

## Introduction

Crystals have long been used as stable frequency sources. They are most commonly used as a stand-alone component in conjunction with an IC that provides an oscillator circuit. The crystal and IC must be matched in terms of several parameters.

## Crystal Background

A crystal resonator is essentially a piece of quartz with two electrodes plated or deposited on opposing sides. The crystalline structure of quartz provides it with the ability to vibrate when provided with an electrical signal. This phenomenon is known as the piezoelectric effect.

The circuit symbol for a crystal resonator is shown in Figure 1.



**Figure 1. Quartz crystal schematic symbol**

The basic parameters associated with a crystal resonator are:

$C_0$  = holder or parallel plate capacitance

$C_1$  = motional capacitance (also called  $C_m$ )

$L_1$  = motional inductance (also called  $L_m$ )

$R_1$  = motional resistance (also called  $R_m$ )

$C_L$  = load capacitance (circuit capacitance)

Sometimes there is confusion on the part of design engineers between  $R_1$  and ESR (equivalent series resistance). It should be noted that they are related by Equation 1.

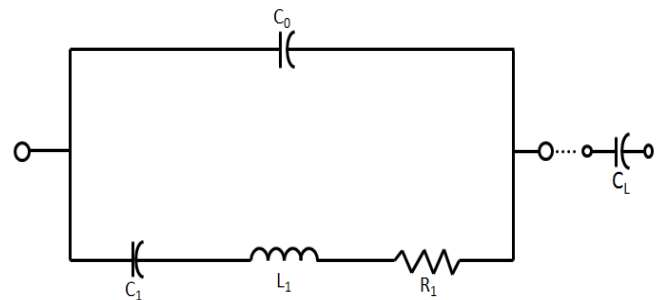
$$R_1 = ESR * \left(1 + \frac{C_0}{C_L}\right)^2$$

### Equation 1. Relationship between ESR and

The electrically equivalent circuit for a crystal is shown in Figure 2.  $C_0$ ,  $C_1$ ,  $L_1$ , and  $R_1$  represent the crystal. Most crystals are operated in parallel mode. This occurs when the crystal is operated in a circuit that presents a capacitance to the crystal. The crystal is manufactured in such a way that its frequency is tuned to that circuit capacitance.

This can present issues in the final circuit design if the crystal is manufactured for one load capacitance value and the electrical circuit is at a different load capacitance.

For example, if a crystal is designed for a load capacitance of 12 pF, but the circuit it is used in is at 8 pF, then the crystal will operate at a much higher frequency in that circuit. It will most likely be tens of ppm high in frequency which could result in a system failing to operate correctly.



**Figure 2. Crystal electrical equivalent model**

## Silego Solution

In order to determine the exact load capacitance that a circuit is operating at, simple measurements will not suffice. Not only must stray capacitance from the IC be accounted for, but stray capacitance from the PCB layout too. External capacitors also have tolerances that can affect circuit load.



Silego's solution is to use a crystal whose parameters have been fully characterized, and then to measure the frequency of this crystal in the end circuit. The difference in frequency will indicate the difference in capacitance between the crystal load and the circuit load. The difference is characterized by Equation 2 where CL1 and CL2 represent the crystal load and circuit load capacitances.

Silego has created a simple Excel tool to help with this task. The basic values from the characterized crystal need to be entered in to it as well as the crystal frequency in the customer circuit. The tool will calculate the frequency change in ppm and the subsequent required change in crystal load capacitors on the customer PCB.

$$\text{Change}(ppm) = \frac{-Cm*(C_{L2} - C_{L1})*10^6}{2*(Co + C_{L2})*(Co + C_{L1})}$$

**Equation 2. Difference in capacitance between the crystal load and the circuit load**

### Related Files

- GreenCLK3 Crystal Load Calculation Tool, Excel spreadsheet, v1.0,

### References

- Vig, J. R., Quartz Crystal Resonators and Oscillators, Powerpoint presentation, January 2004, v8.5.2.0
- Veaser, M., Common Sense Oscillator Techniques.



### About the Author

Name: Chuck Husted

Background: Chuck earned his BSEE from Northern Illinois University with specialization in RF. He has worked for over 20 years in the frequency control field designing many types of quartz crystal based oscillators (XO's, VCXO's, TCXO's, and OCXO's) using discrete analog and RF circuitry. Chuck has also managed engineering teams around the globe. He recently earned his MBA.

Contact: [chusted@silego.com](mailto:chusted@silego.com)



### Document History

Document Title: Determining the Correct Crystal Load Capacitance for use with GreenCLK

Document Number: AN - 1005

Revision	Orig. of Change	Submission Date	Description of Change
A	Chuck Husted	02/02/2013	New application note

### Worldwide Sales and Design Support

Silego Technology maintains a worldwide network of offices, solution centers, manufacturer's representatives, and distributors. To find the office closest to you, visit us at [Silego Locations](#).

### About Silego Technology

Silego Technology, Inc. is a fabless CMIC company headquartered in Santa Clara, California, with operations in Taiwan, and additional design/technology centers in China, Korea and Ukraine.



**SILEGO**  
TECHNOLOGY

**Silego Technology Inc.**  
1715 Wyatt Drive  
Santa Clara, CA 95054

**Phone** : 408-327-8800  
**Fax** : 408-988-3800  
**Website** : [www.silego.com](http://www.silego.com)