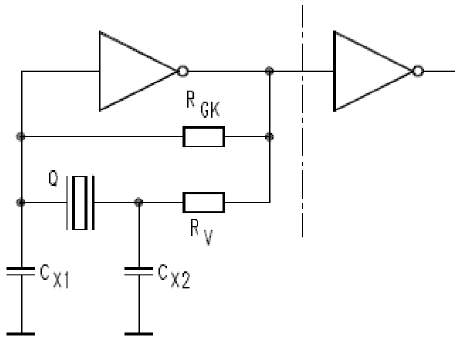
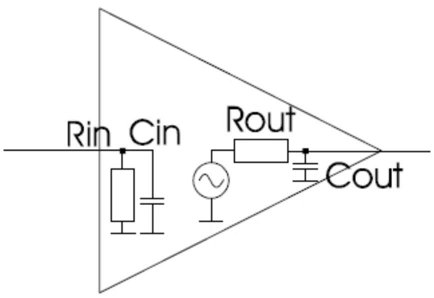
Application Note for Oscillator Circuits with Quartz Crystals

Basic topology of a Pierce-Oscillator



Inside an IC, as part of the oscillator circuit there is an inverting amplifier (phase shift approx. 180°). The external circuitry consists of quartz crystal, Cx1, Cx2 und R_v and another phase shift of approx. 180°, to fulfill the feedback requirements of 360° (or 0°) and enable the circuit to oscillate with the frequency provide of the quartz crystal.

Characteristics of the IC:

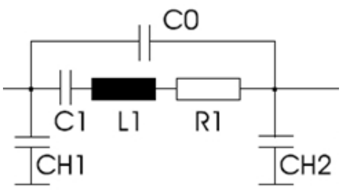


R_{out}, C_{out}: output resistance / output capacitance of the oscillator IC

R_{in}, C_{in}: input resistance / -capacitance of the oscillator IC (start values CMOS: 1 M / 3 pF)

These values should be stated in the manufacturer's IC data sheet, but are rarely specified despite their importance to the circuit design. R_{out} can be calculated by the voltage drop on a known load resistor.

Characteristics of a Quartz Crystal:

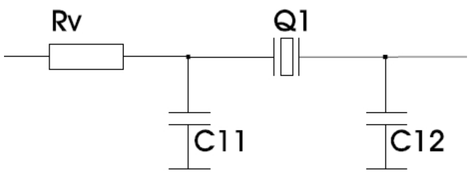


(extended equivalent circuit)

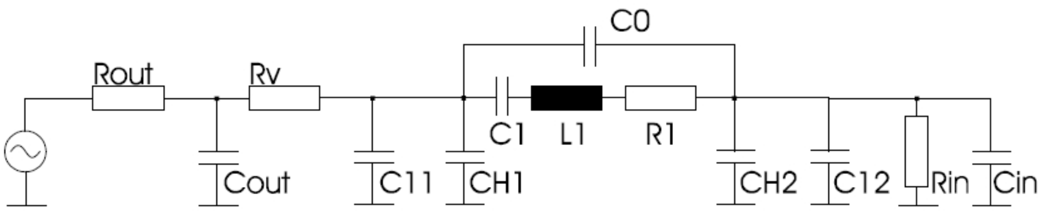
f_L	nominal frequency of quartz crystal
R_1	ESR of quartz crystal (usually specified as upper limit)
C_0	static capacitance of quartz crystal (usually specified as upper limit)
C_1	dynamic (motional) capacitance of quartz crystal (rarely specified)
C_{H1}, C_{H2}	capacitances of connections (ca. 0,8 pF), can mostly be neglected because included in C_0
C_L	nominal load capacitance of quartz crystal
L_1	dynamic inductance of quartz crystal (rarely specified)

These values are 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.

Components around the Quartz Crystal:



(simplified equivalent circuit)



(extended equivalent circuit)

C_a effective capacitance at the input of IC as sum of C_{in} of IC, stray capacitance* of PCB (4~6 pF), body capacitance of quartz crystal C_{H2} (~0,8 pF), and discrete condenser C_{12}.
start value: 1,1…1,2 x C_L

C_b effective capacitance at the output of ICs as sum of stray capacitance* of PCB (4~6 pF), body capacitance of quartz crystal C_{H1} (~0,8 pF) and discrete condenser C_{11}.
start value: 2 x C_a

R_v series resistor (should always be provided in the layout, even if later populated with 0 ohms). The effective series resistor in the design is the sum of R_v und R_{out}.

* The stray capacitance can be determined by measuring an unpopulated PCB for example.

Simulation:

GEYER Electronic offers the Y-QUARTZ App, a tool for, amongst other things, simulating and optimizing the characteristics of a Pierce quartz crystal oscillator. By inputting the above values you can visualize and vary the amplitude and phase characteristic of the feedback circuit, consisting of the quartz crystal and surrounding components, for reliable oscillation without exceeding the maximal drive level of the quartz crystal.

Implementing/Layout:

The layout requires special attention: short traces with low capacitance, symmetric layout, no vias, no “hot” traces nearby. If vias cannot be avoided, they should be laid symmetrically.

Verification:

The correct functioning of the quartz crystal oscillator has to be verified on a prototype PCB, as the parasitic capacitances and resistances are unknown beforehand and the values of the resistors and condensers have to be adjusted for the intended functioning of the quartz crystal oscillator.
The measurements *must* be made with an active low-capacitance probe (<=2 pF) because common probes with capacitances of >10 pF alter the settings completely and render all measurements useless. If a low-capacitance probe is not available, a small ceramic condenser (1~2 pF) can be provisionally put in series with the probe to do the measurements. However, a recalibration of the divider ratio at the given frequency is inevitable.

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