DIGITAL WE DAYS 2024

KEEPING THE RHYTHM: HOW CAPACITOR SELECTION AFFECTS CRYSTAL ACCURACY

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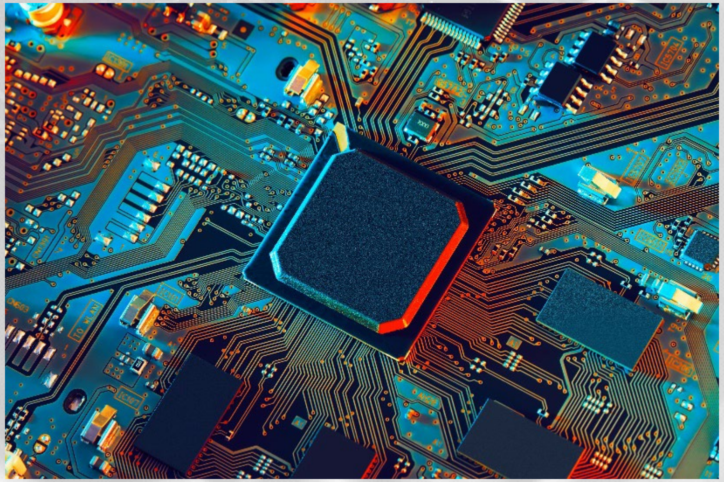
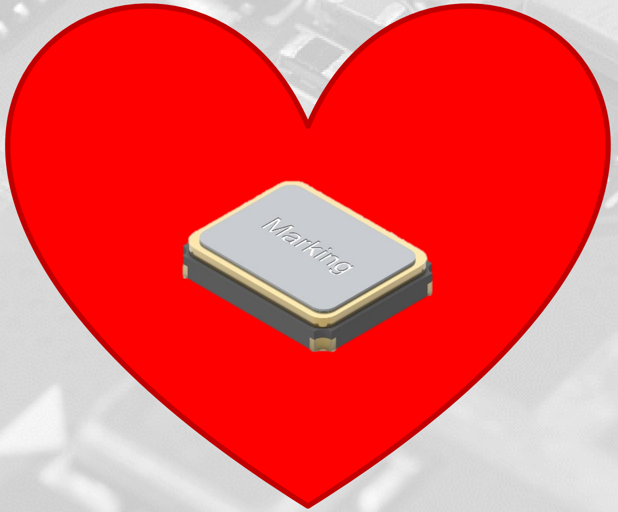
Did you know that choosing the wrong capacitor can cause the heartbeat of your circuit to go out of sync?

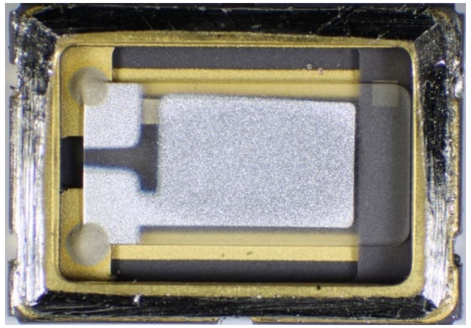


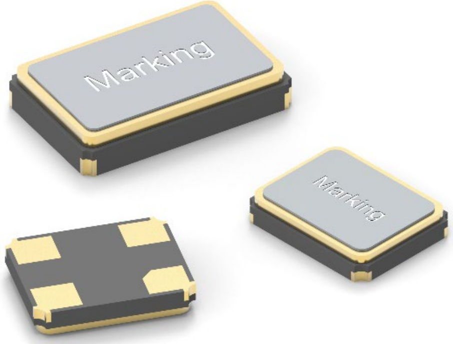


AGENDA

- Pierce Oscillator Circuit
- Load capacitance
- Trim Sensitivity
- How to select the right capacitors
- High vs. Low load capacitance
- PCB Layout recommendation
- Series Resonance

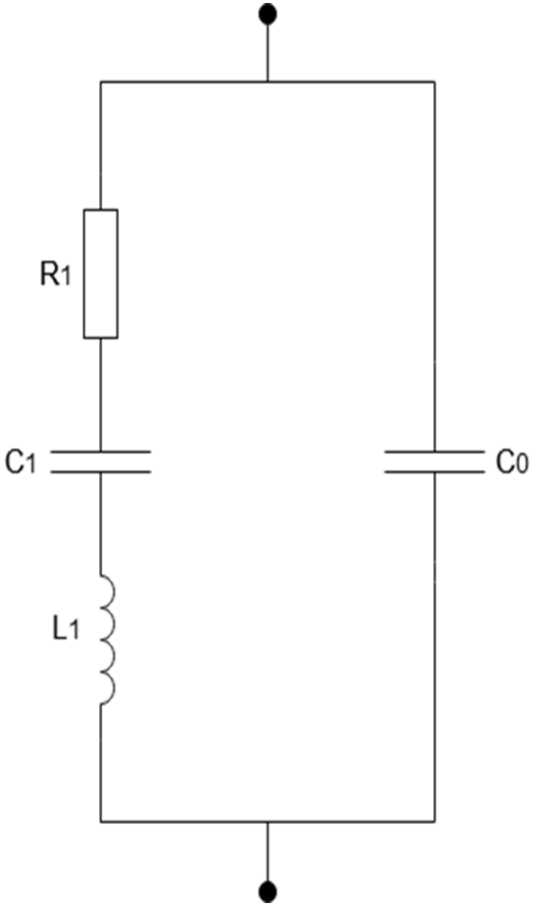
QUARTZ CRYSTALS





Example Spec:

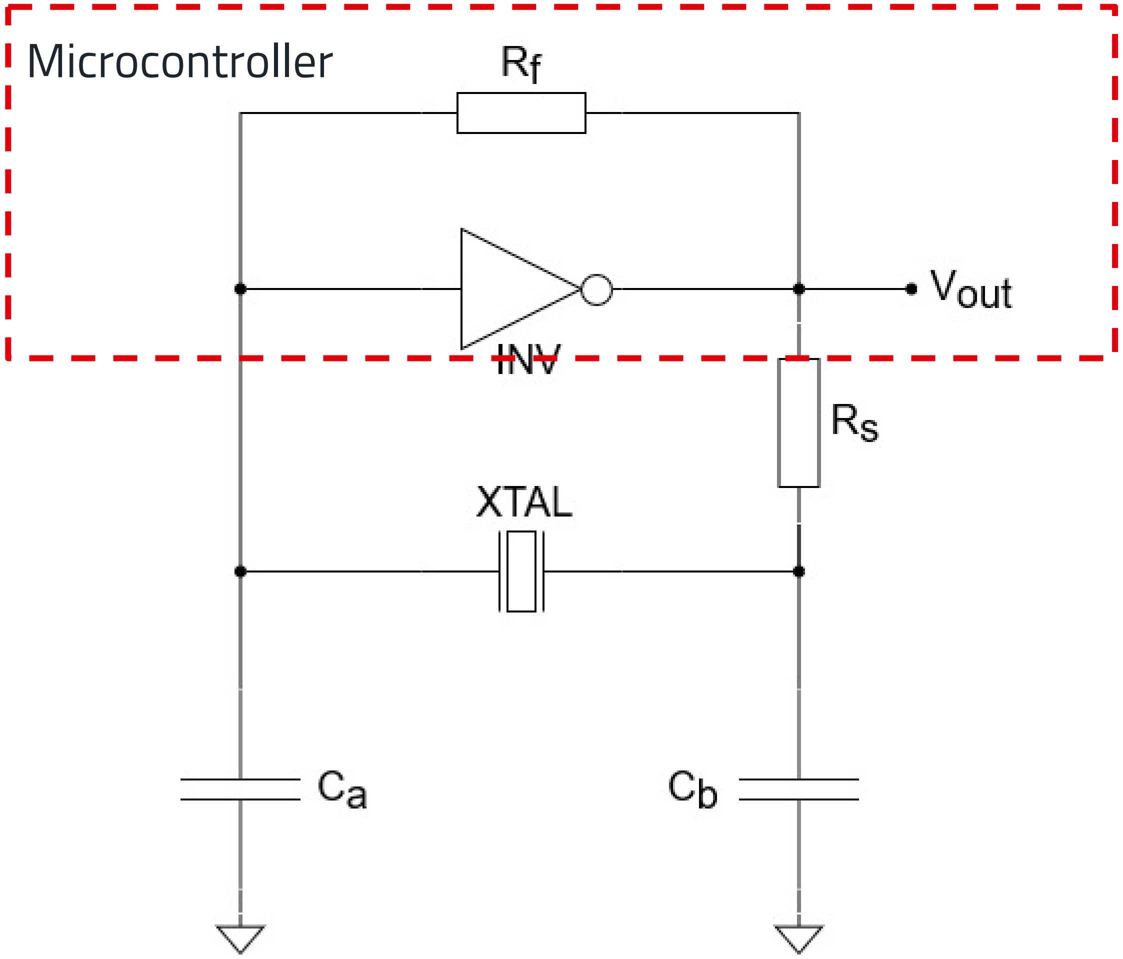
CFPX-180 24.0 MHz 10/20/-40 to 85 °C/8 pF



- R_1: Damping of the mechanical oscillation
- L_1: Oscillating mass of the quartz crystal
- C_1: Dynamic capacitance, piezoelectric effect
- C_0: Shunt capacitance, coupling capacitances of the quartz crystal

PIERCE OSCILLATOR CIRCUIT

Load capacitance



- The load capacitance in the circuit need to be equal to the specified load capacitance of the crystal

Electrical Parameters	
▪ Load Capacitance (CL)	10.00pF

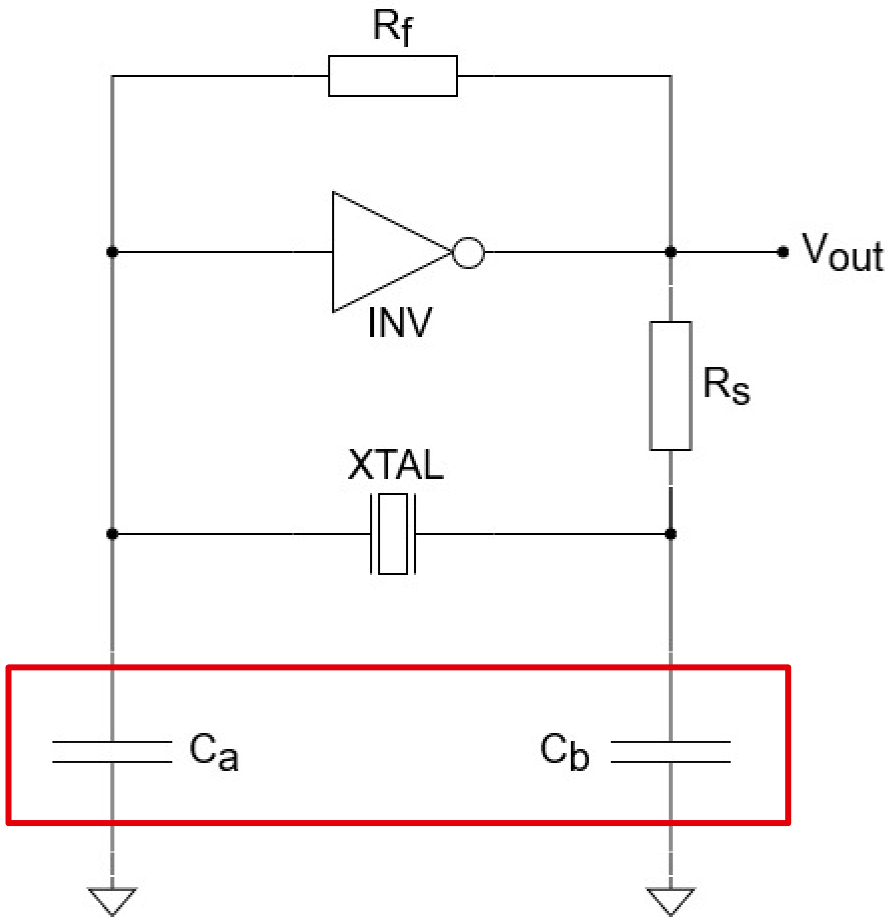
- Formula to calculate the load capacitance in the circuit:

$$C_L = \frac{C_a * C_b}{C_a + C_b} + C_{stray}$$

LOAD CAPACITANCE

C_a and C_b

- In best case, C_a and C_b should have the same value
  - If C_a and C_b are not equal than $C_a < C_b$
- C_{stray} is typically between 2 pF and 7 pF
- C_{stray} includes:
  - the capacitance of the conductive paths
  - input and output capacitance of the microcontroller
- During the design-in phase, the stray capacitance can only be estimated and confirmed later by measurement



$$C_L = \frac{C_a * C_b}{C_a + C_b} + C_{stray}$$

LOAD CAPACITANCE

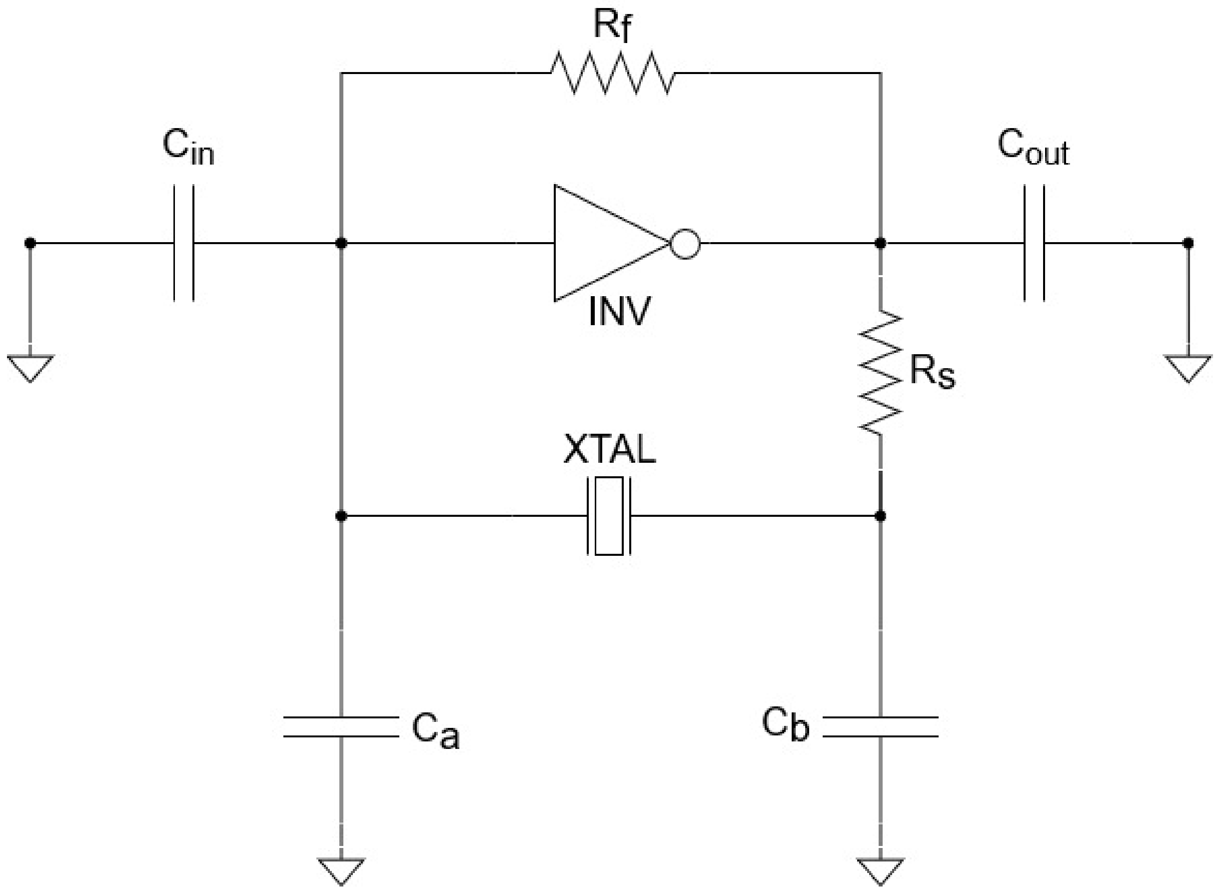
If $\boldsymbol{C_{in}}$ and $\boldsymbol{C_{out}}$ known

- If the input and output capacitance of the microcontroller is known:

$$C_L = \frac{(C_{in} + C_a) * (C_b + C_{out})}{(C_{in} + C_a + C_b + C_{out})} + C_{stray}$$

- C_{in} and C_{out} are the input and output capacitance of the microcontroller

- C_{stray} still contains the capacitance of the conductive paths and is around 2 pF



TRIM SENSITIVITY

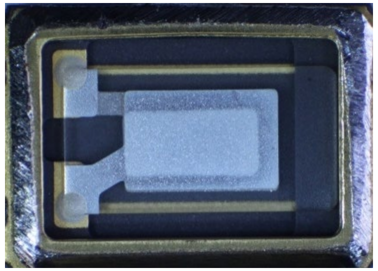
T_s

- Specifies the frequency deviation in ppm if the load capacitance in the circuit changes

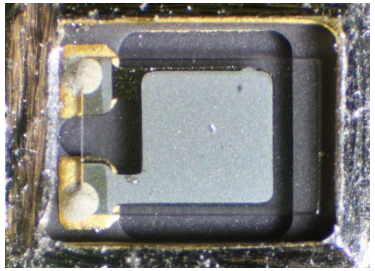
- Trim sensitivity [ppm/pF]:

$$T_s = \frac{C_1 * 10^6}{2(C_0 + C_L)^2}$$

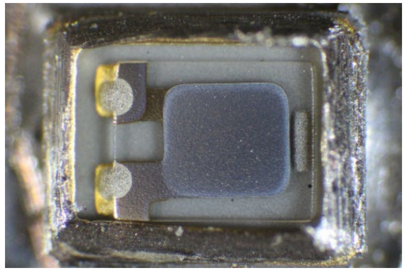
- The trim sensitivity of a crystal depends on:
  - Size of the blank
  - Size and shape of the electrodes
  - The load capacitance in the circuit
  - Frequency



7.0 mm x 5.0 mm



3.2 mm x 2.5 mm



2.0 mm x 1.6 mm

TRIM COMPARISON

CFPX-180 vs. IQXC-42 vs. IQXC-26

Frequency: 24 MHz **Tolerance: 10 ppm** **Load Capacitance: 8 pF**

830108207309
CFPX-180, 3.2 mm x 2.5 mm

$\Rightarrow T_{s\,(8\,pF)} = 22.1\,ppm/pF$

830108212309
IQXC-42, 2.0 mm x 1.6 mm

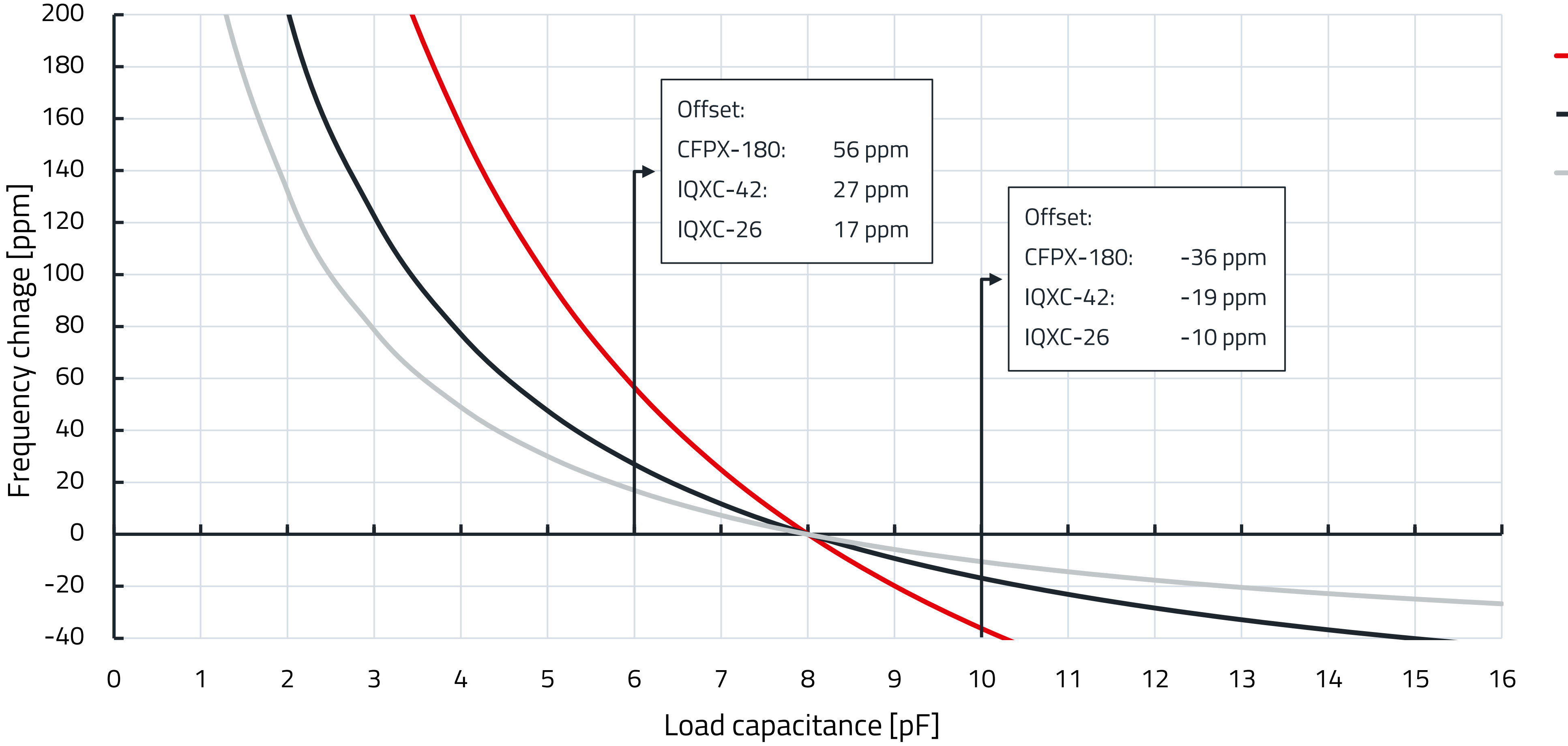
$\Rightarrow T_{s\,(8\,pF)} = 10.4\,ppm/pF$

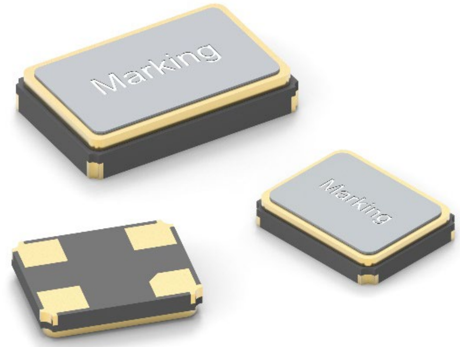
830108160801
IQXC-26,1.6 mm x 1.2 mm

$\Rightarrow T_{s\,(8\,pF)} = 6.5\,ppm/pF$

FREQUENCY DEVIATION

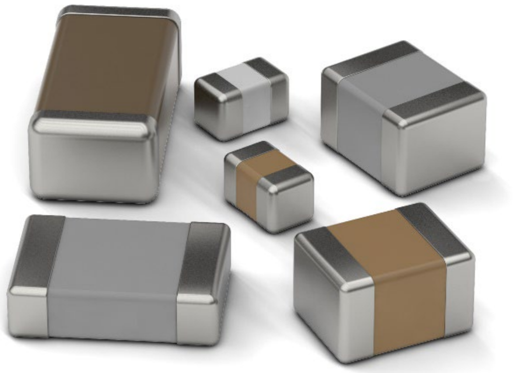
CFPX-180 vs. IQXC-42 vs. IQXC-26





HOW TO CHOOSE THE RIGHT CAPACITOR

General



- Select a capacitor with stable temperature behaviour
  - NPO
- Select a capacitor with a high enough rated voltage
  - >25 V usually not necessary
- Due to the E-series for capacitor values, maybe not every needed capacitor value is available
  - Choose the next highest or lowest available capacitor value

  - Use RedExpert to find the right capacitors!

REDEXPERT

Multilayer Ceramic Chip Capacitors (MLCCs)

HOW TO CHOOSE THE RIGHT CAPACITOR

Example

- Quartz crystal: $C_L = 8\ pF$
- Stray capacitance: $C_{Stray} = 5\ pF$

$$C_L = \frac{C_a * C_b}{C_a + C_b} + C_{stray}$$

→ C_a and $C_b = 6\ pF$

- Available capacitor values at WE:

	Order Code	Spec		Series	Description	Size	Ce...	C...	Tole...	V_R
	885012006030	PDF		WCAP-CSGP	General Purpose	0603	NP0	4.70 pF	±0.5 pF	25.0 V
	885012006001	PDF		**WCAP-CSGP**	**General Purpose**	**0603**	**NP0**	**4.70 pF**	**±0.5 pF**	**10.0 V**
✔	885012005038	PDF		WCAP-CSGP	General Purpose	0402	NP0	4.70 pF	±0.5 pF	25.0 V
	885012005023	PDF		WCAP-CSGP	General Purpose	0402	NP0	4.70 pF	±0.5 pF	16.0 V
	885012005005	PDF		WCAP-CSGP	General Purpose	0402	NP0	4.70 pF	±0.5 pF	10.0 V
	885012007027	PDF		WCAP-CSGP	General Purpose	0805	NP0	6.80 pF	±0.5 pF	25.0 V
	885012006031	PDF		WCAP-CSGP	General Purpose	0603	NP0	6.80 pF	±0.5 pF	25.0 V
	885012005039	PDF		WCAP-CSGP	General Purpose	0402	NP0	6.80 pF	±0.5 pF	25.0 V
	885012005024	PDF		WCAP-CSGP	General Purpose	0402	NP0	6.80 pF	±0.5 pF	16.0 V

FREQUENCY MEASUREMENT

How to test your design

- When testing your design, measure the frequency
  - at an isolated clock output
  - or with a low capacitance probe

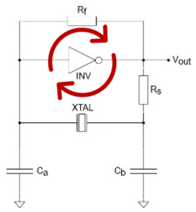
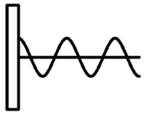
- Use a frequency counter or an oscilloscope to measure the frequency

$$Frequency_{Dev} = \left(\frac{Frequency_{Meas}}{Frequency_{Datasheet}} - 1\right) * 10^6$$

- $Frequency_{Dev} > 0$ → ⇧ increase the capacitance values
- $Frequency_{Dev} < 0$ → ⇩ decrease the capacitance values

COMPARISON

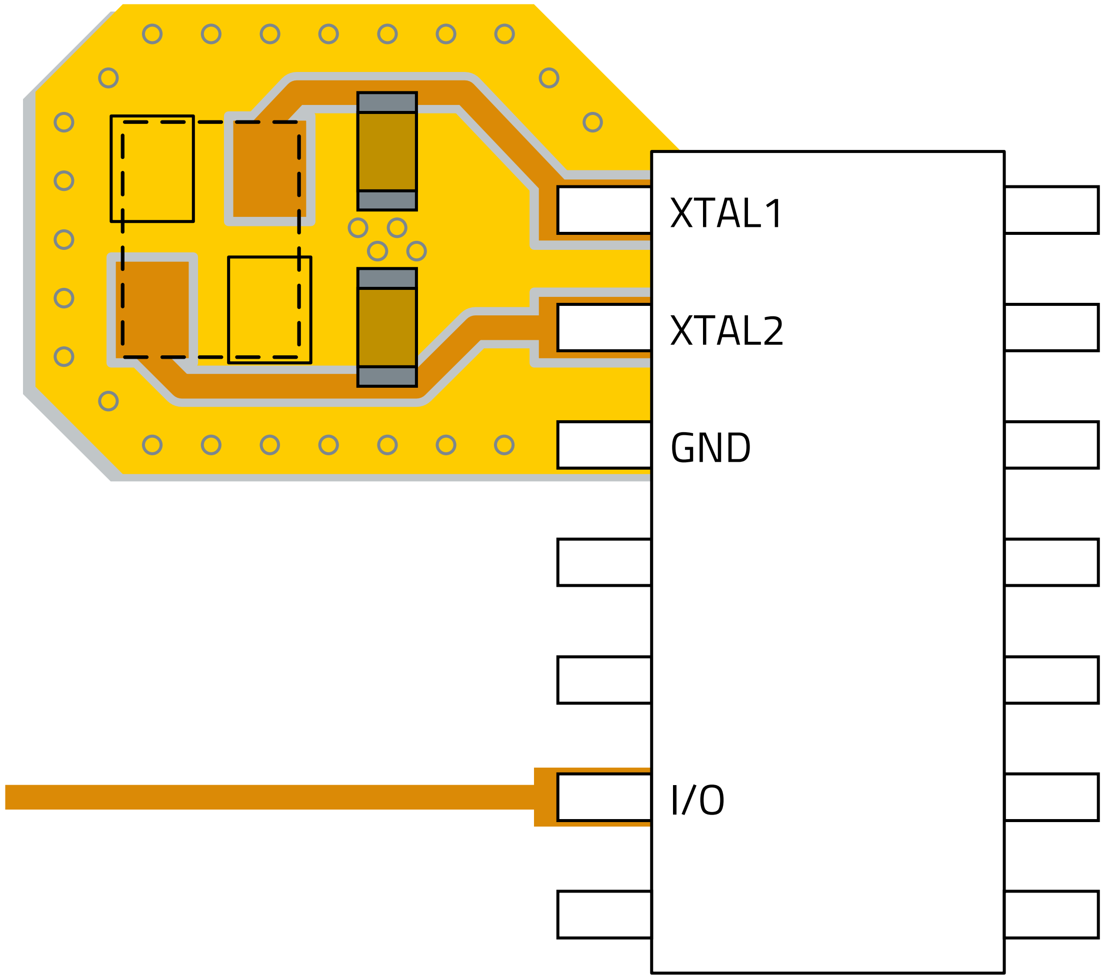
High load capacitance vs. Low load capacitance

		High load capacitance	Low load capacitance
▪ Current consumption		↑	↓
▪ Loop Gain		↑	↓
▪ Frequency Deviation		↓	↑

PCB LAYOUT RECOMMENDATION

General Notes

- **Keep the traces as short as possible!**
- Avoid 90° bends – round right angles!
- Place the crystal away from any high frequency device or traces
- Do not cross any other signal lines!
- Microcontroller should have a stable power supply

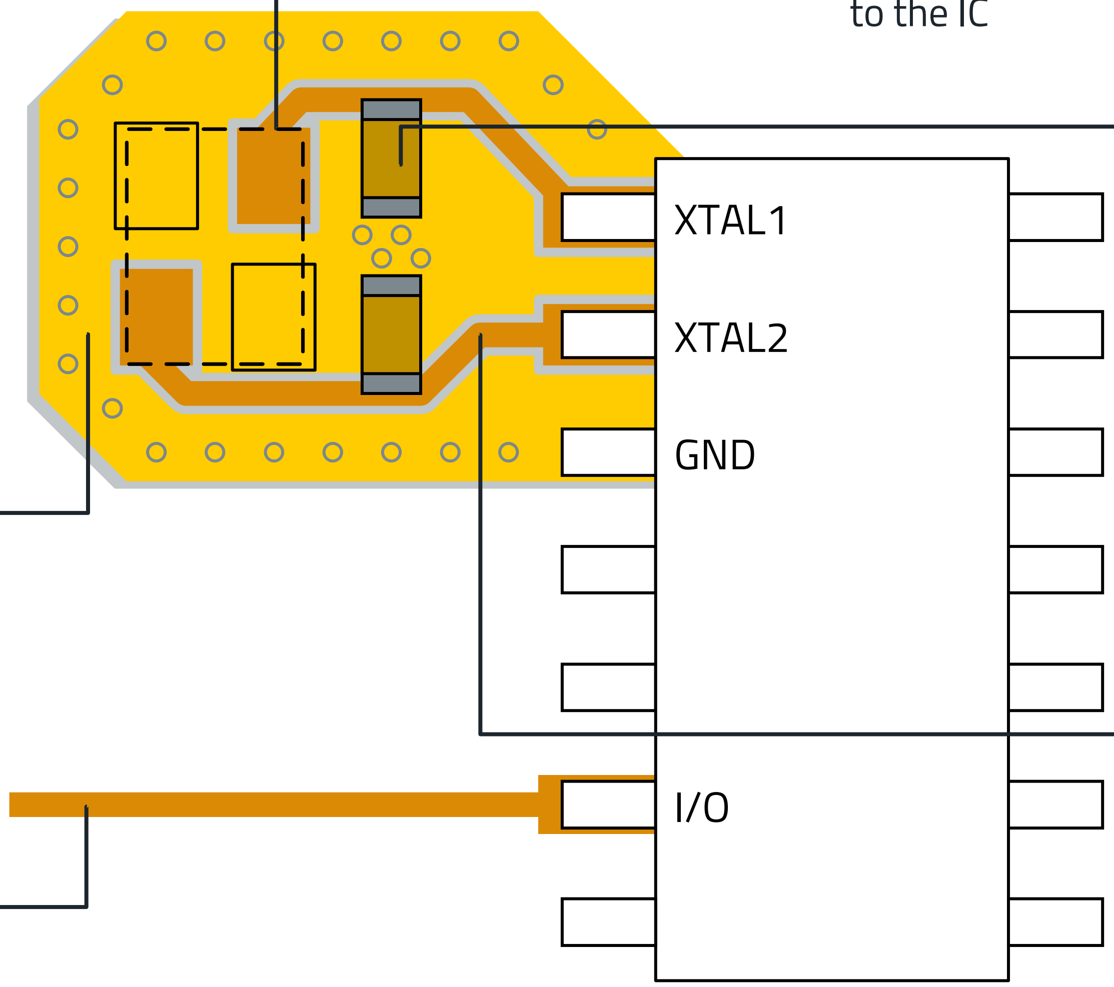


PCB LAYOUT RECOMMENDATION

Crytal Specific Notes

Either an exposed **GND area** under or a **guard ring** around the crystal:

- Connected to separate GND pin of the IC and independent of the other GND
- Also connect C_a and C_b to this GND
- For multilayer PCBs: no further GND area under quartz



Place the crystal, C_a and C_b as **close** as possible to the IC

If C_a and C_b cannot be placed next to each other, $\mathbf{C_a}$ should be placed **closer** to the **IC**

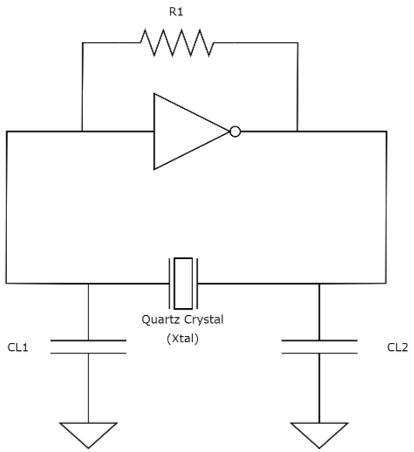
The **traces** should be of the **same length** and as far apart as possible while keeping them **short**

Keep digital signal lines, V_s and fast switching lines **far away** from the crystal

PARALLEL VS SERIES RESONANCE CIRCUITS

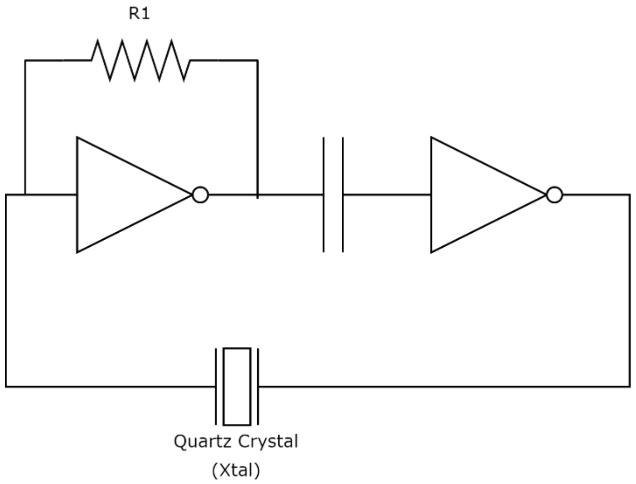
Parallel

- For circuits which contain reactive components (capacitors) in the oscillator feedback loop
- Combination of the reactive components and the crystal to accomplished the phase shift necessary



Series

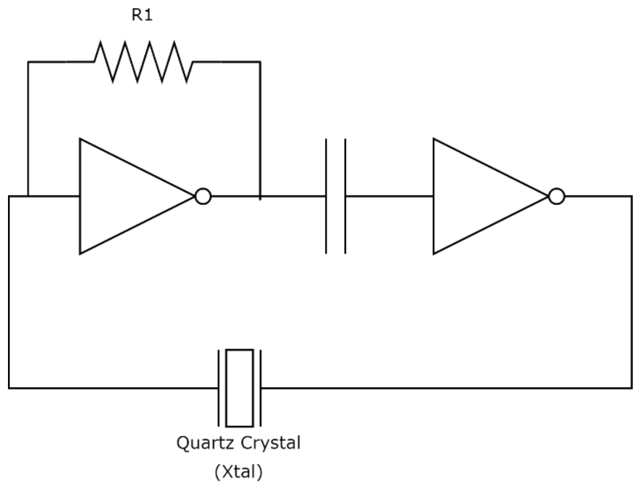
- For circuits which contain no reactive component in the oscillator feedback loop



SERIES RESONANCE

- If a quartz crystal is specified for a series resonant circuit, the crystal is specified in the datasheet with SR

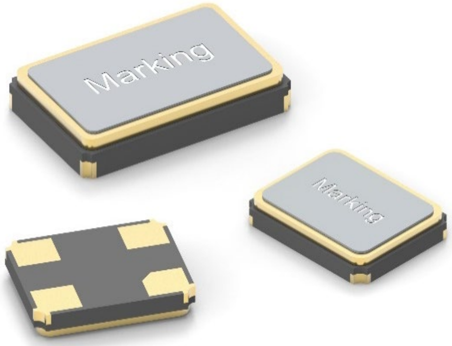
Electrical Parameters	
▪ Load Capacitance	Series Resonant

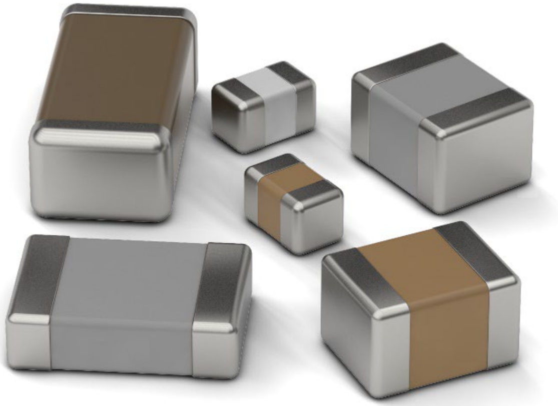


- In the past used for crystals operated at an overtone frequency
- Series resonance circuits are quite rare now
- If a microcontroller operates with series resonance it will be mentioned in datasheet

SUMMARY

- Choosing the right capacitors is very important
- Even a few pF can have a major influence on the frequency of the quartz crystal
- To help you with your design, we will soon lunch a new Design Kit containing crystals and matching capacitors



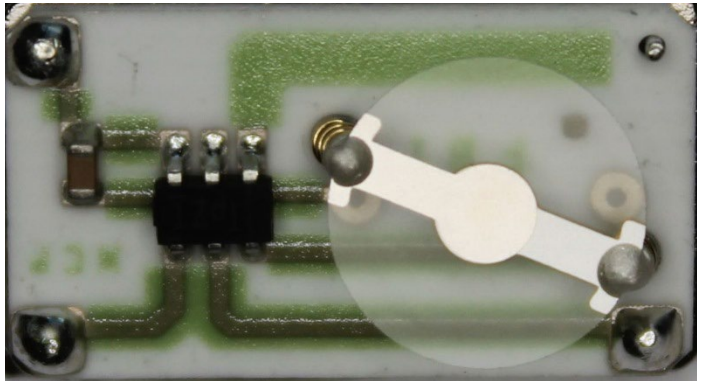


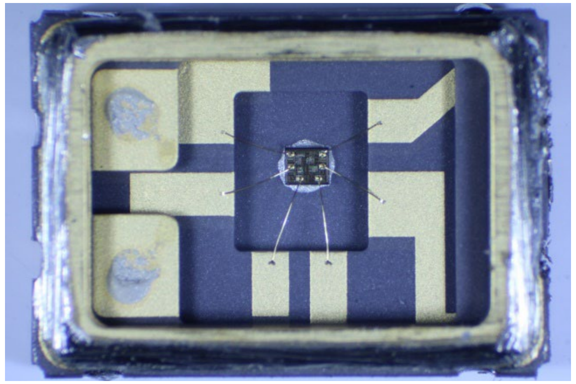
830004 coming soon

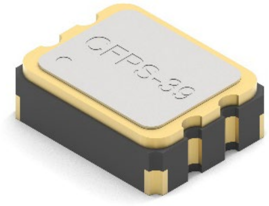
INTEGRATED SOLUTION

SPXO

- To reduce the design work for the oscillation circuit, an integrated solution can be used
- The integrated solution contains a quartz crystal and an IC, where the IC contains the oscillation circuit
- Requires only a supply voltage and provides an output signal at the resonant frequency







WE-SPXO Simple Packaged Quartz Oscillator

Questions

& Answers

We are here for you now!
Ask us directly via our chat or via E-Mail.

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