

Frequency Control Components and Applications using them

Can you imagine your everyday life without the comfort of technology?

Would you like to understand what a garage key lock, an industry robot and a coffee machine have in common?

Then follow these tutorials on the GEYER Homepage to learn about the different component types, the basic technical parameters and how these components are used at their best in various applications.

Piezoelectrical Effect

It all started about 140 years ago when the first demonstration of the direct piezoelectric effect by Pierre and Jacques Curie proved to be a revolutionary breakthrough for the technology that dominates today's life.

Simply said, the piezoelectrical effect is the ability of certain materials to generate an electrical charge upon mechanical stress. The quartz crystal, being a piezoelectrical device, has undergone and continues to undergo technical evolution and is used today in applications in multiple fields, from everyday consumer electronics up to the most advanced industrial machines.

Component Types and Classification

Crystals and oscillators are key components for timing, synchronization and frequency control.

The two component types used to generate the resonating frequency required by an application can be defined as:

- A **Quartz Crystal** - a passive component that requires electrical circuitry to act as an oscillator and resonate on the requested frequency.
- An **Oscillator** - an active component that incorporates both crystal and circuitry and oscillates on the given frequency once it is powered up.

A third, non-crystal, option might be a **Ceramic Resonator** for use in applications where robustness is prioritized over accuracy. The most common component types, along with the main application areas, are listed in the following table:

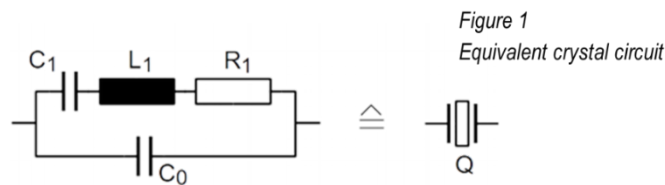
Component type	Short Description	Common Use Fields
Quartz Crystals	Most common used passive component providing precise resonant frequency for an oscillator circuit	Very large use field, such as: • IoT • Wearables & sensors • Healthcare • Embedded systems • Automotive
Resonator	Cost-effective component with good mechanical stability	Usually used in industrial applications requiring robustness
VCXO (Voltage Controlled Crystal Oscillator)	Utilizes a crystal to establish its fundamental frequency, with the added ability to have its output frequency fine-tuned by an external control voltage.	Used in applications requiring precise frequency control: • in phase-locked loops (PLLs) for clock generation • synchronization in telecommunication systems
TCXO (Temperature Compensated Crystal Oscillator)	Uses temperature dependent resistors or similar to adjust voltage for frequency correction.	Used in temperature-sensitive applications requiring high precision: • GPS systems • telecommunication • high-precision instruments • medical equipment

VCTCXO (Voltage-Controlled Temperature-Compensated Crystal Oscillator)	Combining frequency adjustment while maintaining a stable frequency over varying temperatures.	Used in applications requiring precision and fine tuning: - telecommunication - high-precision instruments - GPS systems - military & aerospace
OCXO (Oven Controlled Crystal Oscillator)	A thermostatically controlled oscillator in which the crystal and other temperature-sensitive parts are in a chamber that keeps temperature behaviour constant.	Used in applications requiring high frequency stability and low phase noise: - telecommunications, satellite systems - test & measurement equipment - broadcasting equipment - data centers
MEMS Oscillators (Micro-Electro-Mechanical Systems)	Combine a silicon resonator and a PLL for manufacturing calibration and temperature compensation.	An alternative to crystal oscillators. Often used in: - rugged environments - consumer electronics

Characteristics of a Quartz Crystal - Equivalent Circuit

As mentioned previously, a crystal oscillator is an electrical circuit that uses a piezoelectric crystal as its frequency-determining element.

The mechanical oscillation, piezo-electrically excited by an alternating electrical field of suitable frequency, corresponds with the equivalent circuit in Fig 1., which consists of a series resonant circuit together with a capacitance in parallel.

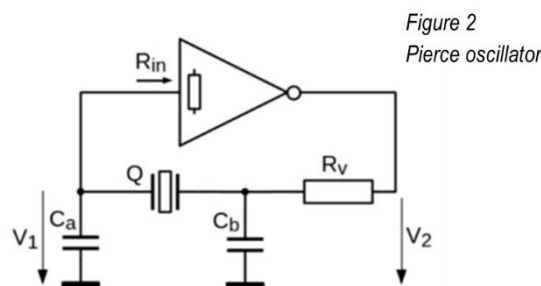


f_L	nominal frequency of quartz crystal
C_L	nominal load capacitance of quartz crystal
R_1	ESR of quartz crystal (usually specified as upper limit)
C_0	static capacitance of quartz crystal (usually specified as upper limit)
C_1	dynamic (motional) capacitance of quartz crystal (rarely specified)
L_1	dynamic inductance of quartz crystal (rarely specified)

These values are usually specified in the datasheet of the quartz crystal manufacturer. Exact values can be found by analyzing a batch of quartz crystals with a network analyzer.

Basic Topology of a Pierce-Oscillator

The Pierce oscillator, named after its inventor George W Pierce, with inverter and feedback network for fundamental crystals, is the most common circuit used as a clock generator in microprocessors.



The output resistance of the inverter, together with the resistor R_v and the PI element $C_0/\text{quartz}/C_a$, forms a narrow bandpass filter with a frequency-dependent phase shift. According to the oscillation condition, the total phase must be 360° , thus enabling the circuit to oscillate at the frequency of the quartz crystal.

The inverter usually provides slightly more than 180° , due to additional, semiconductor-related propagation delays. The external phase shift, due to the bandpass, can therefore be slightly less than 180° .

Most Common Design Parameters

Selecting the right component for the application is not an easy task. It depends on the technical requirements of the application, the target cost of the system, and ultimately on the business case.

Focusing on the technical aspect, the table below summarizes the most important parameters, along with the meaning and importance for crystals and oscillators.

Category	Quartz Crystals	Oscillators
Primary Function	Provide precise resonant frequency for an oscillator circuit	Generate a complete, stable periodic waveform
Nominal Frequency	Specified resonant frequency (fundamental or overtone)	Output frequency (fixed or programmable)
Package Size	Small SMD or through-hole (THT)	Varies from tiny SMD to larger hermetic packages
Load Capacitance (C_L)	Critical — determines actual oscillation frequency	Not applicable (handled internally)
Frequency Tolerance	Initial accuracy at 25°C	Initial accuracy at 25°C
Frequency Stability	Variation across temperature range (ppm)	Depending on type: Variation across temperature range, voltage, load, & aging
ESR (Equivalent Series Resistance)	Important for oscillator startup	Not applicable — internal circuit is optimized for its crystal
Drive Level	Maximum power the crystal can handle safely	Not applicable - Internal drive optimized
Aging	Slow frequency drift over time	Also specified, but includes electronics' contribution
Output Waveform	Not applicable (passive device)	- HCMOS/TTL/Sinewave - LVDS/LVPECL/HCSL
Phase Noise / Jitter	Determined by oscillator circuit quality	Key specification for an oscillator
Startup Time	Not applicable (depends on external circuit)	Specified time from power-on to stable output
Power Consumption	Not applicable (passive device)	Depends on supply voltage and design
Environmental Ratings	Shock, vibration, temperature range	Shock, vibration, temperature range
Other functions	Not applicable	Pulling sensitivity, Tri-state control, etc

Summary

Summing up, crystals act as precise frequency references, and oscillators use them to generate stable clock or carrier signals for timing and communication in electronic systems.

This first article sets the basis for our next technical contribution where we will provide a design guideline using frequency components.