Introduction

Purpose

- To educate about crystal devices and present Epson's crystal device portfolios

Objectives

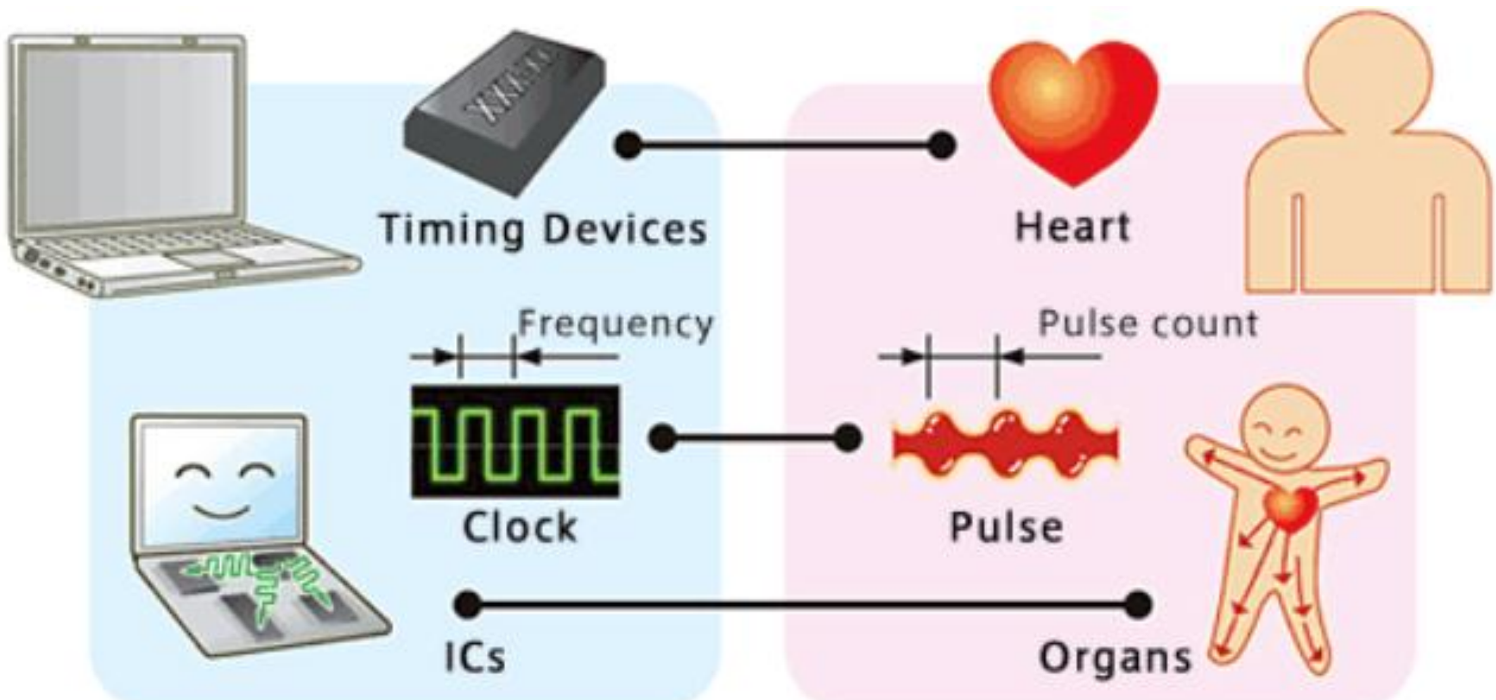
- Explain timing devices, quartz crystals and the manufacturing processes
- Review kHz and MHz crystal cuts and characteristics
- Educate on Epson's breakthrough QMEMS photolithography processing technology
- Provide tips for oscillation circuit designs
- Explain important electrical parameters of crystal devices
- Provide overview of Epson's kHz and MHz crystal device portfolios

Content

- 19 pages

Timing Devices are Vital

A timing device is the "heart" of an electronic equipment!



Why Quartz Crystals?

Crystal Device Timeline

1880
The Curie brothers discover the piezo-electric effect

1905—1909
Italian George Spezi succeeds in growing crystals in an autoclave of his own design.

1917
French physicist Paul Langevin, inventor of ultrasonic equipment using the piezo-electric effect, announces the detection of ice submerged in water using ultrasound pulses.

1922
Cady invents the crystal oscillator in the U.S.

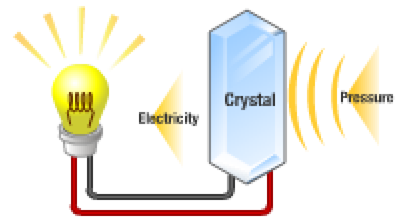
1969
The world's first quartz watch

- the revolutionary Seiko Quartz Astron 35SQ - goes on sale.

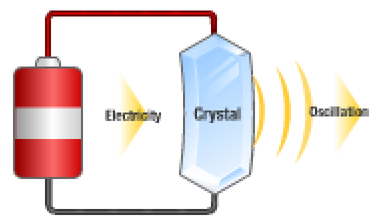
1980s
VTR & PC production booms and crystal unit production expands

1990s
PC, cell phone & car navigation system demand explodes

Crystal Properties



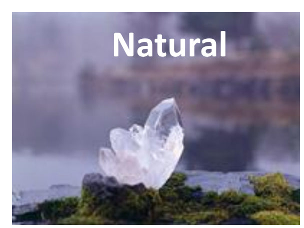
Piezo-electric effect



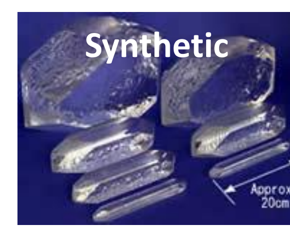
Reverse Piezo-electric effect

Conceptual Illustrations

Natural vs. Synthetic Quartz



Contains Impurities



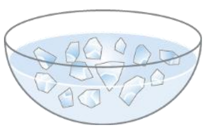
Consistent Quality!

Process of growing synthetic quartz crystals

Material: Natural quartz crystal (fragments), alkaline solution, seed crystals
Temperature: 360 deg. C
Pressure: Approx. 1t **Time:** Approx. 3 months at high heat

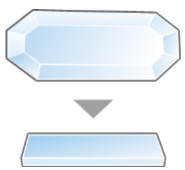
1 Washing the natural quartz fragments

The fragments are washed and then dried.



2 Seed crystal processing

Crystals are cut into the shape required for seed crystals.

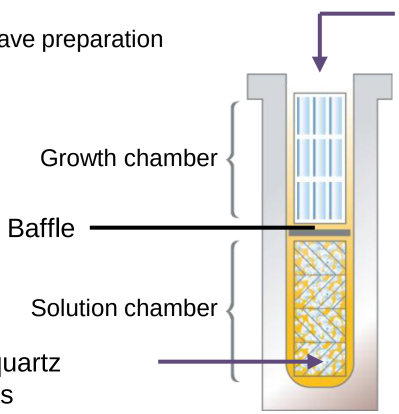


3 Solvent preparation

An alkaline aqueous solution is prepared.

Alkaline solution
NaOH(sodium hydroxide)
Na_2CO_3(sodium carbonate)

4 Autoclave preparation



1.Natural quartz fragments

Placed in the bottom half of the autoclave and separated by a baffle.

2.Seed crystals

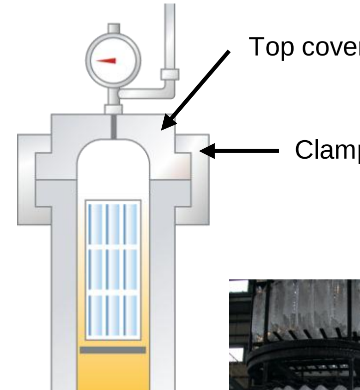
Hung in the top half (growth chamber) of the autoclave

3.Alkaline aqueous solution

Thechamber is filled to about 80%

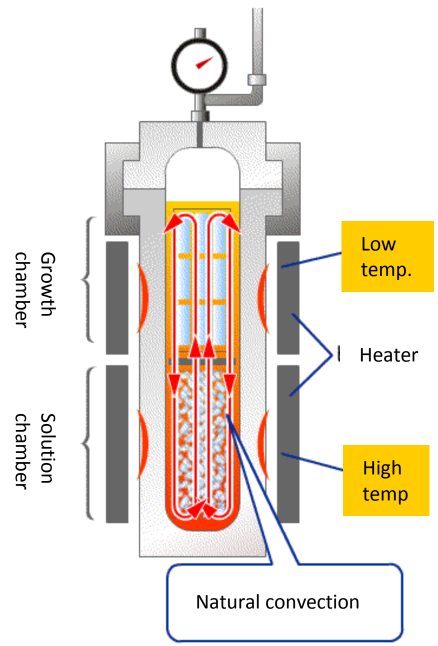
5 Sealing

The autoclave is sealed with a top cover and a clamp.



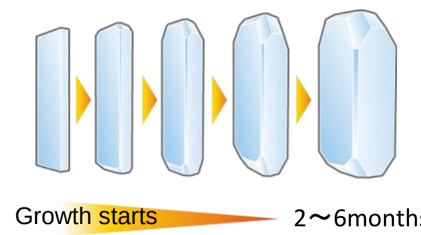
6 Autoclave heating

The top half (growth chamber) is heated to a lower temperature than the bottom half (solution chamber) to produce natural convection.



7 Growth

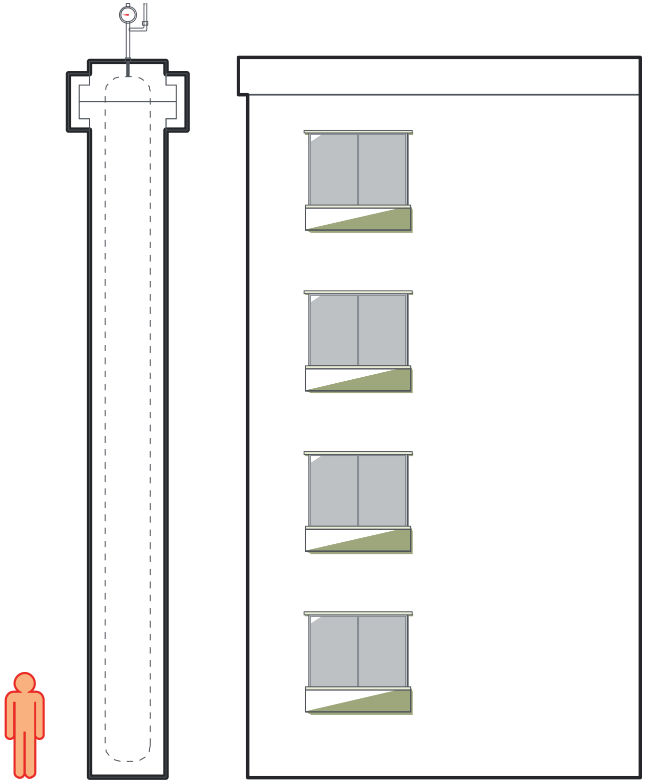
The elevated temperature and pressure of the autoclave are maintained, and the crystals are allowed to grow slowly.



8 **Completion!**

The synthetic crystal growth process, from start to finish, takes about 2-6 months.

Quartz Bars in Autoclave



Autoclaves are as tall as a 4~5 story building

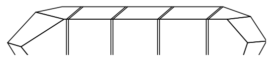
Grown quartz bars in an autoclave

Process for manufacturing tuning-fork crystal devices

The process used to manufacture tuning-fork crystal devices are illustrated and explained here.

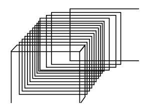
1 From rough sythetic crystal to block cutting

Synthetic crystals grown for tuning-fork crystal devices are cut into blocks.



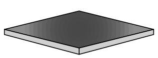
2 Wafer slicing

The blocks are sliced into thin wafers.



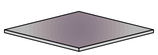
3 Wafer polishing

The quartz crystal wafers are polished.



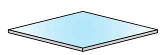
1.Lapping

Surface hills and valleys are removed with a grinding fluid.



2.Etching

The wafer surface is etched to remove roughness.

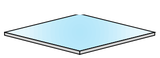


3.Polishing

The wafer is polished to a mirror finish with an abrasive compound

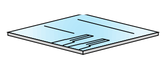
4 Photoetching

A photolithographic process is used to form the tuning-fork shape.



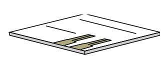
1.Sputtering

The wafer is coated with gold and chrome.



2.Contour etching

The gold and chrome Is removed.

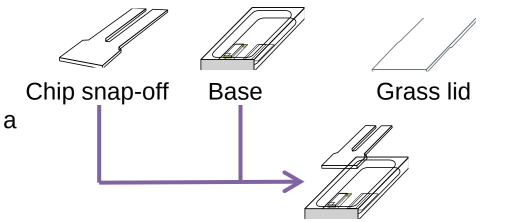


3.Electrode processing

Electrodes are added and circuits are patterned by a photolithographic process.

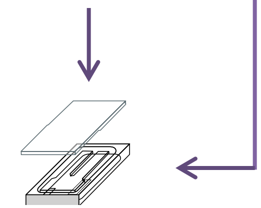
5 Mounting

The crystal chip is connected to a base with a conductive adhesive.



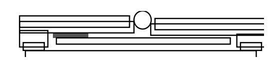
6 Lid sealing

The low-melting-point glass is melted to bond the glass lid to the base.



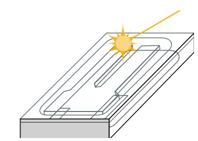
7 Vacuum sealing

A ball of gold and germanium is melted to seal the device in a vacuum state.



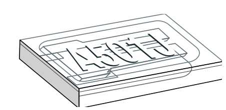
8 Frequency adjusting

The frequency of the crystal chip is fine-tuned by shaving off part of the electrodes on the tips of the crystal chip with a laser.



9 Marking

The products are marked with a designated number.

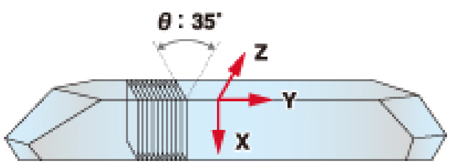


10 **Completion!**

The process from rough synthetic crystal to a finished tuning-fork crystal device takes about one month to complete.

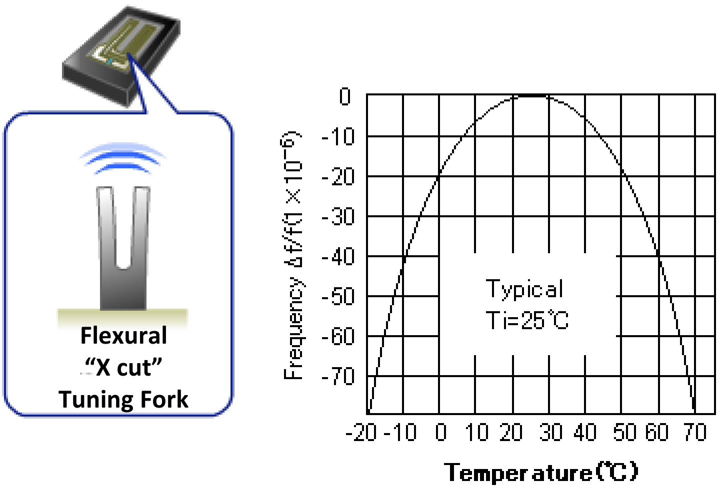
Crystal Cut and Temperature Curves

Crystal Cut



A crystal's vibration mode differs depending on the angle at which it is cut. The vibration mode determines the frequency range of the crystal.

kHz Temperature Curve

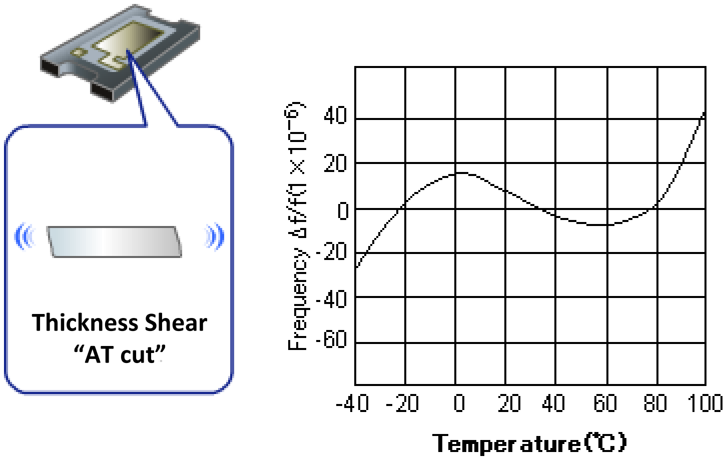


$\Delta f/f = B(Ti\text{-}\theta X)^2$

θX: specified temperature

B: Parabolic coefficient

MHz Temperature Curve



$\Delta f/f = \alpha(\theta X\text{-}25) + \beta(\theta X\text{-}25)^2 + \gamma(\theta X\text{-}25)^3$

θX: specified temperature

QMEMS:
Epson's Breakthrough Technology

There is constant demand for compact, high-precision quartz devices to serve the decreasing form factor and high performance electronic device market.

"QMEMS" is Epson's response to serve this need!

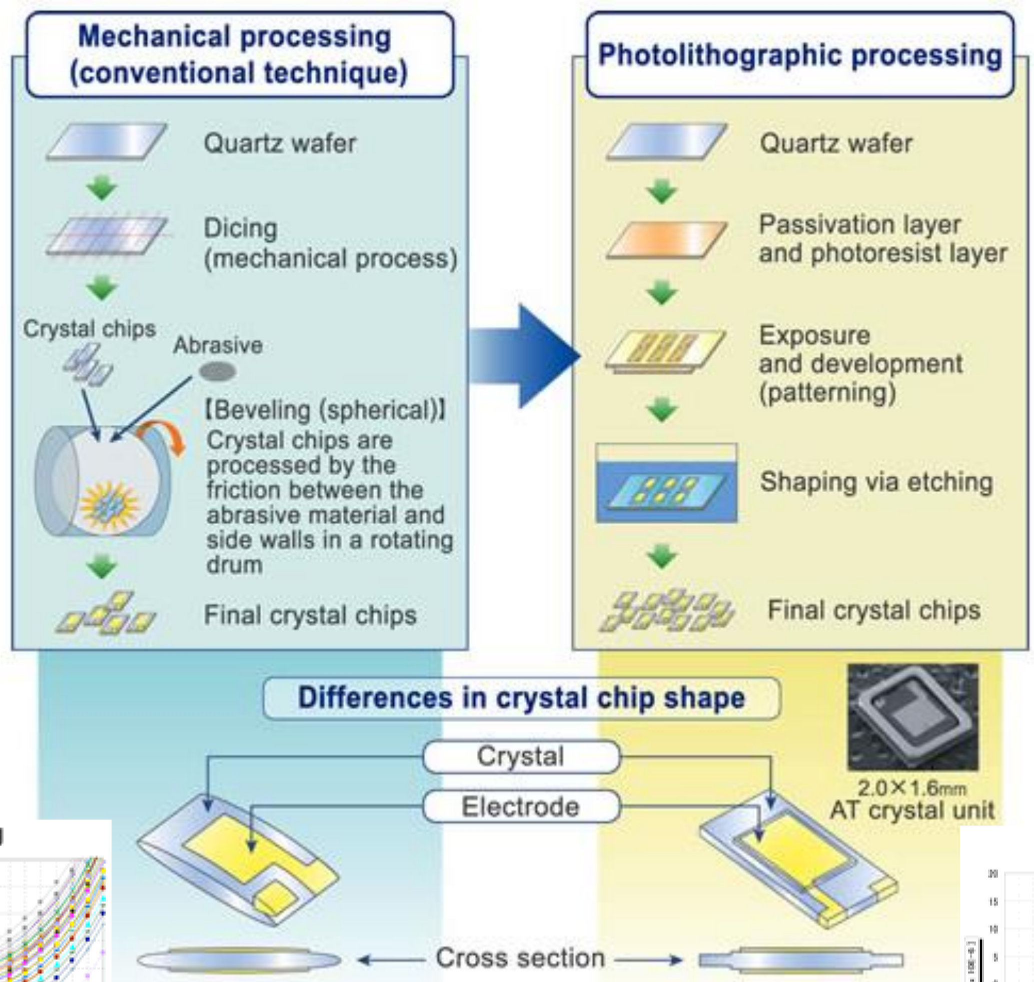
QUARTZ + MEMS

high accuracy and high stability

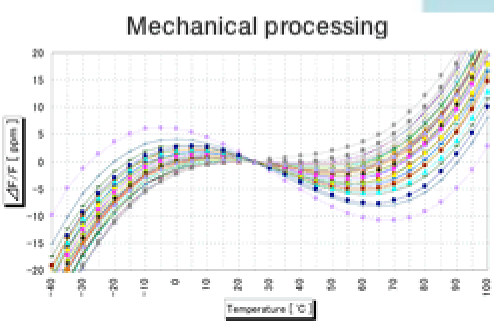
Micro Electro Mechanical Systems

QMEMS

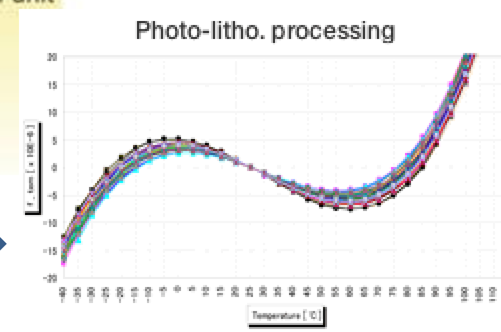
QMEMS – Photolithography Process



Click link below to learn more about QMEMS: http://www5.epsondevice.com/en/quartz/aboutus/qmems/index.html

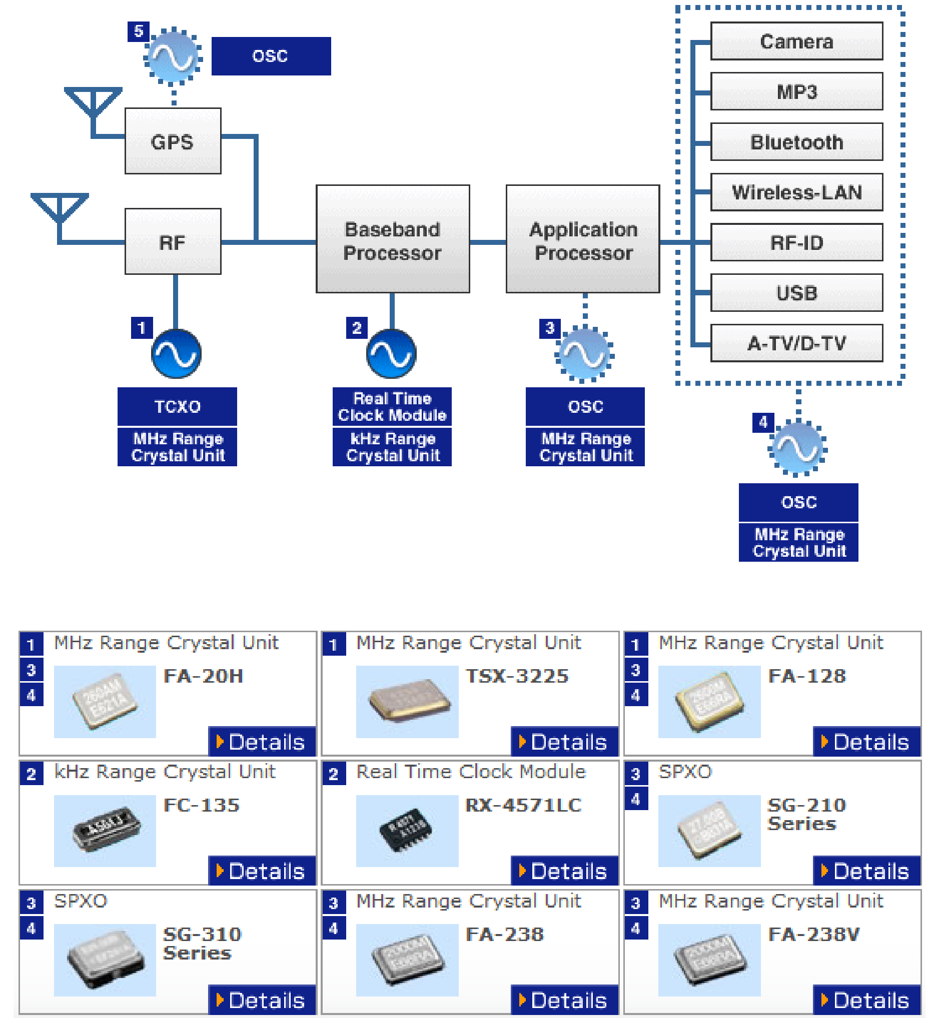


Stability vs. Temperature curve of a 2.0 x 1.6 mm AT crystal unit (26 MHz)



Applications

Cellular (Select "Cellular" as example) → **Cellular (Resulting web page)**



Click link below to access all applications:
http://www5.epsondevice.com/en/quartz/application/index.html

Circuit Design

Freescale
(Select "Freescale" as example)

freescale semiconductor

RENESAS

TEXAS INSTRUMENTS

Xilinx

Freescale (Resulting web page)

For customer designing Freescale Semiconductor IC MC132xx Series ZigBee/IEEE802.15.4 applications

The following provides a basic explanation of design considerations for the external oscillation circuit using quartz crystal for Low Power RF technology including ZigBee,IEEE802154 wireless applications.
"Please refer to Freescale Semiconductor ZigBee/IEEE802154 solution below."

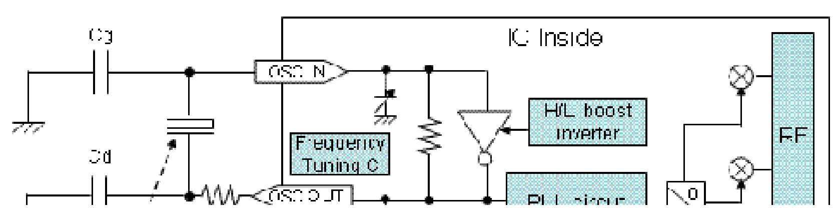
Clock solution recommendations for Freescale MC132xx Series

Please refer to Freescale Semiconductor official site for additional information.

In realizing low power consumption RF designs, the following factors should be taken into consideration.

1.Oscillation start-up time
2.Frequency tuning
3.Lower BER(Bit Error Rate) over operating temperature

No.	Oscillation Circuit Factor	24 GHz < AT crystal unit spec>
1	Quick oscillation start-up time *High oscillation allowance *Boost inverter	*Lower ESR(R1) *High drive level
2	Easy frequency control *inner frequency tuning capacitor	*proper frequency sensitivity *low parameters' variation
3	Lower BER *temperature compensation	*High frequency stability



Click link below to access circuit design info:
http://www5.epsondevice.com/en/quartz/tech/c_design/index.html

Circuit Design

Parameters to consider when designing with a crystal device:

- Rf and U1 are typically internal to the IC
- R_D to control drive level across crystal unit
- C_G and C_D to control center frequency

with respect to the load capacitance (CL)

of the crystal unit :

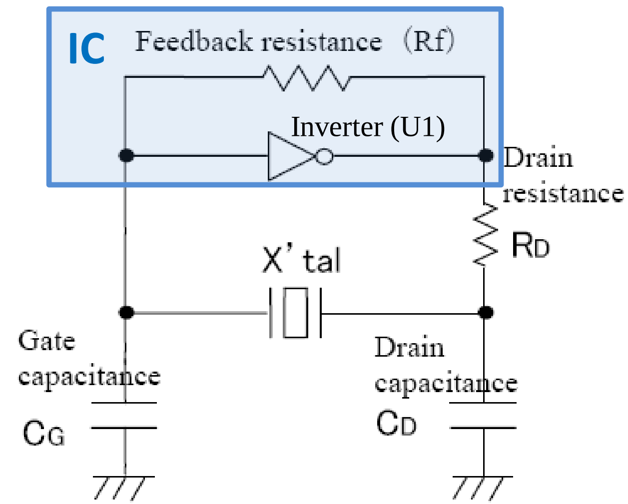
$$C_L \cong \frac{C_G \times C_D}{C_G + C_D} + C_S \ [pF]$$

(stray)

Goal:

- Low drive level
- Fast oscillation start up time
- Sufficient oscillation allowance
- Small frequency deviation

Typical Pierce Oscillator Circuit



Example values:

Preliminary Parameters	Rf [MΩ]	Rd[kΩ]	Cg [pF]	Cd[pF]
20 to 60 [KHz]	20	500	10	10
60 to 165 [KHz]	10	300	10	10
5.5 to 24 [MHz]	1	0.5	10	10

Epson offers both kHz and MHz crystal *oscillators* to help designers reduce board space and design risk, as well as save time and money.

Important Electrical Parameters

- **Package Size and Type** – SMD or Thru-hole
- **Frequency** – Desired nominal frequency
- **Operating Temperature** – Temperature range that the crystal unit electrical parameters are guaranteed
- **Stability** – MHz xtals only, frequency deviation over operating temperature
- **Parabolic coefficient** – kHz xtals only, used to calculate frequency deviation over operating temperature
- **Frequency Tolerance** – Deviation of the actual/measured frequency from the nominal frequency value at +25°C ambient temperature
- **Load Capacitance** – Match the crystal's load capacitance to the oscillation circuit's capacitance. The oscillation output frequency is determined based on this matching.
- **ESR** – Equivalent Series Resistance or motional resistance. It can be regarded as a reference for the ease of oscillation. The higher the value, the more difficult for oscillation start up.
- **Drive Level** – Power or oscillation output level required to operate (drive) a crystal device. 1µW to 100µW range is used to maintain stable oscillation and minimize structural damage to the internal quartz crystal.

kHz Crystal Products

QMEMS

Page	Model	External Dimensions (mm)	t Max.	Frequency (20 kHz / 32 kHz / 100 kHz / 200 kHz / 300 kHz)
4	FC-12D	2.05×1.25×0.35		● 32.768 kHz
	FC-12M	2.05×1.2×0.6	*	32 kHz – 77.5 kHz
5	FC-13A	3.2×1.5×0.9		● 32.768 kHz
6	FC-135	3.2×1.5×0.9	*	32 kHz – 77.5 kHz
	FC-255	4.9×1.8×0.9	*	32 kHz – 100 kHz
7	MC-146	7.0×1.5×1.4	*	32 kHz – 100 kHz
	MC-156	7.1×3.3×1.5	*	
8	MC-306	8.0×3.8×2.54	*	20 kHz – 120 kHz
	MC-405/406	10.41×4.06×3.6	*	20 kHz – 120 kHz
9	MC-30A	8.0×3.8×2.54	*	20 kHz – 120 kHz
10	C-002RX	Φ2.0		● 32.768 kHz
	C-004R	Φ1.5		
	C-005R	Φ1.2		
	C-2-TYPE	Φ2.0	*	20 kHz – 120 kHz
	C-4-TYPE	Φ1.5	*	32 kHz – 120 kHz

New kHz Products

kHz RANGE CRYSTAL UNIT
LOW PROFILE SMD

FC - 12D / FC - 12M

- Frequency range : 32.768 kHz (32 kHz to 77.5 kHz)
- External dimensions : 2.05 × 1.25 × 0.35 mm···FC-12D
  : 2.05 × 1.2 × 0.6 mm···FC-12M
- Overtone order : Fundamental
- Applications : Smart card, Small devices···FC-12D
  : Small devices···FC-12M

Pb Free
RoHS Compliant

Product Number (please contact us)
FC-12D: X1A000111xxxx00
FC-12M: X1A0000x1xxxx00

Actual size

FC-12D FC-12M

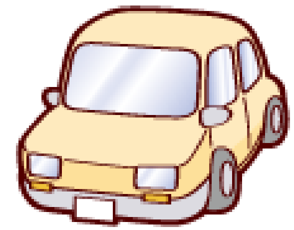
Thin Tuning-fork crystal units contribute to the realization of slim, card-mountable crystal devices for secure smart cards.

Small and thin Tuning-fork crystal units contribute to the realization of small, thin, stylish mobile devices.

Specifications (characteristics)

Item	Symbol	Specifications			Conditions / Remarks
		FC-12D	FC-12M		
Nominal frequency range	f_nom	32.768 kHz	32.768 kHz	32 kHz to 77.5 kHz	Please contact us for inquiries regarding available frequency.
Storage temperature	T_stg	-55 °C to +125 °C			Store as bare product.
Operating temperature	T_use	-40 °C to +85 °C			
Level of drive	DL	0.25 μW Max.	0.5 μW Max.		
Frequency tolerance (standard)	f_tol	$\pm 20 \times 10^{-6}$	$\pm 20 \times 10^{-6}$ $\pm 30 \times 10^{-6}$		+25 °C, DL=0.1 μW Please ask for tighter tolerance
Turnover temperature	Ti	+25 °C ±5 °C			
Parabolic coefficient	B	-0.04×10^{-6} / °C^2 Max.			
Load capacitance	CL	7 pF, 9pF, 12.5pF	12.5pF		Please specify
Motional resistance (ESR)	R_1	75 kΩ Max.	90 kΩ Max.	90 kΩ to 65 kΩ	
Motional capacitance	C_1	3.7 fF Typ.	6.4 fF Typ.	7.0 fF to 2.7 fF	
Shunt capacitance	C_0	0.8 pF Typ.	1.3 pF Typ.	1.6 pF to 0.8pF	
Frequency aging	f_age	$\pm 3 \times 10^{-6}$ / year Max.			+25 °C, First year

New kHz Products



kHz RANGE CRYSTAL UNIT
FOR AUTOMOTIVE APPLICATIONS
LOW PROFILE SMD

FC-13A

- Frequency range : 32.768 kHz
- External dimensions : 3.2 × 1.5 × 0.9 mm
- Overtone order : Fundamental
- Applications : Accessories and ECU sub clock
- Conforms to AEC-Q200

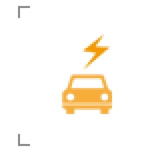
Product Number (please contact us)
X1A000091xxxx00

Actual size

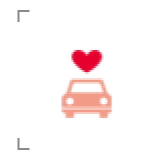
Specifications (characteristics)

Item	Symbol	Specifications	Conditions / Remarks
Nominal frequency range	f_nom	32.768 kHz	
Storage temperature	T_stg	-55 °C to +125 °C	Store as bare product.
Operating temperature	T_use	-40 °C to +125 °C	
Level of drive	DL	0.5 μW (1.0 μW Max.)	Please contact us if you require 1.0μW Max.
Frequency tolerance (standard)	f_tol	$\pm 20 \times 10^{-6}$, $\pm 30 \times 10^{-6}$, $\pm 50 \times 10^{-6}$	+25 °C, DL=0.1 μW
Turnover temperature	Ti	+25 °C ±5 °C	
Parabolic coefficient	B	-0.04×10^{-6} / °C^2 Max.	
Load capacitance	C_L	9 pF, 12.5 pF	Please specify
Motional resistance (ESR)	R_1	70 kΩ Max.	
Motional capacitance	C1	3.2 fF Typ.	
Shunt capacitance	C0	0.9 pF Typ.	
Frequency aging	f_age	$\pm 3 \times 10^{-6}$ / year Max.	+25 °C, First year

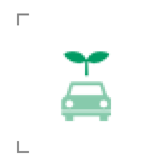
Infotainment Systems



Safety & Security Systems



Environmental Systems



Engine Control Systems

MHz Crystal Products

Model	Actual size (mm) t Max.	Frequency (1 MHz / 10 MHz / 20 MHz / 64 MHz)
FA-118T	NEW 1.6×1.2×0.35 t	24 MHz – 54 MHz
FA-128	2.0×1.6×0.5 t	24 MHz – 54 MHz
FA-20H	2.5×2.0×0.55 t	12 MHz – 48 MHz
FA-238V	3.2×2.5×0.7 t	12 MHz – 15.999 MHz
FA-238	3.2×2.5×0.7 t	16 MHz – 60 MHz
TSX-3225	3.2×2.5×0.6 t	16 MHz – 48 MHz
FA-365	6.0×3.5×1.4 t	● 12 MHz 14 MHz – 41 MHz
MA-306	8.0×3.8×2.54 t	● 14.31818 MHz 17.734 MHz – 41 MHz
MA-406	11.7×4.8×3.7 t	4 MHz – 64 MHz*
MA-505/506	13.46×5.08×4.6 t	4 MHz – 64 MHz*
CA-301	Φ3.1	4 MHz – 64 MHz*

* 8.0 MHz < f_nom < 8.2 MHz : Unavailable.
Available frequencies from 4 MHz to less than 5.5 MHz
(4 MHz ,4.032 MHz ,4.096 MHz ,4.19 MHz ,4.194304 MHz ,
4.433619 MHz ,4.5 MHz ,4.8 MHz ,4.9152 MHz)

New MHz Products

MHz RANGE CRYSTAL UNIT
ULTRA MINIATURE SIZE LOW PROFILE SMD

FA-118T

Pb Free | RoHS Compliant

Product Number (please contact us)
FA-118T : X1E000251xxxx00

- Nominal frequency range : 24 MHz to 54 MHz
- External dimensions : 1.6 × 1.2 × 0.35 t (mm)
- Overtone order : Fundamental
- Applications : Mobile phone, Bluetooth, W-LAN ISM band radio, Clock for MPU

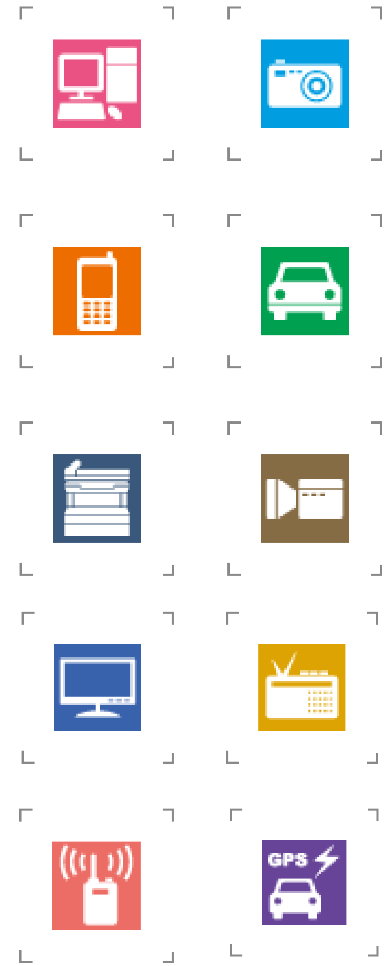
Actual size

NEW

Specifications (characteristics)

Item	Symbol	Specifications		Remarks
		For RF Reference	For Clock	
Nominal frequency range	f_nom	24.000 MHz to 54.000 MHz		Fundamental Please contact us for inquiries regarding the available frequencies.
Storage temperature range	T_stg	-40 °C to +125 °C		Store as bare product after unpacking
Operating temperature range	T_use	-40 °C to +85 °C		
Level of drive	DL	100 μW Max.	200 μW Max.	Recommended: 1 μW to 100 μW
Frequency tolerance (standard)	f_tol	$\pm 10 \times 10^{-6}$ *1	$\pm 30 \times 10^{-6}$	+25 °C For the out of standard specifications, please contact us for inquiries.
Frequency versus temperature characteristics (standard)	f_tem	$\pm 12 \times 10^{-6}$ *1	$\pm 30 \times 10^{-6}$	-20 °C to +75 °C For the out of standard specifications, please contact us for inquiries.
Load capacitance	CL	6 pF to ∞		Please specify.
Motional resistance (ESR)	R1	As per below table		-20 °C to +75 °C
Frequency aging	f_age	$\pm 1 \times 10^{-6}$ / year Max.	$\pm 5 \times 10^{-6}$ / year Max.	+25 °C, First year

Minimization trend (ex)…



Summary

- Epson offers an extensive portfolio of kHz and MHz crystal devices.

- kHz crystal devices are sometimes called tuning fork crystals or clock crystals. MHz crystal devices are sometimes called AT crystals.

- Epson offers both kHz and MHz crystal oscillators to help designers reduce board space and design risk, as well as save time and money.

- A timing device is the “heart” of an electronic equipment

- Epson has extensive knowledge of the growing and manufacturing processes of synthetic quartz since it started producing it in 1960

- QMEMS photolithography processing technology enables Epson to produce miniature quartz crystals with outstanding electrical characteristics.

- Epson’s website has great tips for recommending the appropriate crystal for various applications and common circuit designs.