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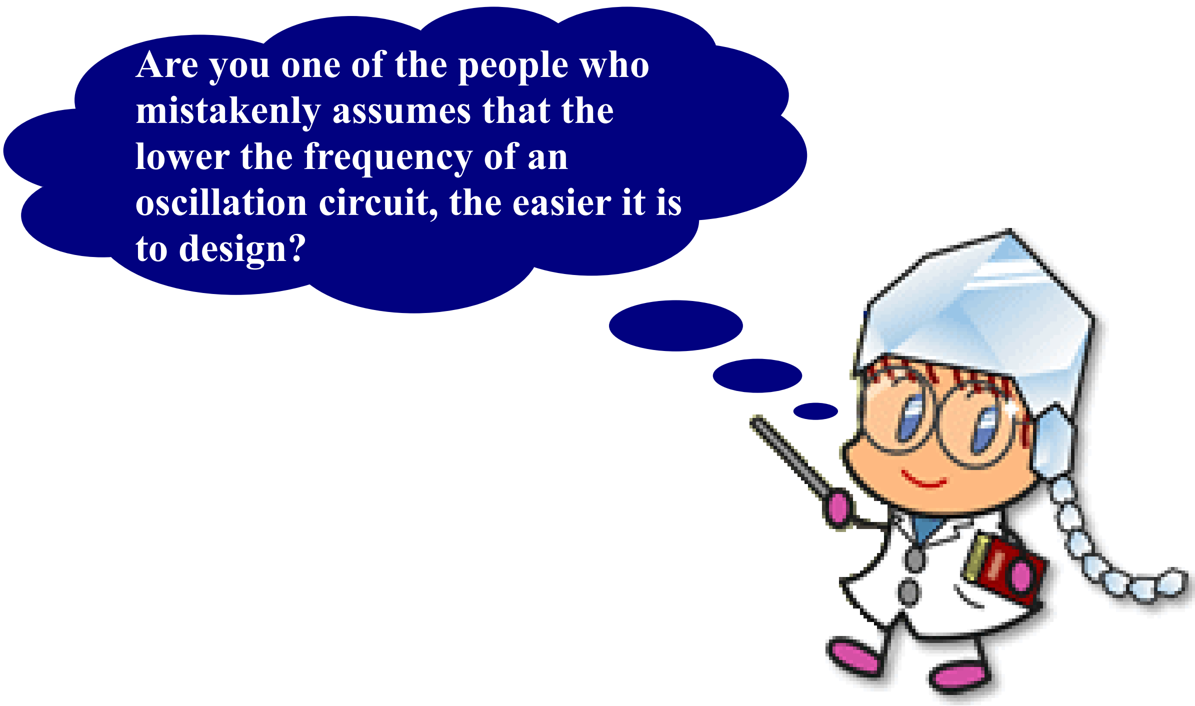
The Latest in Low-Frequency Oscillation Circuits!



Contents

1. Market Trends in Electronics

In recent years, heightened awareness of the need to reduce environmental impacts has spurred market demand for compact electronics products that use fewer raw materials and consume less power than their predecessors yet provide even greater functionality. This trend also holds true for the electronic components, including crystal devices, that go into consumer and industrial electronics products. For this reason, the crystal devices used as reference clocks in electronics have to meet increasingly rigorous size, power consumption, accuracy and reliability requirements. Reducing the size of the crystals, however, amplifies certain existing problems and gives rise to other new problems.

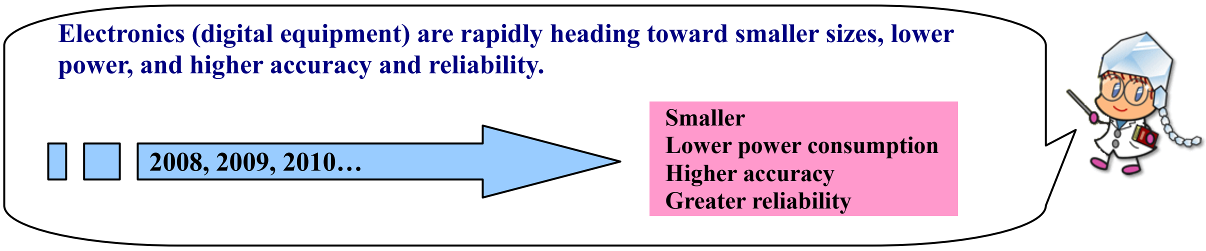


Table 1 summarizes the main requirements in major applications for kHz range crystal units (tuning fork crystal units). As the table indicates, tuning fork crystal units are essential in a wide range of applications that require device clocks, microcontroller sub-clocks, and timer functions. In every one of these applications the trend is toward ever more stringent size, power, accuracy and reliability requirements.

Table 1. Main Requirements for Tuning Fork Crystal Units

Application	Main Uses	Device Requirements
Cellular	Sub-clock Main CPU wakeup clock Clock	Small size Low power High accuracy & stability High reliability
Digital home electronics	Sub-clock Clock	Small size Low power High accuracy & stability High reliability
Digital camera	Sub-clock Clock	Small size Low power High accuracy & stability High reliability
Wireless LAN	Transmission acknowledgement clock Clock	Small size Low power High accuracy & stability High reliability
Automotive	Clock Sub-clock	Small size High accuracy & stability High reliability

2. Trends in Tuning Fork Crystal Units and Semiconductor Process Technologies

Figure 1 shows the size trend for tuning fork crystal units. Over the past 20 years, the cubic volume of these devices has rapidly shrunk, from a size of about 150 mm^3 all the way down to a tiny 1.5 mm^3. Further device scaling is expected as R&D in this area advances.

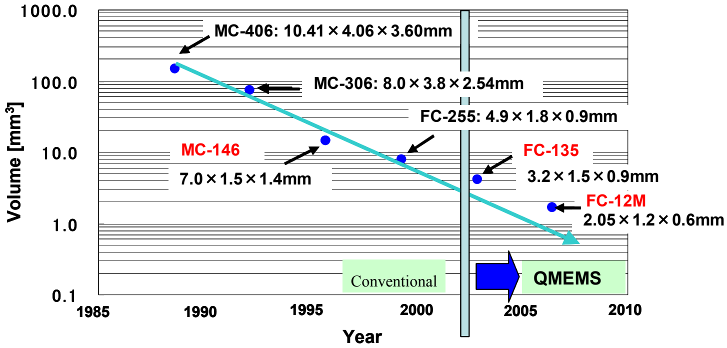


Figure 1. Size Trend for Tuning Fork Crystal Units

Figure 2 shows the shrinking process rules for low-voltage MPUs with integrated oscillation circuits for tuning fork crystal umits.
Process rules of 0.2 µm to 0.3 µm and supply voltages (VDD) of 1.8 V - 3.0 V were once typical. In recent years, however, these devices have been shifting to the 0.1 µm to 0.15 µm process rules and 1.5 V to 1.8 VDD domains.
Requirements for standby power consumption are also becoming tougher. Once about 0.3 µW, standby power now has to be in the range of 0.1 - 0.2 µW. Pressure to shrink process rules to reduce costs and to reduce driving voltages to conserve power is not likely to ease anytime soon.

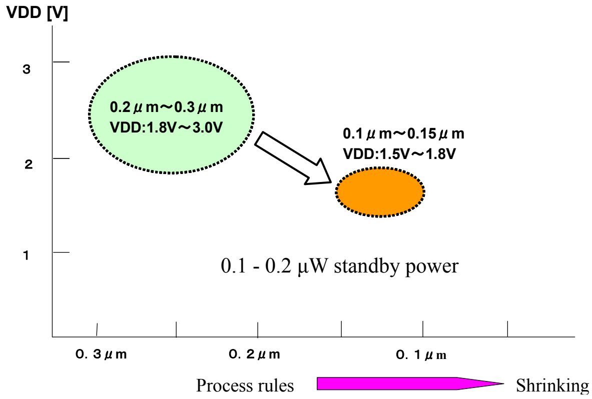


Figure 2. Low-Voltage MPU Process Rule Trend

These trends in tuning fork crystal units and in semiconductor process technologies are already resulting in a number of problems. Our technical support team has been hearing reports of problems such as the following:

- Oscillation stability is being hurt by increased CI values of tuning fork crystal units.
- Oscillation frequency deviation has been increasing due to the heightened frequency sensitivity of tuning fork crystal units.
- Stable oscillation cannot be obtained because shrinking semiconductor process rules and lower voltages are giving rise to reduced power supply noise resistance and insufficient oscillation allowance.

The next section presents some important points specifically with regard to tuning fork crystal units as sizes and voltages decline.

3. Effects of Miniaturization on Characteristics and Measures to Counter Them

3-1. Reduced oscillation stability due to increased CI value (crystal impedance value)

An example of an equivalent circuit for a crystal unit is shown in Figure 3. In this example, electrical circuits replace the crystal unit's resonance operation mode, and the CI value corresponds to the equivalent circuit's R_1.
In general, the CI value of a crystal unit increases as the crystal becomes smaller. The effect that the higher CI value has on the oscillation circuit is described below, along with measures taken to combat them.

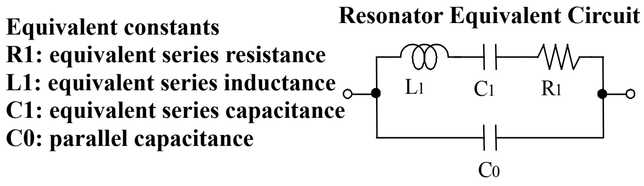


Figure 3. Equivalent Circuit for a Crystal Unit

Effects
A large CI value results in higher oscillation start up & stop voltages. In other words, even if the voltage is raised, oscillation does not always easily start; and even a slight drop in voltage causes oscillation to either become unstable or susceptible to stopping altogether.
The CI value is the equivalent resistance of the crystal at its resonant frequency. It is one of the key parameters in that it determines the oscillation allowance, which has an effect on oscillation instability and oscillation failures.

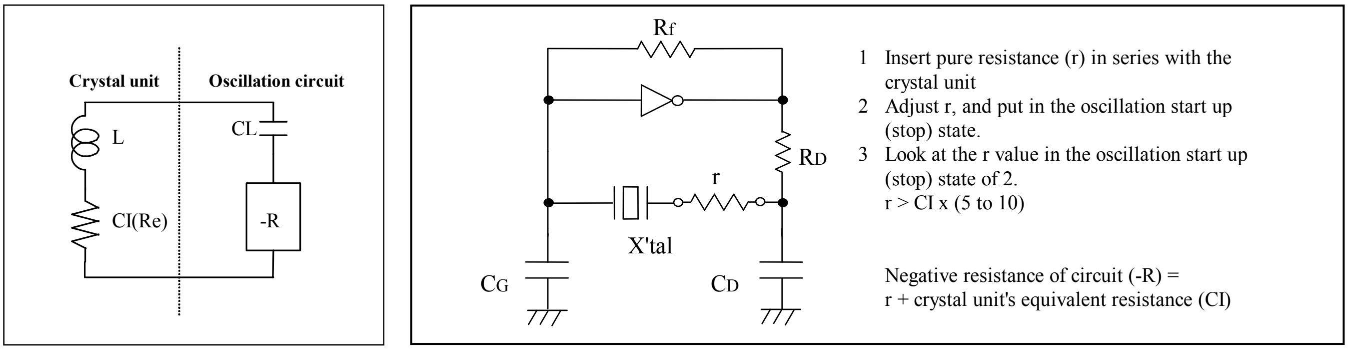


Figure 4. Method of Checking Oscillation Allowance

Countermeasures
First, an oscillation allowance of at least 5 to 10 needs to be secured. Oscillation allowance serves as a yardstick for gauging whether an oscillation circuit is capable of oscillating stably. The oscillation allowance can be expressed as a value found by dividing the negative resistance (CI) of the oscillation circuit of Figure 4 by the maximum equivalent series resistance (r) of the crystal unit.
An insufficient oscillation allowance produces problems; namely, slow oscillation start-up times and higher oscillation start-up voltages. If the oscillation allowance becomes markedly less sufficient, oscillation may become unstable or may not start at all.

There are two methods for effectively raising the oscillation allowance.

(1) Generally speaking, the oscillation allowance can be raised by improving negative resistance. As shown in Figure 5, oscillation circuit current consumption increases as negative resistance rises. Therefore, the deterioration in oscillation stability that is associated with elevated CI values can be alleviated by boosting the oscillation circuit current. The disadvantage of this method is that power consumption increases.

(2) The oscillation allowance can also be improved by using a crystal with a small CI value but, as explained above, CI values tend to grow as crystal unit size shrinks.

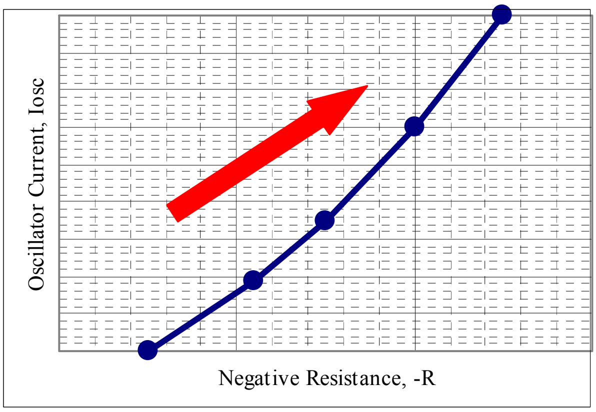


Figure 5. Relationship Between Oscillator Current Consumption and Negative Resistance

There is thus a trade-off between size and oscillation stability. To counter this, Epson Toyocom has introduced QMEMS technology and come up with designs that hold down CI values even for very small crystals. At Epson Toyocom we help our customers achieve quality designs by providing them with the best selection of components for their systems from an extensive lineup of crystal units in sizes for every need.

3-2. Oscillation frequency deviation

Crystals exhibit greater frequency sensitivity as they become smaller, and when they are mounted on a PCB inside a piece of electronic equipment, the oscillation frequency can deviate from the desired value. The effects of this deviation and measures to counter it are explained below.

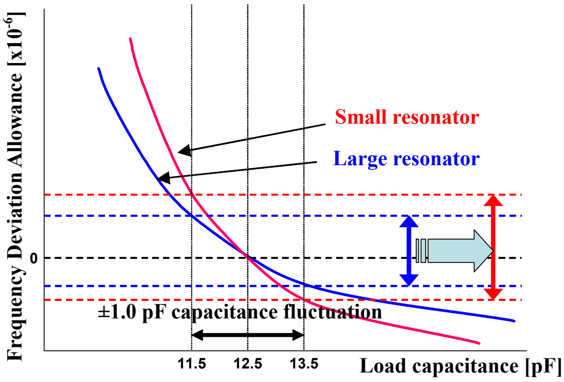


Figure 6. Frequency/Load Capacitance Characteristic

Effects

The frequency of a crystal unit changes depending on the load capacitance of the oscillation circuit. This change is called "frequency/load capacitance characteristic." As indicated in Formula 1, the load capacitance is determined by the oscillation circuit capacitor value and stray capacitance.

The frequency/load capacitance characteristic differs depending on the size of the crystal, as shown in Figure 6. Frequency stability is affected by stray capacitance variations of the entire PCB because as crystal units become smaller, their frequency sensitivity per 1 pF of capacitance increases (the inclination of the curve steepens). As a result, frequency becomes susceptible to fluctuation. In other words, deviations in oscillation frequency increase.

The measures used in crystal oscillation circuits to counter this are explained below.

Formula 1) $CL \approx Cg \times Cd / (Cg + Cd) + Cs$ **(Cs: circuit floating capacitance)**

Countermeasures

Figure 7 illustrates a typical crystal oscillation circuit with a CMOS IC.
The oscillation frequency can be adjusted by changing the gate capacitance, CG, and drain capacitance, CD. Therefore,
(1) Select a capacitor with little variation in CG and CD.
(2) Select a low-sensitivity crystal unit.
A stable, accurate frequency can be obtained by selecting components that satisfy these requirements.
Epson Toyocom, employing QMEMS technology, designs products that are small yet exhibit limited variation in sensitivity and from product to product.
Using our products is also an effective way of mitigating oscillation frequency deviation.

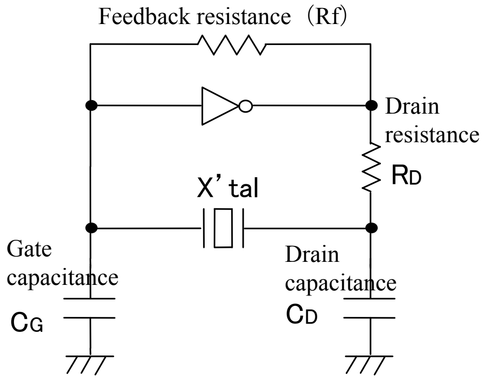


Figure 7. Oscillation Circuit

3-3. Oscillation problems arising from low-voltage MPUs

(1) Trends in low-power MPU development

Modern electronics are shrinking in size and consuming less power even as they pack more functions. This means that MPUs, which are used in a great many applications, also have to be smaller, have more modest power needs, and provide a host of functions. MPUs that meet these requirements are being developed, with particular emphasis on the following areas:

- Development of single-chip products with lower chip counts
- Use of finer design/process rules (Figure 2)
- Development of products that operate on lower voltages and consume less power

(2) Reducing the power consumption of oscillation circuits for 32.768 kHz tuning fork crystal units

Meanwhile, advances in the foregoing areas of development end up levying a variety of constraints on 32.768 kHz oscillation circuits. The demand for low power is greatest for 32.768 kHz clocks, since they run constantly in MPUs.
The low-power trend is particularly apparent in sensor networks and eco products, as these promising applications require the ability to operate for long periods of time on batteries.
Semiconductor manufacturers are using a variety of innovative approaches to design 32.768 kHz oscillation circuits so as to reduce the power consumed by 32.768 kHz clocks. Some of these approaches are listed below. Figure 8 shows a sample structure of an oscillation circuit block, but every chip company has its own specifications.

- Variable inverters (voltage gain and internal inverter count)
- Variable built-in capacitors
- Shoot-through current reduction process when inverters are turned on

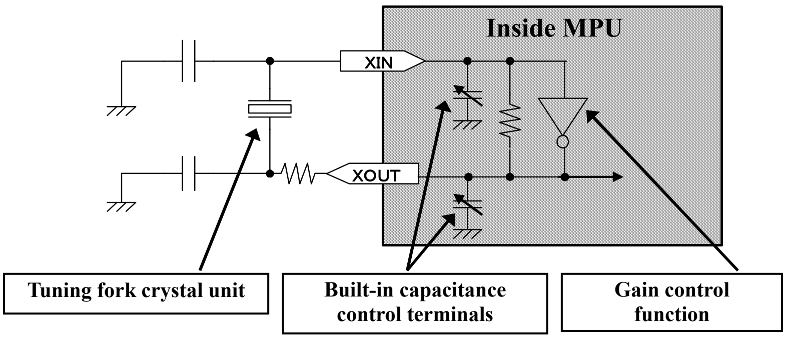


Figure 8. MPU Internal 32.768 kHz Oscillation Circuit Block Structure

Effects

The shift to lower power consumption is being driven forward by the foregoing two trends, but the trade-off is increased susceptibility to:

- noise
- oscillation frequency deviations
- inability to secure oscillation allowance

The proper evaluation of semiconductors, circuit boards and crystal units is extremely important for achieving the dual objectives of low power consumption *and* stable oscillation.

Countermeasures

Oscillation circuit evaluations are an important part of the product design phase, and it is important to test circuits equipped with the actual chips, circuit boards and crystal units that are to be used. You will have to ask the crystal unit manufacturer to perform oscillation circuit evaluation testing, but the key here is the board design.

You need to carefully note the following when designing your circuit board (Figure 9):

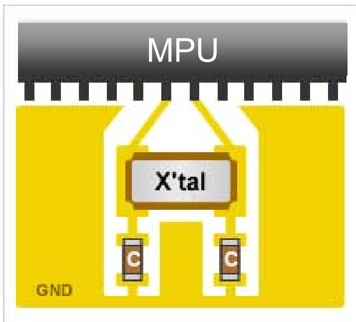


Figure 9. Example of a Packaged Board

(1) Place the oscillation circuit (the crystal unit and oscillation capacitor) near the oscillation IC (MPU, etc.)
(2) Board wires (traces) should be as short as possible (no more than 20 mm) and should not intersect.
(3) Provide GND on the surface of the board on which the crystal unit is mounted.
(4) If you are using a multilayer board, do not place other signal lines in an inner layer on which the crystal unit is mounted.

Please be aware that failure to follow these design considerations will result in a variety of problems, including oscillation failures, oscillation instability, and frequency deviation.

Epson Toyocom is running a reference campaign with semiconductor manufacturers, and the following key considerations are explained on our Web site:

- Semiconductor circuit configuration
- Recommended crystal units matched with semiconductors
- Circuit board design precautions

We plan to increase the number of semiconductors going forward. For details, please see:
http://www.epsontoyocom.co.jp/english/tech/circuitdesign.html

3-4. Crystal oscillators

Product designs that use crystal oscillators are another extremely effective solution to the problems associated with small size and low power.
Crystal oscillators, integrated products that combine a crystal unit with an oscillation circuit, have several advantages:

- Since the oscillation circuit is built-in, crystal oscillators come ready for use, with pre-optimized characteristics such as oscillation operation, frequency accuracy, and oscillation waveform.
- Circuit constants for oscillation capacitance and so forth do not need to be changed, and board-level circuit evaluations are not necessary.
- The crystal unit and oscillation circuit are matched so as to obtain the best balance in the trade-off between stable oscillation and low power operation.

These advantages enable crystal oscillator users to greatly reduce their design risk, as well as save time and money on the increasingly difficult job of designing low-frequency oscillation circuits.

Besides, crystal oscillators offer certain space saving and flexibility benefits. Epson Toyocom's miniature SG-3050BC crystal oscillator, for example, comes in a tiny package that measures just 2.2 mm x 1.4 mm x 1.0t mm. Because of its small size and the fact that it needs only a power connection to function, the SG-3050BC gives board designers extra flexibility in the use of their circuit board real estate.
Epson Toyocom simultaneously offers both small size and superior oscillation characteristics.

Epson Toyocom Initiatives

Designing circuits for small crystal units is difficult because many crystal characteristics, including CI value, property variation and frequency sensitivity, deteriorate the smaller the crystal unit becomes. Epson Toyocom contributes to the development of compact, high-end electronics by using "QMEMS" technology, a photolithographic process technology the company has evolved over the past 30 years, to design and fabricate tiny tuning fork crystal units that provide outstanding performance.
By using QMEMS technology instead of the conventional machining process to produce tuning fork crystal units, Epson Toyocom is able to three-dimensionally process tiny crystal chips whose electrodes and outer shapes are extremely accurate. This enables us to design tuning fork crystal units with the optimal characteristics.
This technology advantage allows Epson Toyocom to provide tuning fork crystal units that have the following characteristics:

- A consistent crystal chip shape (and thus limited variation in CI value and frequency accuracy) due to the use of a wafer etching process
- Low CI values, achieved by forming three-dimensional grooves in the oscillating arms of the tuning fork to provide greater area for the electrodes
- Extremely small size due to the use of a microfabrication process

QMEMS technology has enabled Epson Toyocom to develop a product lineup that can help reduce our customers' design and quality risks, if even only a little.
Moving forward, Epson Toyocom will further evolve its QMEMS technology so that we can develop and provide crystal devices that are smaller yet offer even better performance.

* QMEMS is registered trademark of Epson Toyocom.

4. Epson Toyocom's kHz-band Total Solutions

As the leader in crystal devices, Epson Toyocom dominates in sales of tuning fork crystal units. The first to develop miniature crystal products with thin profiles, Epson Toyocom helps its customers' product development efforts by providing total solutions that include resonators and oscillators.

4-1. Epson Toyocom's tuning fork crystal units

(1) Tuning fork crystal unit product lineup

As indicated in the table below, Epson Toyocom boasts an extensive lineup of kHz-band tuning fork crystal units for a wide range of applications. The lineup includes everything from cylinder-encapsulated crystals to SMD products for automated assembly. The MC-146 and FC-135, core models in the small package category, have become global standard sizes. In March 2007, moreover, Epson Toyocom took another step toward meeting mounting demands for miniaturization by commercializing the ultra-miniature FC-12M, a model that, despite its diminutive size, offers excellent accuracy and stability, a low CI value and low sensitivity.

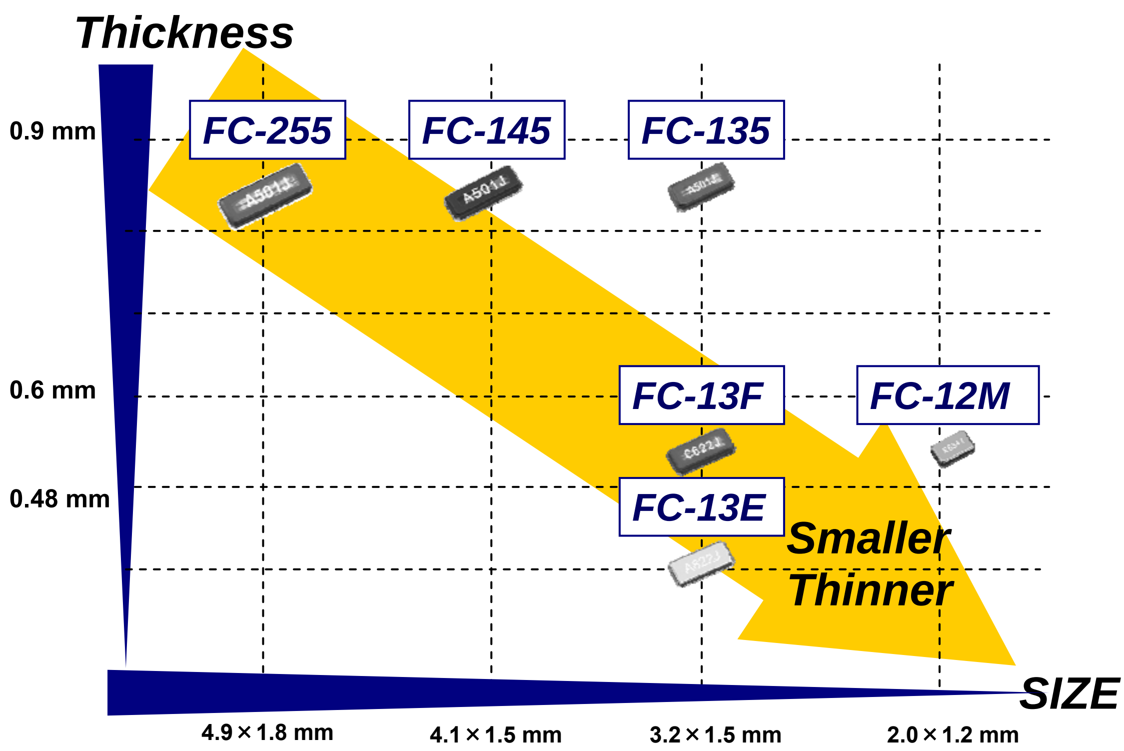
■ Epson Toyocom's Tuning Fork Crystal Units

Model	Size (mm) Max.	Frequency (20 kHz / 32 kHz / 100 kHz / 200 kHz / 300 kHz)
FC-12M	2.05×1.2×0.6 t	32 kHz – 77.5 kHz
FC-13E	3.2×1.5×0.48 t	● 32.768 kHz
FC-13F	3.2×1.5×0.6 t	● 32.768 kHz
FC-135	3.2×1.5×0.9 t	32 kHz – 77.5 kHz
FC-145	4.1×1.5×0.9 t	● 32.768 kHz
FC-255	4.9×1.8×0.9 t	32 kHz – 100 kHz
MC-146	7.0×1.5×1.4 t	32 kHz – 100 kHz
MC-156	7.1×3.3×1.5 t	32 kHz – 100 kHz
MC-306	8.0×3.8×2.54 t	20 kHz – 165 kHz
MC-405/406	10.41×4.06×3.6 t	20 kHz – 165 kHz, ● 307.2 kHz
MC-30A	8.0×3.8×2.54 t	20 kHz – 165 kHz
C-001R	Φ3.1	● 32.768 kHz
C-002RX	Φ2.0	● 32.768 kHz
C-004R	Φ1.5	● 32.768 kHz
C-005R	Φ1.2	● 32.768 kHz
C-2-TYPE	Φ2.0	20 kHz – 165 kHz, ● 307.2 kHz
C-4-TYPE	Φ1.5	32 kHz – 120 kHz, ● 192 kHz

■ Main Specifications of Small Form Factor Products

	FC-12M	FC-135	MC-146
Nominal frequency	32.768 kHz	32.768 kHz	32.768 kHz
Frequency tolerance	$\pm 20 \times 10^{-6}$ $\pm 30 \times 10^{-6}$	$\pm 20 \times 10^{-6}$	$\pm 20 \times 10^{-6}$ $\pm 50 \times 10^{-6}$
Load capacitance (CL)	12.5 pF	7 pF, 9 pF, 12.5 pF	7 pF, 9 pF, 12.5 pF
Series resistance (CI)	90 kΩ	70 kΩ	65 kΩ
Series capacitance	6.4 fF Typ.	3.4 fF typ.	1.9 fF typ.
Parallel capacitance	1.3 pF Typ.	1.0 pF typ.	0.8 pF typ.
External dimensions	2.0 x 1.2 x 0.6t mm max.	3.2 x 1.5 x 0.9t mm max.	7.0 x 1.5 x 1.4t mm max.

■ FC series miniaturization trend



4-2. Epson Toyocom's 32.768 kHz oscillators

(1) Our 32.768 kHz crystal oscillator product lineup

Along with our tuning fork crystal unit product lineup, Epson Toyocom has commercialized 32.768 kHz crystal oscillators that, like tuning fork crystal units, are being used for a wide variety of applications. Our flagship small-package oscillator, the SG-3030LC, has helped many of our customers succeed in product development.
Moreover, Epson Toyocom is bolstering its 32.768 kHz crystal oscillator lineup with the SG-3050BC, currently in development. The SG-3050BC not only will be the world's smallest 32.768 kHz oscillator, it will offer even better performance than any product before it.

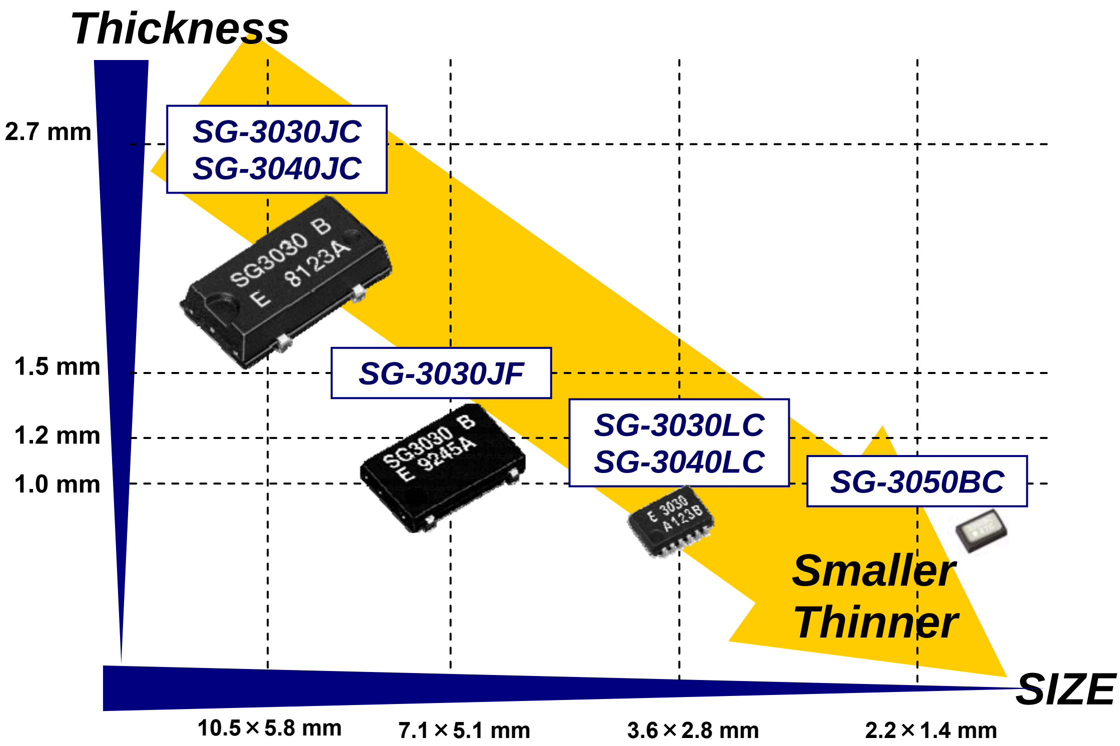
■ Epson Toyocom's 32.768 kHz Crystal Oscillators

Model	Size (mm)		Frequency (1 Hz, 1 MHz, 50 MHz, 100 MHz, 500 MHz, 800 MHz)
SG-3050BC Preliminary		2.2×1.4×1.0 t (Max.)	●32.768 kHz
SG-3030LC SG-3040LC		3.6×2.8×1.2 t (Max.)	
SG-3030JF		7.1×5.1×1.5 t (Max.)	
SG-3030JC SG-3040JC		10.5×5.8×2.7 t (Max.)	

■ Main Specifications of 32.768 kHz Crystal Oscillators

	SG-3030LC	SG-3040LC	SG-3050BC New!
Storage temperature	-55 to +125ºC		
Operating temperature range	-40 to +85ºC		
Supply voltage (Vcc)	1.5 to 5.5 V	0.9 to 3.6 V	1.2 to 5.5 V
Current consumption	2 μA Max.	3.1 μA Max.	2 μA Max.
	(Vcc = 3.3 V, no load)	(Vcc = 3.3 V, no load)	(Vcc = 3.3 V, no load)
Frequency tolerance (Ta = +25ºC)	5±23 x 10^{-6}		5±5 x 10^{-6}
Frequency aging (Ta = +25ºC)	±5 x 10^{-6} / year		
	Vcc = 3.3 V		
Symmetry	45 to 55 %		
Rise/fall times	200 ns Max.		

■ **32.768 kHz crystal oscillator miniaturization trend**



About Epson Toyocom

Epson Toyocom Corporation, formed in October 2005 through the integration of Seiko Epson Corporation's crystal device business and Toyo Communication Equipment,
is pursuing a "3D strategy" designed to drive both horizontal growth through expansion in three device categories—timing devices, sensing devices and optical devices—and vertical growth through combinations of products in these categories. With this strategy, Epson Toyocom aims to be the global leader in the crystal device industry and the leading provider of a wide range of crystal products for both consumer and industrial applications, including mobile terminals, core network devices, and automotive systems.
The company's timing devices are extremely accurate, stable crystal products that serve as reference signal sources in all manner of devices. The lineup currently includes products in frequencies ranging from the kilohertz band up to 800 MHz. In the kilohertz range, Epson Toyocom offers tuning forks. At frequencies up to about 2.4 GHz band, Epson Toyocom offers AT-crystal products that use thickness-shear vibration. In the hundreds of megahertz range, the company applies its AT vibration technology to provide crystal products that use an HFF (high-frequency fundamental) or SAW (surface acoustic wave).
Epson Toyocom web site: http://www.epsontoyocom.co.jp/english