8/16/32-Bit

Crystal Oscillator Basics

AP56002

Application Note

V1.0, 2012-08

Microcontrollers

Edition 2012-08

Published by
Infineon Technologies AG
81726 Munich, Germany

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Device1
Revision History: V1.0 2012-08

Previous Version(s):

Page	Subjects (major changes since last revision)
–	This is the first release …

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1 Introduction

This Application Note provides recommendations for the selection of quartz crystals and for the circuit composition for each oscillator.

The cooperation between the IC oscillator and the quartz crystal does not always work properly because of problems in the composition of external circuits. This application note provides users with the appropriate knowledge to help ensure trouble-free oscillator operation.

Note: The content of this document relating to measurements to find the right external circuits is generic information and can be used for all Pierce oscillators using an oscillator-inverter.

2 Oscillator-Inverter

Microcontrollers include the active part of the oscillator, called the oscillator-inverter. For historical and evolutionary reasons, different oscillator-inverters are implemented in different Infineon microcontroller product families. The main differences are in:

- oscillator gain
- oscillation amplitude
- oscillator supply voltage
- frequency range

XTAL1 is the oscillator-inverter input. XTAL2 is the output.

Some devices include a 32 kHz oscillator. This is a real-time clock oscillator-inverter, where XTAL3 is the oscillator-inverter input and XTAL4 is the output.

Note: Details about electrical parameters are described in the Data Sheet of each particular device.

The on-chip oscillator-inverter can either run with an external crystal and appropriate external oscillator circuitry (also known as the passive part of the oscillator), or it can be driven by an external oscillator. The external oscillator directly connected to XTAL1, leaving XTAL2 open, feeds the external clock signal to the internal clock circuitry.

The oscillator input XTAL1 and output XTAL2 connect the internal CMOS Pierce oscillator to the external oscillator circuitry. The oscillator provides an inverter and a feedback element, with the resistance of the feedback element typically in the range of 0.2 MΩ to 1 MΩ.

Depending on the Infineon microcontroller family, the oscillator is either enabled at power-on or, because of power consumption issues, it is disabled at power-on and has to be enabled by user software. Note that also for reasons of power consumption, some oscillators allow gain to be reduced after stable oscillation of the oscillator circuitry.

Note: The oscillator-inverter can be used in combination with quartz crystals and also with ceramic resonators.

3 Oscillator Circuitry

The standard microcontroller oscillator circuitry typically consists of

- the on-chip oscillator-inverter,
- a quartz crystal,
- two load capacitors,
- a series resistor R_{X2} to limit the current through the crystal. Use of this resistor depends on the crystal used and the required resonance frequency.

The crystal is used as the system frequency reference, typically in the range from 4 MHz to 25 MHz (40 MHz). This reference frequency is used by the on-chip PLL to provide system and CPU frequencies higher than the crystal frequency.

3.1 What is a Crystal?

A quartz crystal consists of piezoelectric material equipped with electrodes and housed in a hermetically sealed package. In an oscillator circuit the crystal is mechanically vibrating on its resonance frequency f_{OSC}, and provides a stable reference oscillation signal to the microcontroller and is used as input reference clock.

The resonance frequency of a quartz crystal is the rate of expansion and contraction of the crystal and is determined by the size and cut of the crystal.

Depending on the crystal resonance frequency, different cuts in the crystal structure are used for the crystal blank. AT-cut crystals vibrating in thickness shear, fundamental mode are typically used for microcontroller oscillator circuits for the frequency range from 4 MHz to 40 MHz. Real-time clock oscillators with 32 kHz resonance frequency use tuning fork crystals.

Quartz crystals used in oscillator circuits are produced synthetically in autoclaves.

When a crystal is running on its resonance frequency an equivalent circuit diagram can be used for simulation and calculation.

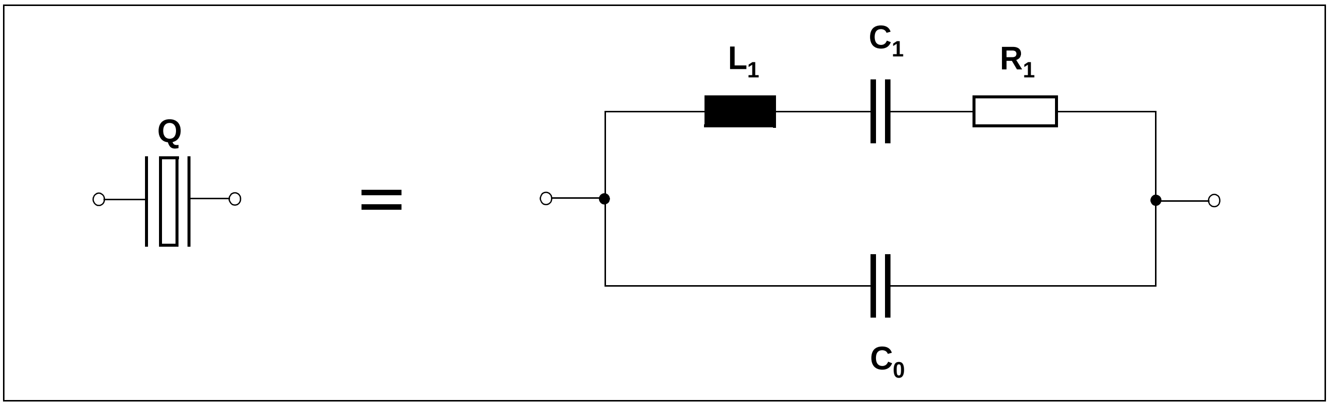

Figure 3-1 Equivalent Circuit of a Quartz Crystal

- The oscillating mass of the crystal hardware blank represents the dynamic inductance L_1.
- The elasticity of the crystal hardware blank represents the motional dynamic capacitance C_1.
- The molecular friction, the damping by the mechanical mounting system and acoustical damping by the gas filled housing, is represented by R_1.
- C_0 is the shunt capacitance which is given by the electrodes on the quartz crystal.

The total frequency deviation of a quartz crystal is effected by different factors such as temperature range or

capacitive load, and is typically in a range of |+/-100 ppm| to |+/-300 ppm| for microcontroller applications using AT-cut crystals.

Table 3-1 Typical AT-Cut Quartz Crystal Characteristics

Initial frequency tolerance at 25°C	+/-30 ppm
Pullability	+/-15 ppm/pF
Temperature stability	+/-0.5 ppm/°C
Aging	+/-2.0 ppm/Year

3.2 Fundamental Mode Circuitry

The external crystal circuitry can be prepared for fundamental mode or 3rd overtone mode.

For a microcontroller frequency range from 4 MHz to 40 MHz, crystals are used in fundamental mode.

3.2.1 External Load Capacitors

Most of today's microcontroller oscillator circuitries use external load capacitors.

Besides the typical oscillator components, a test resistor R_Q may be temporarily inserted to measure the oscillation allowance (negative resistance) of the oscillator circuitry. The circuitry is shown in **Figure 3-2**.

How to check start-up reliability is discussed in the chapters that follow.

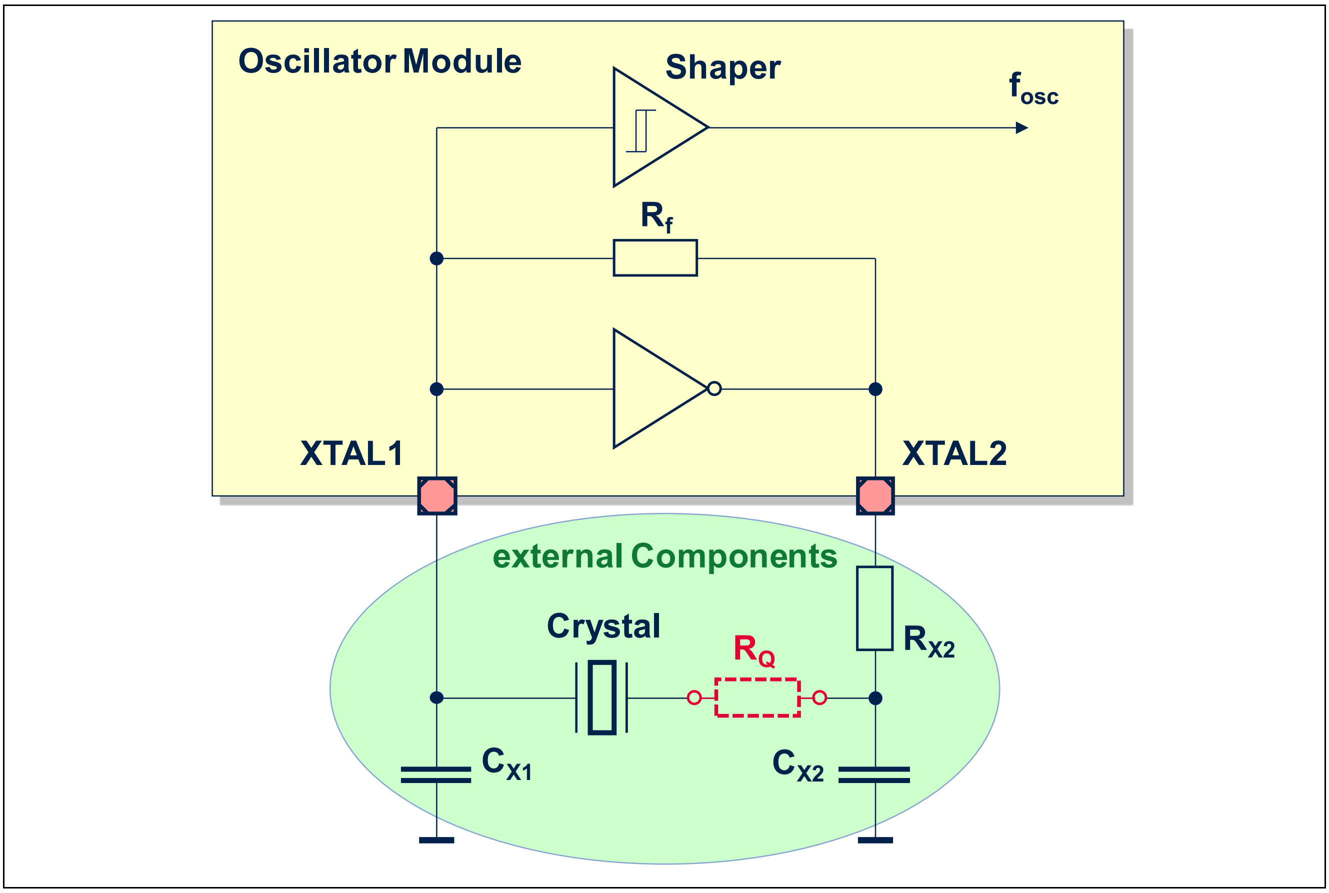

Figure 3-2 Oscillator Circuit Block Diagram with External Load Capacitors (Fundamental Mode)

3.2.2 On-Chip Load Capacitors

New designs of oscillator-inverters offer the possibility to use on-chip load capacitors to save external components and optimize the BOM (Bill Of Materials).

The on-chip load capacitors should only be used in combination with the Amplitude Regulation Feature of the oscillator.

The Amplitude Regulation Feature prevents the quartz crystal drive level from being exceeded. This is required because the on-chip load capacitor feature does not allow a damping resistor to be inserted in series, as is done with external load capacitors.

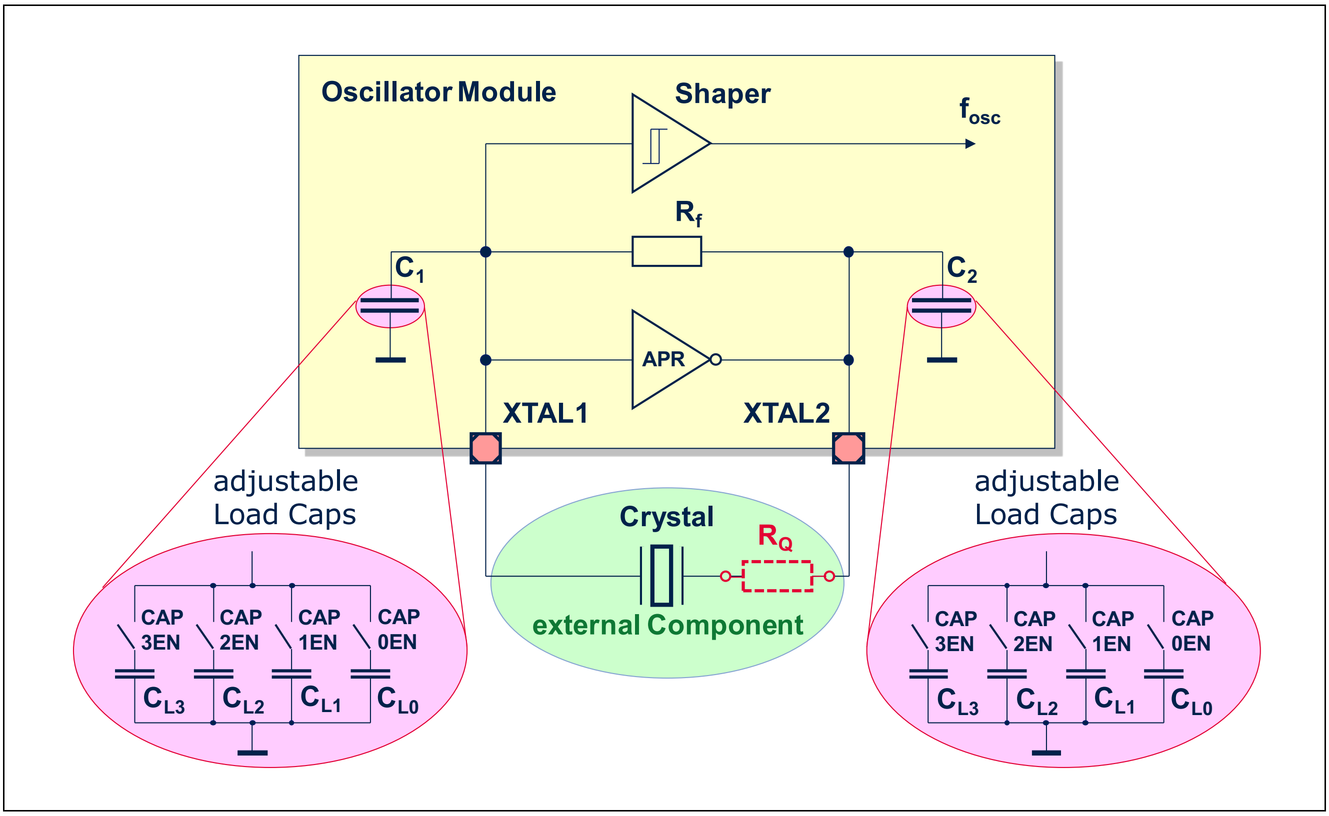

Figure 3-3 Oscillator Circuit Block Diagram with On-Chip Load Capacitors (Fundamental Mode)

4 Oscillator Start-up Time

With small amounts of electrical system noise or thermal noise caused by resistors, oscillation starts with a very small amplitude. Then with amplification from the oscillator-inverter, the oscillation amplitude increases and reaches its maximum after a certain time period; t_{st_up} (start-up time). The oscillator start-up time depends on the oscillator frequency.

Typical values of the start-up time are within the range of 0.1 msec ≤ t_{st_up} ≤ 10 msec for an oscillator frequency 4 MHz ≤ f_{OSC} ≤ 25 MHz.

The oscillator frequency of a real-time clock oscillator is 32 kHz in standard applications and typical values of the start-up time are within the range of 1 sec ≤ t_{st_up} ≤ 10 sec.

Theoretically the oscillator-inverter performs a phase shift of 180°, and the external circuitry performs a phase shift of 180° to fulfill the oscillation condition of an oscillator. A total phase shift of 360° is necessary.

In reality, the actual phase shift of the oscillator-inverter depends on the oscillator frequency and is approximately in the range of 100° to 210°. It is necessary to compose the external components in such a way that a total phase shift of 360° is performed. This can be achieved by a variation of C_{x1} and C_{x2}.

4.1 Definition of Oscillator Start-up Time (t_{st_up})

The oscillator start-up time is not a well defined value in published literature. Generally it depends on

- the power supply rise time dV_{DD}/dt at power on
- the electrical system noise
- the oscillation amplitude

For this application the oscillator start-up time t_{st_up} is defined from $V_{DD}/2$ to $0.9*V_{OSC\_max}$ of the stable oscillation, where V_{DD} represents oscillator supply voltage.

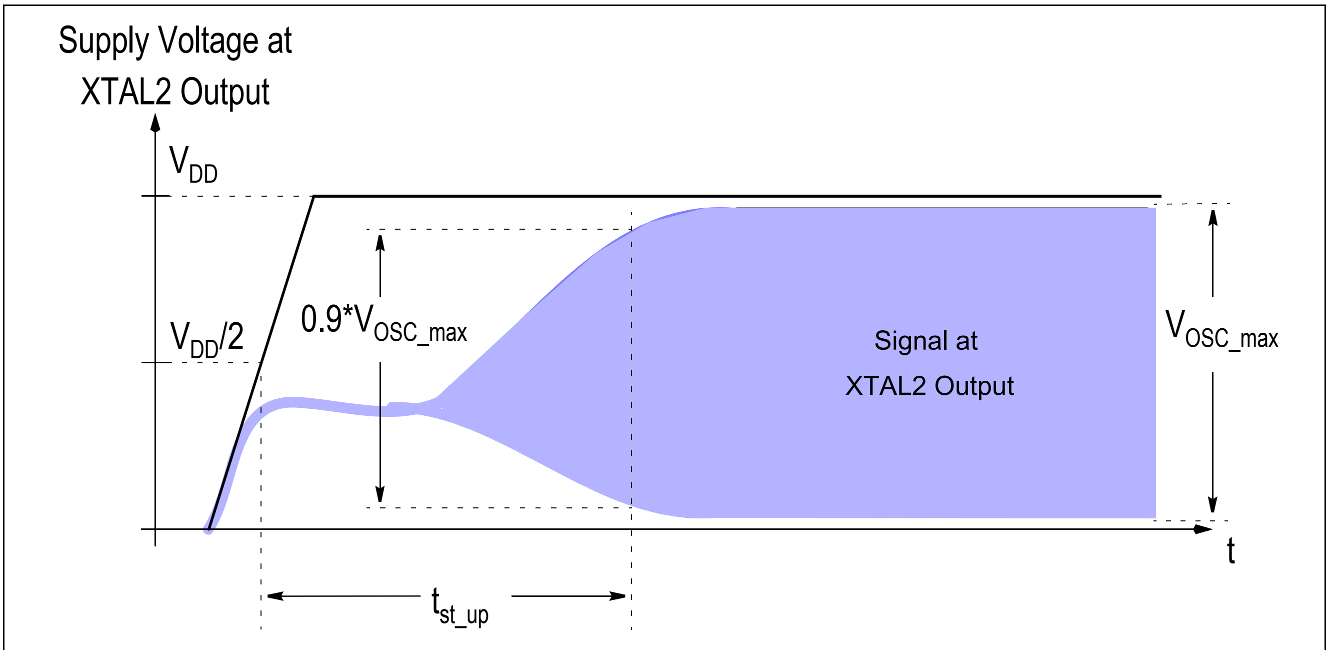

Figure 4-1 Oscillator Start-up Time

If, for power consumption reasons, oscillator gain is changed by software after the oscillator start-up phase, this is only allowed when the oscillation has settled to the maximum amplitude V_{OSC_max}. That is why the crystal in use can show frequency deviations (or spurious results) when oscillator gain is changed abrupt during the oscillator start-up phase.

Oscillator start-up time is measured at XTAL2 (output) to avoid influencing the oscillator circuit. A specified XTAL1 voltage is measured at XTAL1 using an active probe with low capacitive load and high impedance (C_{probe}~1 pF, R_{probe}~10 MΩ)).

Depending on the implemented on-chip oscillator type and the external circuitry, peak-to-peak amplitude of V_{OSC_max} can be significantly smaller than the supply voltage.

Note: It is important that V_{OSC_max} measured at XTAL1 is in the range specified in the appropriate Data Sheet.

If the oscillator gain is also reduced after the oscillator start-up phase, the specified XTAL1 voltage also has to be measured with reduced gain.

4.2 Definition of Oscillator Off Time (t_{off})

Measurement of the oscillator start-up time is normally performed periodically. After switching off the power supply, the oscillation continues until the total reactive power oscillating between inductance and capacitance is consumed. Therefore in order to get reproducible results, the time between switching the power supply off and on again (t_{off}) must not be too short.

t_{off} depends on the composition of the oscillator components.

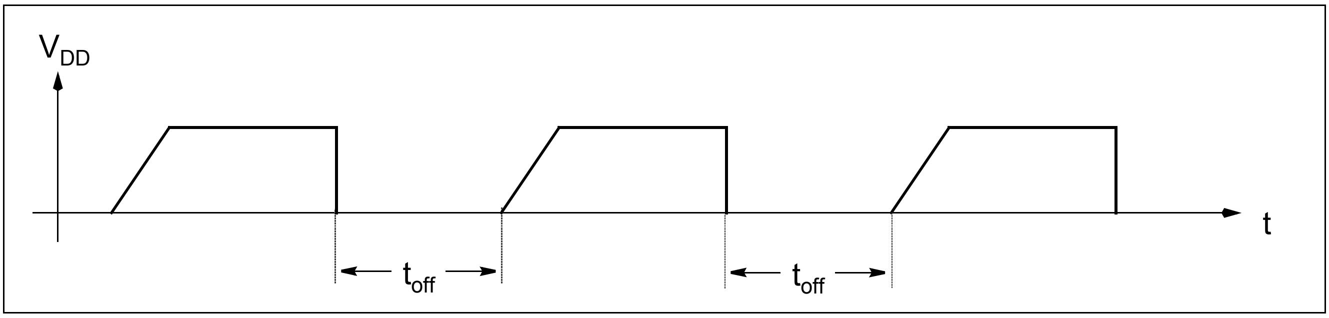

Figure 4-2 Oscillator Off Time

The recommendation is to use an oscillation 'off' time $t_{off} \geq 0.5$ sec for an oscillator frequency within the range of 4 MHz ≤ f_{OSC} ≤ 40 MHz

The off time of a real-time clock oscillator (32 kHz) should be at least $t_{off} \geq 60$ sec.

Note: See also IEC 60679-1, clause 4.5.9

5 Drive Level

The drive level is the current through the crystal.

5.1 Drive Current Measurement Method

The mechanical vibration amplitude of the quartz crystal increases proportionally to the applied current amplitude.

The power dissipated in the load resonance resistance R_L (also called ‘effective resistance’ or ‘transformed series resistance’) is given by the drive level P_W.

The peak-to-peak drive current I_{pp} is measured in the original application with a current probe directly at the crystal lead or in the crystal path.

The drive level is calculated with the formulas described in the following sub-sections of this chapter. The drive level is mainly controlled via R_{X2}, C_{X1} and C_{X2}.

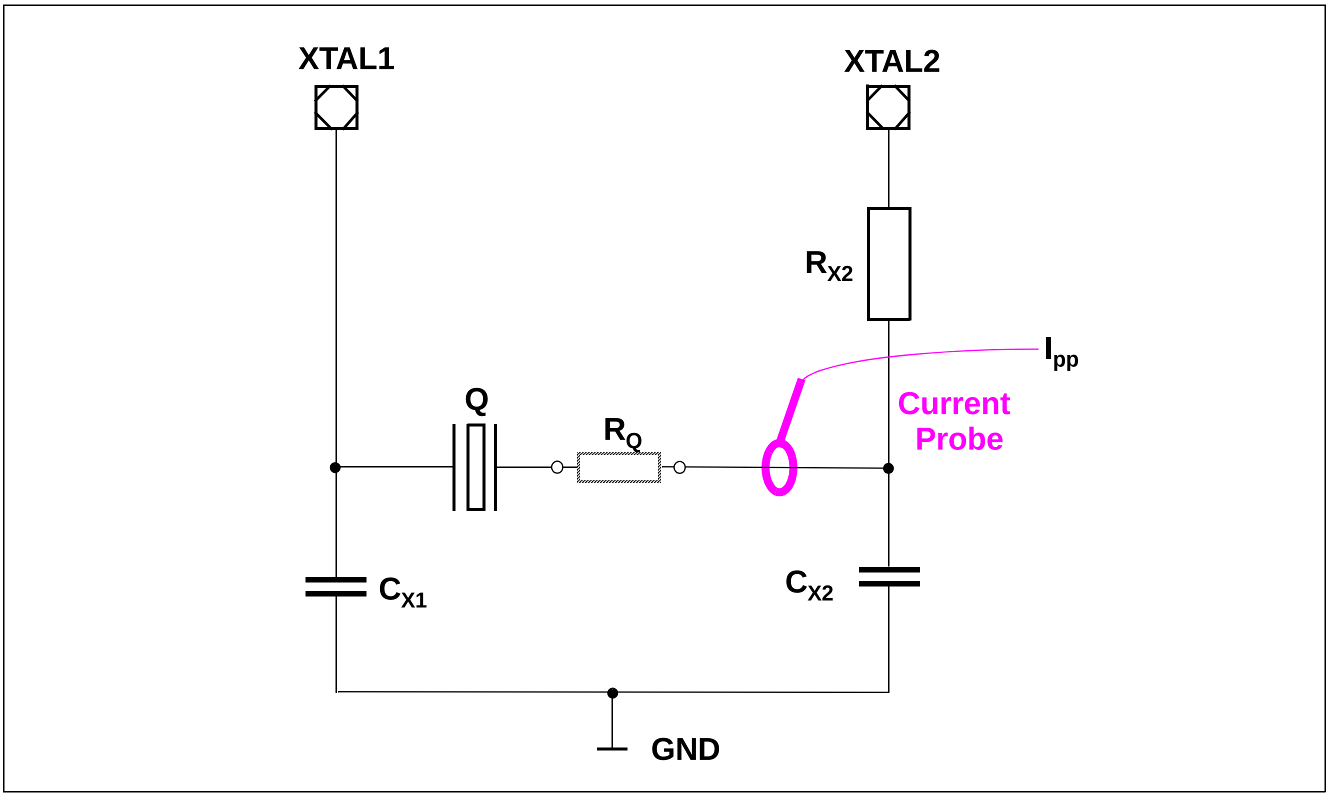

Figure 5-1 Measurement Method of Drive Current with a Current Probe

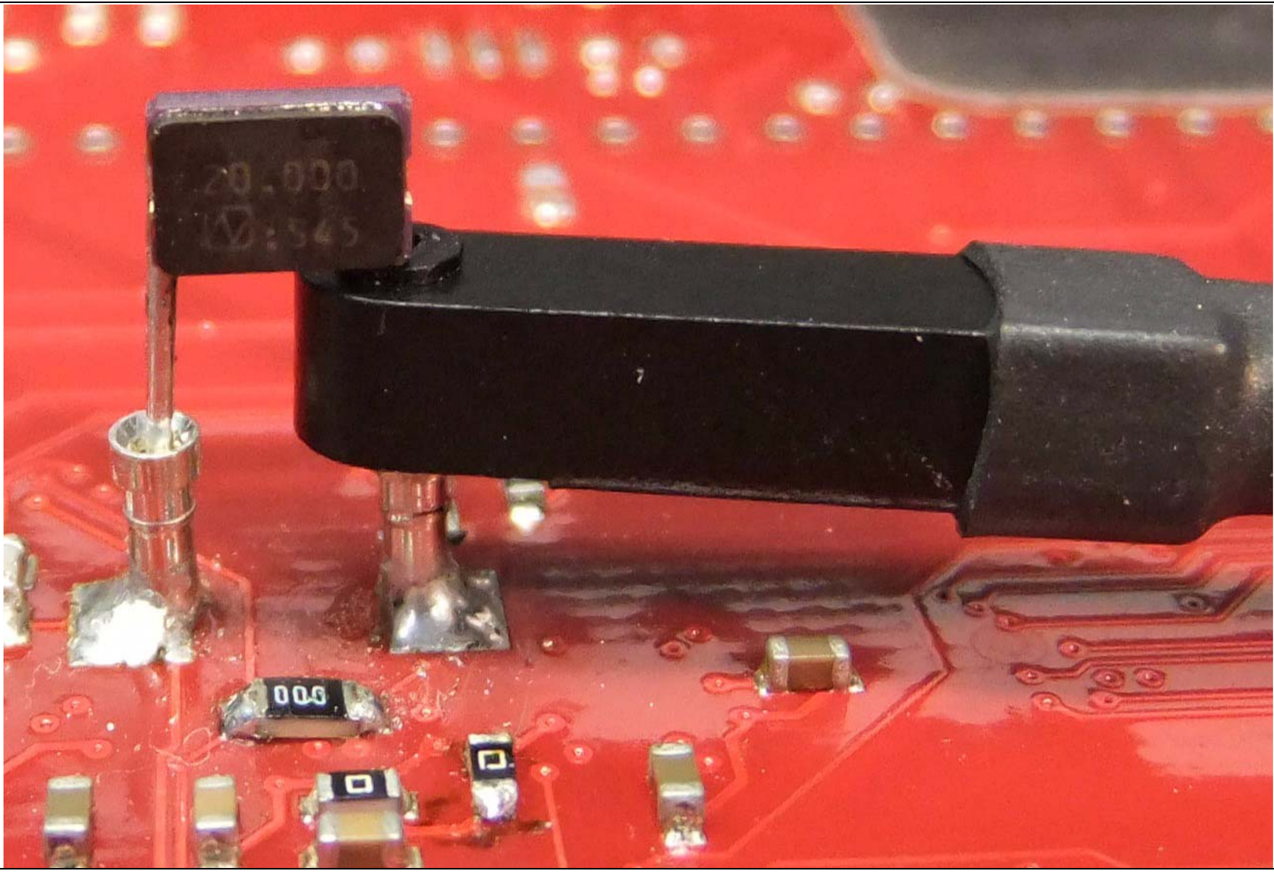

Figure 5-2 Example for using a Current Probe (CT6)

5.2 Drive Level Calculation for Fundamental Mode

The maximum and minimum allowed drive level depends on the crystal used, but is typically in the range of 10 µW ≤ P_W ≤ 500 µW.

Note: For more detailed information, please refer to the specific quartz crystal specification.

The load resonance resistance R_{Ltyp} is calculated with the typical values of the quartz crystal and of the system. The formula is shown below.

- The typical values of R_1 (R_{1typ}) and C_0 (C_{0typ}) are supplied by the crystal manufacturer.
- The stray capacitance C_S consists of the capacitance of the board layout, the input pad capacitance of the on-chip oscillator-inverter and other parasitic effects in the oscillator circuit.
- A typical value of the input pin capacitance of the inverter is 2 pF. The maximum value is 10 pF.
- A typical value of the stray capacitance in a normal system is C_S = 5 pF.

Drive level:

$$P_W = I_Q^2 \cdot R_{Ltyp} \tag{5.1}$$

Drive Current (for sine wave):

$$I_Q = \frac{I_{PP}}{2 \cdot \sqrt{2}} \tag{5.2}$$

Load Resonance Resistance:

$$R_{Ltyp} = R_{1typ} \cdot \left[1 + \frac{C_{0typ}}{C_L}\right]^2 \tag{5.3}$$

Load Capacitance:

$$C_L = \frac{C_{X1} \cdot C_{X2}}{C_{X1} + C_{X2}} + C_S \tag{5.4}$$

Note: In systems were gain is changed after oscillator start-up, the drive level is calculated with the drive current (I_Q) of the final gain setting.

6 Start-up and Oscillation Reliability

Most oscillator problems in a microcontroller system are related to the oscillation start-up. At start-up, the drive level of the oscillation is very small and increases up to the maximum. During that time the resistance of the crystal can reach high values because crystals show resistance dips depending on drive level and temperature. This effect is called drive level dependence (DLD).

The DLD of a quartz crystal depends on it's quality and can alter during production and during the life-time of a crystal. If crystal resistance dips increase in a range where the loop gain of the oscillator is lower than one, then the oscillation cannot start. **A strong recommendation therefore, is to check the start-up and oscillation reliability.** Such a test typically uses the negative resistance method.

For further details please refer to the following IEC standards:

- IEC 122-2-1: Quartz crystal units for microprocessor clock supply
- IEC 444-6: Measurement of drive level dependence (DLD)

6.1 Principle of the Negative Resistance Method

The oscillator can be divided into the on-chip oscillator-inverter and the external circuitry. The oscillator circuitry can be simplified as shown in **Figure 6-1**, below.

The load capacitance C_L contains C_{X1}, C_{X2} and the stray capacitance C_S.

The gain of the oscillator-inverter is replaced with a negative resistance $-R_{INV}$ and the quartz crystal is replaced by the load resonance resistance R_L (effective resistance) and the effective reactance L_Q.

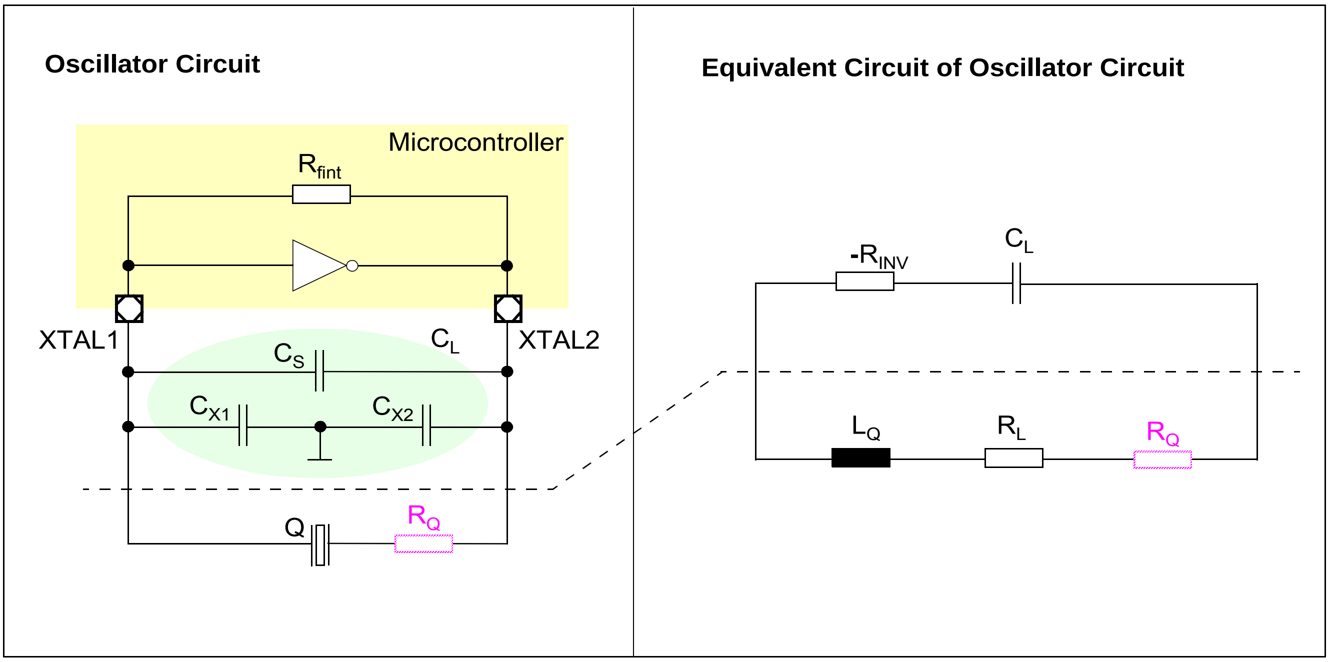

Figure 6-1 Equivalent Circuit for Negative Resistance Method

The condition required for oscillation is:

$$\left|-R_{INV}\right| \geq R_L \tag{6.1}$$

The negative resistance must be large enough to cover all possible variation of the oscillator circuitry, especially the crystal drive level dependency (DLD). This condition is necessary to ensure trouble-free oscillator operation.

The negative resistance can be analyzed by connecting a series test resistor R_Q to the quartz crystal (see **Figure 6-1**), used to find the maximum value R_{Qmax} that keeps the circuit oscillating with a small amplitude.

R_L is the resistance of the quartz crystal at oscillating frequency and creates the power dissipation.

Negative Resistance:

$$\left|-R_{INV}\right| = R_L + R_{Qmax} \tag{6.2}$$

R_{QMAX} is usually referred to as negative resistance.

6.2 Measurement Method of Start-up and Oscillation Reliability

The most common test used by crystal vendors to check the start-up and oscillation reliability of the oscillator is the negative resistance method of inserting a test resistor R_Q in series to the quartz crystal (as shown in **Figure 6-1**).

Typically this test does not result in one set of circuitry values which is the 'right one', but instead results in a recommended range which shows the optimized oscillator circuit start-up behavior. Depending on other system requirements such as XTAL1 amplitude specification or oscillator frequency, the final circuitry values for the oscillator are then selected.

6.2.1 General Description

In this section we described measuring negative resistance in oscillator circuitry where gain is not changed after start-up and where it is changed.

Gain NOT changed after start-up

When using oscillator circuitry were gain is not changed after oscillator start-up, negative resistance analysis can also be performed after oscillator start-up time.

- The test resistor value R_Q is increased until the oscillation does not start any more.
- From the state of no oscillation, R_Q is then decreased until oscillation starts again.

The observed amplitude may be very small but has to oscillate with the crystal resonance frequency. This measured value $R_{Qmax} = R_Q$ is called "negative resistance", "safety margin", "oscillation allowance" or "oscillation margin".

Gain changed after start-up

When using oscillator circuitry were gain is changed after start-up via hardware or software, the negative resistance must be measured during the oscillator start-up phase.

This can be achieved by starting the oscillator circuitry via a pulse generator controlled power supply.

The basic timing of V_{DD} during testing is equal to the described timing for testing the oscillation start-up time (see chapter **"Oscillator Start-up Time" on Page 9**) specially oscillator off time t_{off}.

Notes

1. *The series resistor R_Q should be an SMD device or a potentiometer which is suitable for RF (Radio Frequency). Depending on the RF behavior of the potentiometer, the results between using an SMD resistor or a potentiometer can be different. The result of the potentiometer is sometimes worse than for the SMD resistor. It is therefore recommended to use the potentiometer in order to find the final value R_{Qmax} and to perform a verification of R_{Qmax} with an SMD resistor.*
2. *The start-up and oscillation reliability can be also influenced by using a socket for the microcontroller during measurement. The influence is caused by the additional inductance and capacitance of the socket. Depending on the demands to the final system used for mass production consideration should also be given to start-up and oscillation reliability without a socket.*
3. *Depending on the system demands, the verification of the start-up and oscillation reliability should also be checked for variations of supply voltage and temperature.*

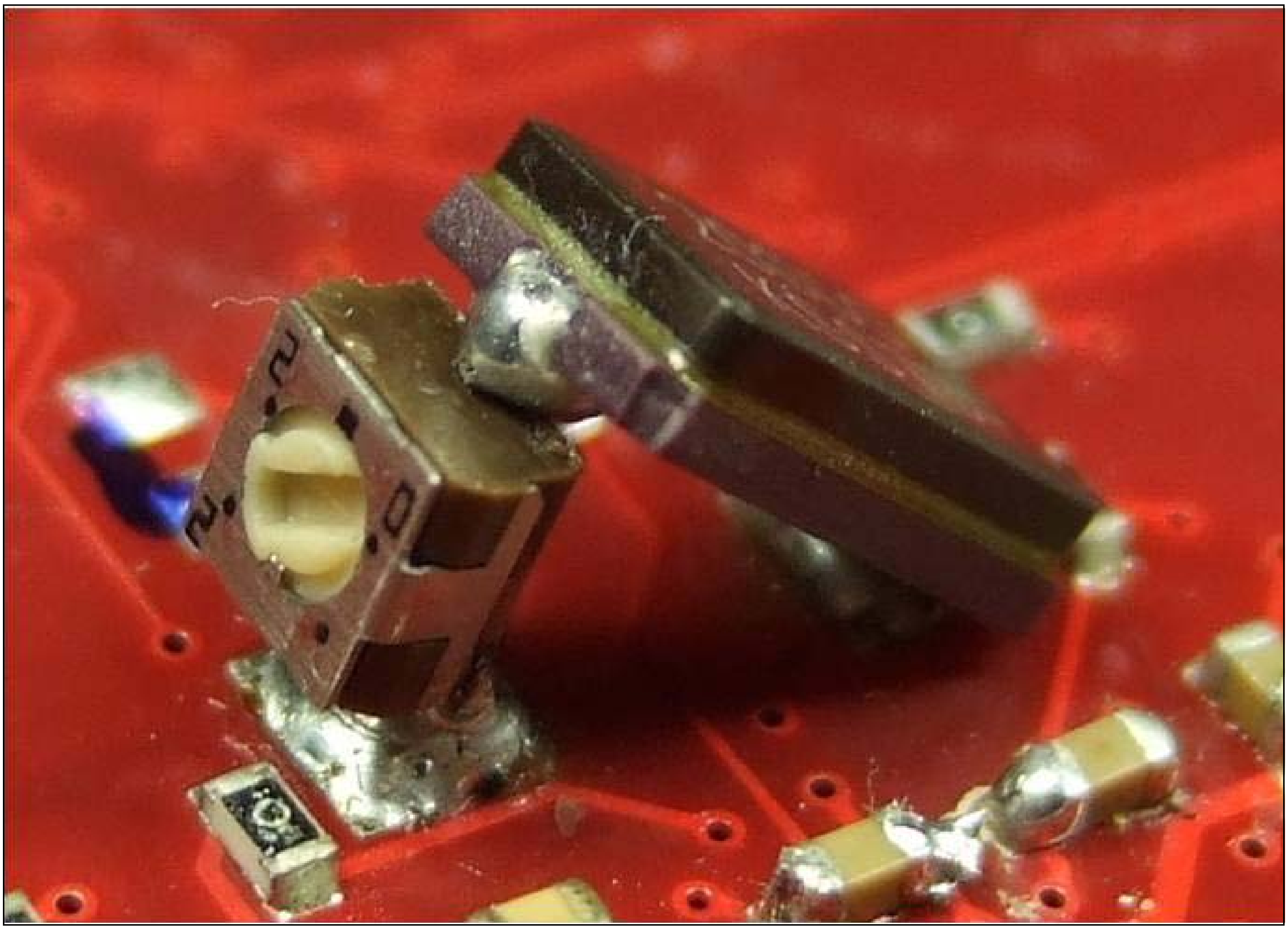

Figure 6-2 Example for Inserting the "negative" Resistor

6.2.1.1 Quick Negative Resistance Test

Measure negative resistance:
Measurement of the negative resistance in the final application as previously described.

Check whether measured negative resistance fits to crystal specification:
Every crystal vendor specifies negative resistance values. Depending on the crystal type, crystal frequency, target application and manufacturer, there are different specified minimum (and maximum) values for the negative resistance.
The measured negative resistance must fit to the specified values of the crystal used.

Measure XTAL1 amplitude:
The amplitude at XTAL1 has to be measured using an active probe with low capacitive load and high impedance (C_{probe}~1 pF, R_{probe}~10 MΩ) to prevent the probe from influencing the oscillator circuit resulting in a variation of the measured signal.

Check whether measured XTAL1 amplitude fits to specification in the Data Sheet:
Hysteresis at the XTAL1 input suppresses noise. That is why the XTAL1 oscillation amplitude has to be at least the minimum specified value.

A typical specification in the Data Sheet is:

- input high voltage at XTAL1
- input low voltage at XTAL1
- depending on the oscillator type, a minimum amplitude (peak-to-peak).

Attention: It is strongly recommended that the quartz crystal vendor should themselves be asked to analyze the start-up and oscillation reliability in the final system. This service is offered free of charge from all well-known crystal vendors, worldwide.

6.2.1.2 Comprehensive Negative Resistance Test

If there is no recommendation for oscillator circuit start-up values available, or if there are certain problems with the oscillator circuit, it is necessary to perform a detailed negative resistance test by varying external circuit parameters over a wide range.

A typical measurement range for the external circuit parameters is shown in the following table:

Table 6-1 External Circuit Parameter Range for Test

Circuit	Range
C_{X1}	0 - 100 pF
C_{X2}	0 - 100 pF
R_{X2}	0 - 10 kΩ

The described measurement procedure for R_{Qmax} has to be performed for different values of R_{X2}, C_{X1} and C_{X2}. For the test, the values of the different elements have to be changed one after another, and the results are noted in a table. A proposal for a protocol table which also includes the drive level is shown below (**Table 6-2**).

For the first test it is recommended to use $C_{X1} = C_{X2}$. The range of the elements depends on the quartz crystal used and on the characteristics of the printed circuit board. After the test, the measured values can be displayed in a diagram, as shown in **Figure 6-3** and **Figure 6-4**.

Table 6-2 Proposal for a Protocol Table

R_{X2} = ... Ω			
$C_{X1} = C_{X2}$	**I_Q or P_W**	**R_{QMAX}**	**Comment**
0 pF			
2.7 pF			
...			
...			
...			
...			
47 pF			

The next diagram (**Figure 6-3**) shows examples for negative resistance measurement results at different frequencies with a low R_{X2} value. The typical behavior of a Pierce oscillator where gain decreases with rising oscillator frequency, can be seen at the negative resistance values.

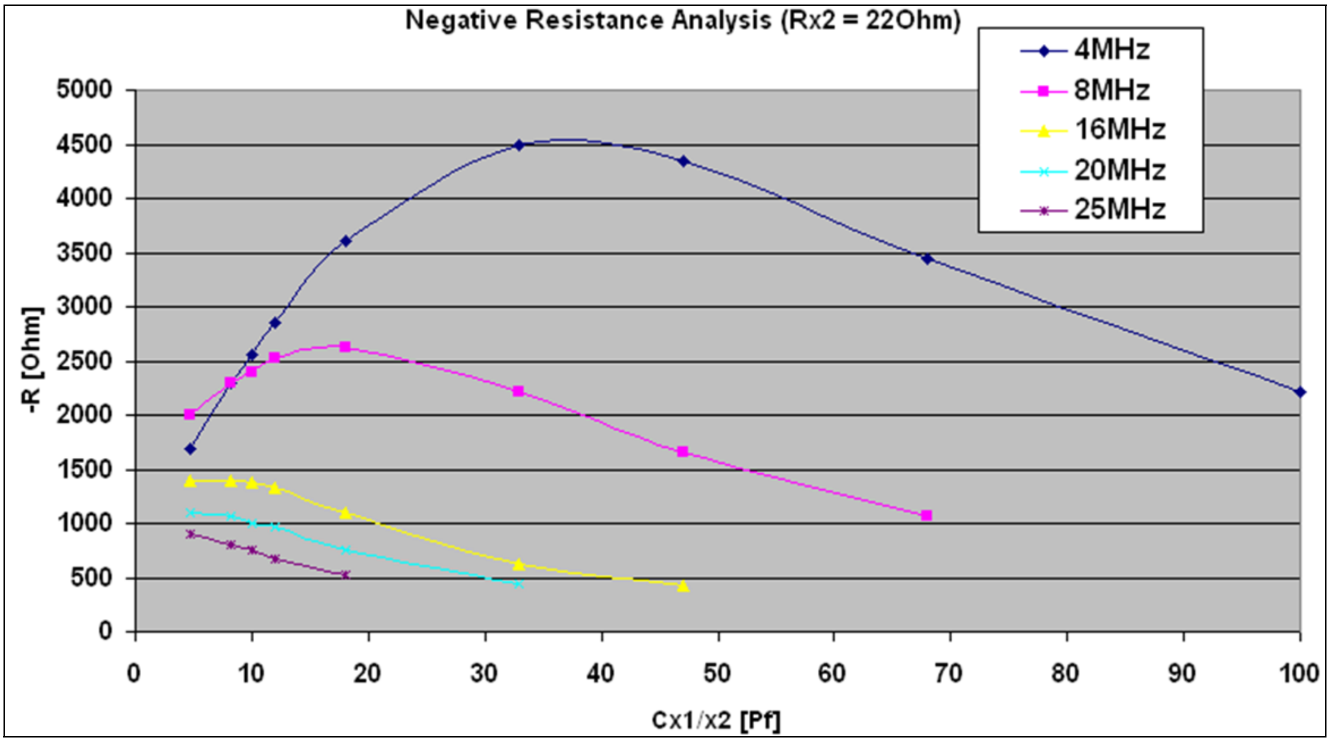

Figure 6-3 Example Negative Resistance Diagram with different Quartz Crystal Frequencies

6.3 Trouble Shooting

For standard applications, the previously described method of determining negative resistance by changing the load capacitors is sufficient and successful for finding appropriate external oscillator circuitry.

If the application system still shows problems, despite following all of the information already given in this application note, then the following hints may help to solve the problems.

6.3.1 Parasitic RC or LC Oscillation

In seldom cases the crystal does not start-up at its resonance frequency but the oscillator circuit starts very fast with low amplitude at a very high frequency. The start-up of the oscillator at quartz crystal resonance frequency is delayed with unstable start-up times, or the oscillator does not start at all when powered on.

This behavior may be caused by “parasitic” RC or LC oscillation and can be solved by inserting a small damping resistor R_{X2}, of about 10 Ω to 50 Ω, between XTAL2 and the load capacitor C_{X2}. This behavior is never seen in applications were a damping resistor R_{X2} has already been used for adapting drive level.

6.3.2 Pull down Resistor R_{X1}

An additional resistor R_{X1}, within the value range of 5 MΩ to 12 MΩ, in parallel to C_{X1}, can increase oscillator loop gain, since the internal feedback resistor of the oscillator-inverter and the additional external resistor form a voltage divider at the input of the inverter. This combination decreases damping in the active part of the inverter. Therefore the start-up behavior of the oscillation is improved and negative resistance is increased.

The additional resistor R_{X1} should only be used when the oscillation circuit is already optimized but when the measured negative resistance is not sufficient for the quartz crystal being used.

6.3.3 Feedback Resistor R_f

An additional external feedback resistor connected to XTAL1 and XTAL2 with a value R_f ~ 100 kΩ stabilizes the operating point (DC point) of the oscillator inverter input.

This combination can improve the start-up behavior in an application system where there is a lot of noise caused by adjacent components, or in systems with disturbance on the supply voltage.

This problem can be seen in a start-up time which is too long or which is not stable.

The additional external resistor R_f should only be used when the oscillation circuit is already optimized, but when the measured negative resistance is not sufficient for the quartz crystal being used.

6.4 Assessment of the Results

The basis for the evaluation of the measured results are the protocol tables. The results are displayed in evaluation diagrams.

For each protocol table with a fixed R_{X2}, one evaluation diagram should be used.

The evaluation diagram includes the characteristic curve for the negative resistance R_Q, (see **Figure 6-4**) and if necessary, the drive level P_W or crystal current I_Q are also included.

Depending on the circuit composition, the characteristic curve of the negative resistance (R_{Qmax}) very often includes a maximum for low capacitance values of C_{X1} and C_{X2}. The recommended range for the negative resistance (R_{Qmax}) should be in the falling area of the characteristic curve as marked in the diagram.

Depending on the selected area for the negative resistance (R_{Qmax}) a specific range for C_{X1} and C_{X2} is given.

When included, the specified minimum and maximum values of P_W (I_Q) of the crystal being used can also be marked. This results in a fixed range for the allowed load capacitor values C_{X1} and C_{X2}.

Now two areas for C_{X1} and C_{X2} are given, one by P_W (I_Q) and the other by the negative resistance (R_{Qmax}). The load capacitor range which is in both areas can be used for the oscillator circuit (see marked area in the diagram **Figure 6-4**). This analysis must be done for every R_{X2} value.

The final selection of components should only be made after consideration of:

- the specified negative resistance
- the frequency
- the specified drive level
- the specified XTAL1 amplitude
- quality of the start-up behavior of the oscillator
- start-up time of the oscillation
- the specified load capacitance C_L of the crystal

Note: It is NOT recommended to include the measured negative resistance maximum (R_{Qmax}) for the load capacitance selection because in many cases in this area the gradient of the characteristic curve for low C_{X1}/C_{X2} values is very high. If C_{X1} and C_{X2} were chosen in that area, small parameter variations of the components used during production could reduce the negative resistance value very quickly, and in the worst case the oscillator does not work at all.

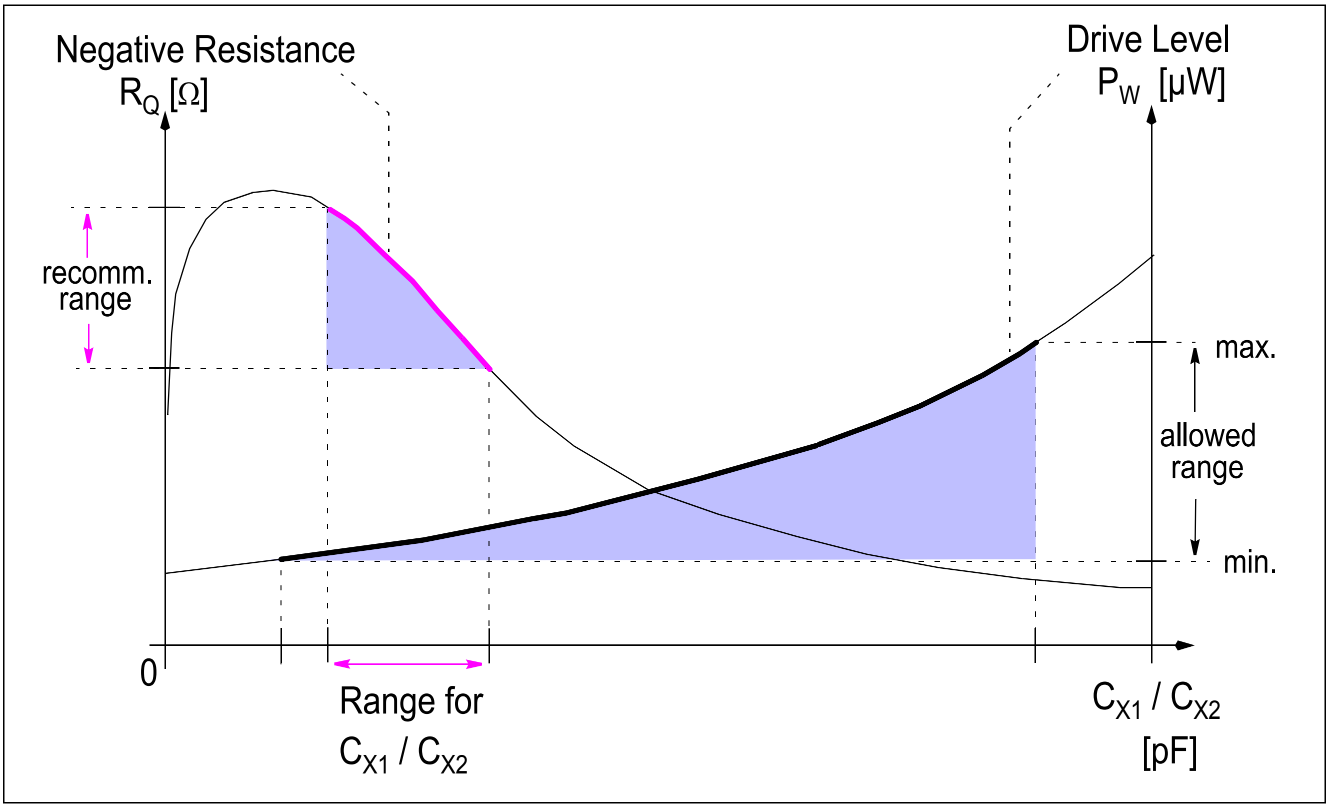

Figure 6-4 Evaluation Diagram for C_{X1} and C_{X2}

6.5 General Hints

Oscillator start-up and oscillation reliability analysis is very important and is **strongly recommended** for every oscillator design and whenever changing oscillator components, including PCB layout.

Oscillator start-up problems are in most cases statistical phenomenons. An oscillator is typically always running during the development phase in the lab environment, but in mass production when small parameter variations of all oscillator components move in the same direction, it can result in the oscillator sporadically not starting in some applications.

An oscillator system design with well selected oscillator component values will very rarely show problems, and then usually only for some small ppm of systems. If negative resistance analysis were not done the oscillator field rejects could be in the range of 1000 ppm or more!
It is therefore strongly recommended to measure the negative resistance (oscillation margin) in the final target system (layout) to determine the optimal parameters for the oscillator operation.

Note: This service is offered free of charge from all the well-known crystal vendors worldwide.
Some links are on www.infineon.com
Home > Microcontrollers > Service, Support and Training > Design Services

7 Oscillator Circuitry Layout Recommendations

The layout of the oscillator circuit is important for the RF and EMC behavior of the design.

The following recommendations can help to reduce problems caused by PCB layout. This design recommendation is optimized on EMC aspects.

Note: Please refer also to Infineon application note "Design Guideline for Microcontroller Board Layout".

For an optimal layout, the following points must be noted:

7.1 Ground Island

A separated V_{SSOSC} island on the top layer which is carved out from the global GND layer, reduces radiation and coupling from and to the oscillator circuit. This ground island is connected at one point to the GND layer. This shields the oscillator circuit from surrounding noise, keeps noise generated by the oscillator circuit locally on this separated island and reduces noise on the reference clock at the XTAL1 input. The ground connections of the load capacitors and V_{SSOSC} are also connected to this island. Traces for the load capacitors and crystal should be as short as possible.

7.2 Ground Connection of the Crystal Package

When using a metal case, the connection of the crystal package to the ground island directly underneath the crystal has the following advantages:

- The crystal metal package reduces the electromagnetic emission.
- The mechanical stability of the crystal can be increased.
- The ground island underneath the crystal shields the oscillator. This shielding de-couples signals on the other PCB side.

Note: The connection to the ground should be made with a top-pin-clip because the heat of soldering can damage the quartz crystal.

7.3 Ground Supply

The ground supply must be realized on the base of a low impedance. The impedance can be made smaller by using thick and wide ground tracks. Ground loops must be avoided, because they act like antennas.

7.4 Avoid Capacitive Coupling

The crosstalk between oscillator signals and other signals must be minimized. Sensitive inputs must be separated from outputs with a high amplitude.

Note: The crosstalk between different layers must also be analyzed.

7.5 Avoid Parallel Tracks of High Frequency Signals

In order to reduce the crosstalk caused by capacitive or inductive coupling, tracks of high frequency signals should not be routed in parallel and not routed on different layers.

7.6 Correct Module Placement

Other RF modules should not be placed near the oscillator circuitry in order to prevent them from influencing the crystal functionality.

7.7 Layout Example

The following is a layout example for an SMD quartz crystal.

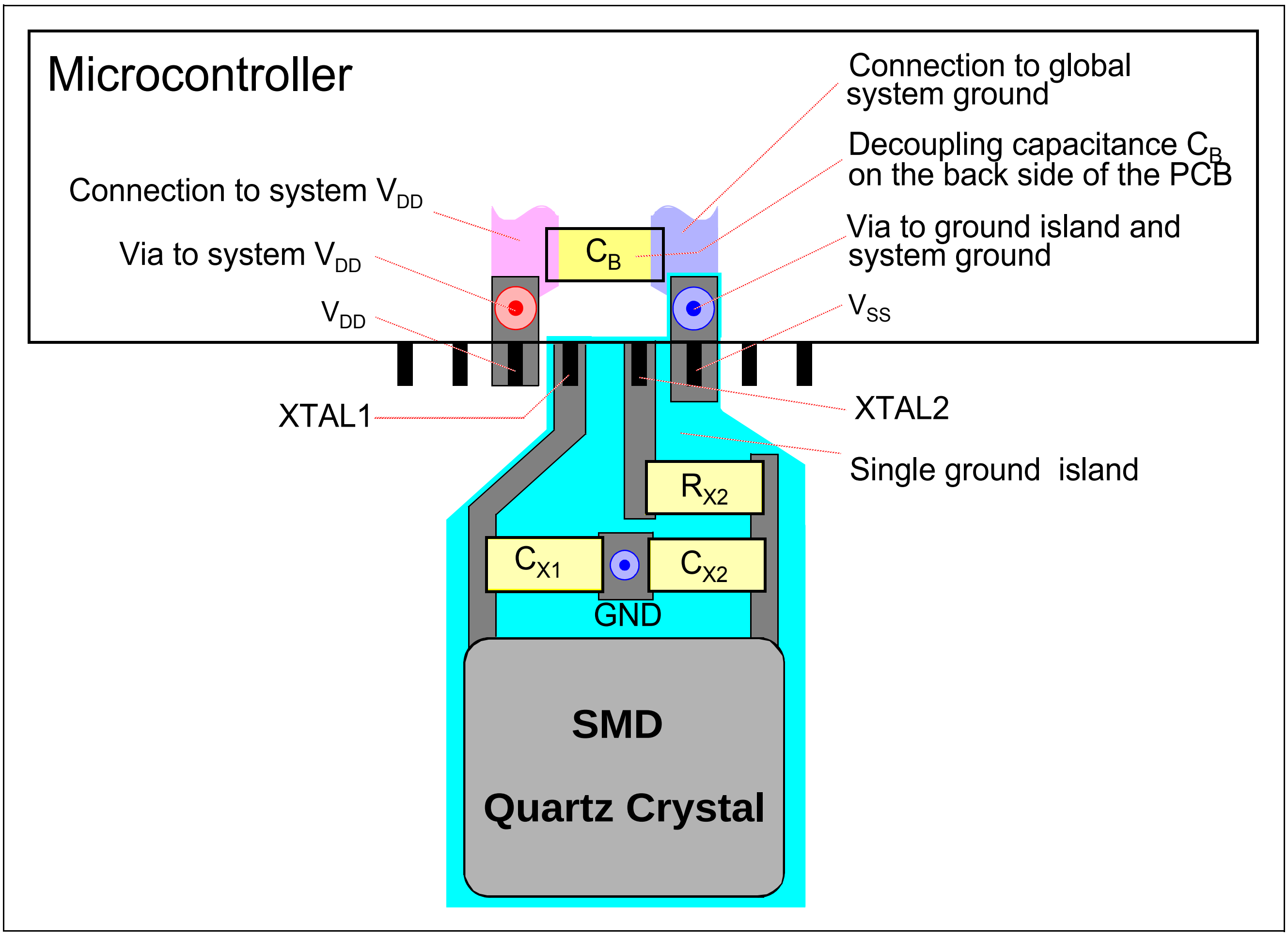

Figure 7-1 Layout Example for a SMD Quartz Crystal

8 List of Abbreviations

Table 8-1 List of Abbreviations

Abbreviation	Explanation
C_0	Quartz crystal shunt capacitance (static capacitance)
C_{0typ}	Typical value of the shunt capacitance of the quartz crystal
C_1	Motional capacitance of the quartz crystal (dynamic capacitance). Mechanical equivalent is the elasticity of the quartz crystal hardware blank.
C_{1typ}	Typical value of the quartz crystal motional capacitance
C_L	Load capacitance of the system in respect of the quartz crystal
C_{L0}, C_{L1}, C_{L2}, C_{L3}	Adjustable on-chip load capacitors
C_S	System stray capacitance
C_{X1}, C_{X2}	External load capacitors
C_B	De-coupling capacitance for V_{DD} and V_{SS} on the Printed Circuit Board (PCB). Depending on the EMC behavior the value is typical in the range: 22nF to 100nF
DLD	Drive level dependence. R_L dependency from quartz crystal driver level
I_{pp}	Peak to peak value of the quartz crystal current
I_Q	Drive current
L_1	Motional inductance of the quartz crystal (dynamic inductance). Mechanical equivalent is the oscillating mass of the quartz crystal hardware blank
L_Q	Effective reactance of the quartz crystal
P_W	Drive level
Q	Quartz Crystal
R_1, R_r	Series resistance of the quartz crystal at series resonance frequency (series resistance). In other technical descriptions also called: 'equivalent series resistance, ESR' or 'transformed series resistance'). Mechanical equivalent is the molecular friction, the damping by mechanical mounting system and acoustical damping by the gas filled housing.
R_{1typ}	Typical value of the series resistance at room temperature
R_{1max}	Maximum value of the series resistance at room temperature
$-R_{INV}$	Oscillator inverter gain
R_{Ltyp}, R_{Lmax}	Typical and maximum load resonance resistor (also called: 'effective resistance'). R_L is the resistance of the quartz crystal at oscillating frequency and creates the power dissipation
R_Q	Test resistor for measuring "critical starting resistance" also called negative resistance (-R)
R_{Qmax}	Maximum value of the test resistor which does not stop the oscillation
R_{X1}	Pull down resistor to increase gain (trouble shooting)
R_{X2}	Drive level control resistor (damping resistor)
R_f	On-chip feedback resistor or additional external feedback resistor to stabilize DC point (trouble shooting)
V_{DD}	Supply Voltage

Table 8-1 List of Abbreviations

V_{OSCMAX}	Maximum peak-to-peak amplitude of oscillation voltage
V_{SS}	Ground
t_{off}	Oscillator off time for measurement of start-up behavior

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