 MHz
1 pF	8.0024 MHz	16.000 MHz
22 nF	0 MHz	16.000 MHz
0.1 uF	0 MHz	16.000 MHz

Table 2: Loading effects on internal crystal oscillator circuit when using a parallel resonant crystal.

Crystal manufacturer: Fox Electronics
Part number: FOX120-20
Special note: AT-cut;quarts crystal value = 12.000 MHz;designed for parallel resonant operation

Capacitor Values (C3)	Frequency "phi"	Crystal Frequency
100 pF	5.9993 MHz	12.000 MHz
33pF	5.9998 MHz	12.000 MHz
15 pF	6.0004 MHz	12.000 MHz
8 pF	6.0009 MHz	12.000 MHz
1 pF	6.0018 MHz	12.000 MHz
22 nF	0 MHz	12.000 MHz
0.1 uF	0 MHz	12.000 MHz

Table 3: Loading effects on internal crystal oscillator circuit when using a parallel resonant crystal.

Crystal manufacturer: Raltron
Part number: 3.6864-S
Special note: AT-cut; quarts crystal value = 3.6864 MHz; designed for parallel resonant operation

Capacitor Values (C3)	Frequency "phi"	Crystal Frequency
100pF	1.8434 MHz	3.6868 MHz
22pF	1.8436 MHz	3.6872 MHz
15pF	1.8437 MHz	3.6874 MHz
8pF	1.8438 MHz	3.6876 MHz
1pF	1.8440 MHz	3.6880 MHz
22nF	0 MHz	0 MHz
.1uF	0 MHz	0 MHz

Table 4: Loading effects on internal crystal oscillator circuit when using a parallel resonant crystal.

Crystal Manufacturer: Fox Electronics
Part number: FOX018S
Special note: AT-cut; quarts crystal value = 1.8432 MHz; designed for parallel resonant operation

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Capacitor Values (C3)	Frequency "phi"	Crystal Frequency
100pF	921.54 KHz	1.84308 MHz
22pF	921.57 KHz	1.84314 MHz
15pF	921.59 KHz	1.84318 MHz
8pF	921.62 KHz	1.84324 MHz
1pF	921.67 KHz	1.84334 MHz
22nF	0 MHz	0 MHz
.1uF	0 MHz	0 MHz

Table 5: Loading effects on internal crystal oscillator circuit when using a parallel resonant crystal.

Crystal Manufacturer: Fox Electronics
Part number: FOX200
Special note: AT-cut; quarts crystal value = 20.000 MHz; designed for series resonant operation

Capacitor Values (C3)	Frequency "phi"	Crystal Frequency
100pF	10.0015 MHz	20.0030 MHz
22pF	10.0030 MHz	20.0060 MHz
15pF	10.0035 MHz	20.0070 MHz
10pF	10.0040 MHz	20.0080 MHz
4pF	10.0050 MHz	20.0100 MHz
1pF	10.0060 MHz	20.0120 MHz
.1uF	0 MHz	0 MHz

Table 6: Loading effects on internal crystal oscillator circuit when using a series resonant crystal.

Crystal Manufacturer: CTS Electronics Corp.
Part number: MP150
Special note: AT-cut; quarts crystal value = 15.000 MHz; designed for series resonant operation

Capacitor Values (C3)	Frequency "phi"	Crystal Frequency
100pF	7.5028 MHz	15.0056 MHz
22pF	7.5039 MHz	15.0078 MHz
15pF	7.5043 MHz	15.0086 MHz
8pF	7.5050 MHz	15.0100 MHz
1pF	7.5063 MHz	15.0126 MHz
22nF	0 MHz	0 MHz
.1uF	0 MHz	0 MHz

Table 7: Loading effects on internal crystal oscillator circuit when using a series resonant crystal.

Observations

The above data indicates that varying the load capacitance C3 will have very little effect on the generated system clock frequency if the capacitance values are kept between 1-100pF. However, there is a maximumand minimum value above which the oscillator will seize to operate. Hence, care must be taken when selecting an appropriate capacitor. Hitachi recommends using capacitor values between 10-22pF. These values can be used at any frequency with good quality crystals.

To vary the system clock to generate the desired E-clock, the engineer will need to replace the crystal. If a controller is rated to operate at 10 MHz, the engineer can select a crystal rated at **20Mhz or below** to generate the desired system clock.

Because a controller is rated to operate at 10 MHz doesn't mean that the on chip oscillator will work only with a 20 MHz crystal. To the contrary, the on-chip oscillator circuit will work with any crystal that meets the recommended parameters and the chips minimum system clock frequency. Please refer to table 8.

Test conditions: Room termperature; H8/534 MCU rated at 10 MHz; C2=C3=22pF +/-10%, 50V

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Crystal Value	Frequency "phi"	Crystal Frequency
20.0000 MHz	10.0030 MHz	20.0060 MHz
15.000 MHz	7.5032 MHz	15.0064 MHz
13.0280 MHz	6.5175 MHz	13.0350 MHz
10.000 MHz	5.0026 MHz	10.0052 MHz
5.0688 MHz	2.5352 MHz	5.0704 MHz
4.0000 MHz	2.0004 MHz	4.0008 MHz

Table 8: Effects of using different crystals on the internal oscillator circuit

Temperature Effects

A heating gun was used in the lab to heat the environment around the crystal to above several 100 degrees Farenheit. The clock was found to function properly with no noticable effects in the quality of the signal waveform. This observation should be expected since the oscillator circuit resides on-chip and is less succeptable to temperature changes.

The following crystals manufacturers and part numbers were used to obtain the experimental data in table 8:

<u>Crystal manufacturer</u>	<u>Part number</u>
Fox Electronics	FOX200
CTS Electronix Corp.	MP150
Pletronics	SRMP18
Raltron	A-10.000-3
NDK	NDK051
CTS Electronix Corp.	MP-040

Other Crystal Alternatives

Ceramic resonators operate in the same way as quartz crystals. This is because the two are electrically equivalent. The only thing separating the two is that the parameters and tolerances are different. Quartz crystals generally are offered with better frequency tolerances and as a result are generally twice as expensive. So if you can live with a frequency deviation of .5% or better, than an inexpensive ceramic resonator should be used in place of the costly quartz crystal.

Although the use of ceramic resonators give you less frequency control, the oscillator circuit will startup a lot faster because of the circuits lower Q. For some applications, this feature is desirable in which case a ceramic resonator should be selected.

Crystal Layout Considerations

In the design of microcontroller based embedded systems, component layout often receives little attention from new and sometimes experienced hardware design engineer. Even at 20 MHz, if the components aren't placed properly on the PCB, the internal oscillator may cease to operate properly because of the added impedance to the input network.

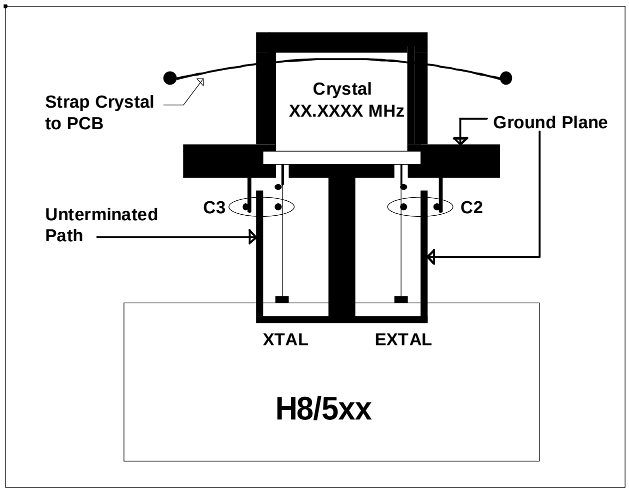

Figure 7: Crystal Layout

The following suggestion are made in an effort to improve the oscillator circuits responce, performance, and minimize potentially unwanted Rf interferences.

- Account for scope probe capacitance during measurement.
- Certain types of crystal holders should be strapped down to the PCB.
- All component leads should be kept as short as possible to avoid presenting an undesired load to the input of the oscillator circuit.
- The ground plane shown above will help to minimize Rf interferences from the noisy lines of the oscillator circuitry.
- Avoid ground loops around the oscillator circuit. Do not try an terminate the unterminated path shown in figure 7.

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- To reduce excessive clock noise to a manageble level, use multiple layer PCB with power and ground plane in the middle
- Noisy lines should be kept as far as possible from the oscillator components

Caution:

To measure the frequency of the system clock, we recommend you not connect a scope probe to the EXTAL or XTAL pins. The scopes internal impedance may present an undesirable load to the oscillator network and as a result the oscillator circuit may cease to operate or the resonant frequency may change. To avoid this unwanted condition, we recommend that you connect a scope probe to the "phi" pin to measure the frequency of the system clock.

Conclusion

This Tutorial focused on the study of crystals and their importance in the design of a crystal clock oscillator using the on-chip oscillator circuit found in Hitachi's H8/5xx family of devices.

We chose to not discuss the design of external oscillators because of the following reasons:

- Cost and increased component count

- The added design costs to isolate the high frequency clocked signal lines from other digital and analog signal lines.

- The readily available single packaged oscillators offered from a number of manufacturers.

- Decreased reliability in the case of a discrete oscillator design

A number of customers in the field have asked us to provide them with exact values for the external components required by the on-chip oscillator circuit in order to guarantee the accuracy and long term stability of the oscillator. Hitachi will not make any claim nor guarantee the operation of the on-chip oscillator circuit just as transistor manufacturer make no guarantee of a circuits operation using their device. They can only guarantee the devices operation under the specified test conditions. The same holds true for Hitachi.

It is intended that this application note along with the experimentally observed data be used as a guide in the design of the on-chip oscillator circuit. Please understand that we were interested in the circuits general operation with a number of crystals from various manufacturers and the effects of varying the load. The long term circuit stability, temperature and environmental effects, and other important design considerations weren't examined in the lab.

It should be mentioned that specifications are constantly being updated as newer parts are released. The current data sheet should always be consulted for the latest crystal parameters and the recommended range of values for the load capacitance, CL.

For your reference, Appendix A contains a list of crystal manufacturers that should be able to help you select an appropriate crystal for your application. The list is by no means complete. A number of other crystal manufacturers not included should be able to supply you with an appropriate crystal meeting Hitachi's specifications.

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APPENDIX A

REFERENCES

1. MF Electronics Corp., Crystal Product Guide
2. ECLIPTEK Corp., Catalog of Products, pg. XN01
3. CAL CRYSTAL LAB, Inc., Crystal and Clock Oscillator Product Catalog, pg. 2 to 7
4. CTS Corp., Crystal/Hybrid Oscillators/Crystal Oscillators Product Catalog, pg. 4 to 11
5. ECLIPTEK Corp., "The Crystal and Oscillator Specialists", EDN, December 13, 1993
6. Chuck Husted, "Select the Right Crystal for your Oscillator", Electronic Products, November 1993, pg. 59
7. Hitachi America Ltd., H8/532 Hardware Manual, January 1992, pg. 135 to 138
8. Fox Electronics, Quarts Crystal Products 1993, pg. 74 to 75
9. E.C. Young, "The New Penguin Dictionary of Electronics", Penguin Books, 1986, pg. 383 to 386
10. John Watson, "Mastering Electronics", McGraw- Hill, third edition, 1990,pg. 331 to 332
11. Dan Becker, "Crystal Oscillators", Electronics Now, January 1993, pg. 45 to 54
12. Electronics World + Wireless World, "An end to spurious oscillations", May 1993, pg. 377 to 380

Acknowledgements

I would like to thank **Joe Maddock** of CAL CRYSTAL LAB, INC and **Jim Northuck** of FOX ELECTRONICS for their suggestions and answers to a number of questions that I had in regards to crystals, specifications, and the manufacturing process.

Crystal Manufacturers

CTS Electronics Corp. , 400 Reimann Ave., Sandwich, IL 60548, (815) 786-8411
Fox Electronics, 5570 Enterprise Parkway, Fort Myers, Fl 33905, (813) 693-0099
Cal Crystal Lab, Inc., 1142 North Gilbert Street, Anaheim, Ca. 92801, (714) 991-1580
Champion Technologies, Inc., 2553 N. Edgington Street, Franklin Park, IL 60131, (708) 451-1000
Statek Corp., 512 N. Main Street, Orange, Ca. 92668, (714) 639-7810
MF Electronics Corp., 10 Commerce Drive, New Rochelle, NY 10801, (914) 576-6570
SaRonix, 151 Laura lane, Palo Alto, Ca. 94303, (415) 856-6900
Ecliptek Corp., 3545 Cadillac Ave., Costa Mesa, Ca. 92626, (714) 433-1200
Raltron Electronix, 2315 N.W. 107th Ave., Miami, Fl 33172, (305) 593-6033
NDK America, Inc., 47671 Westinghouse Dr., Fremont Ca. 94539, (510) 623-6500
Murata Manufacturing Co., Ltd., 26-10, Tenjin 2 chome, Nagaoka-kyo-shi, Kyoto, Japan 617, Ph: 075-951-9111
Pletronics, Inc., 19015 36th Ave. West Suite H, Lynnwood, Wa 98036, (206) 776-1880

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