SIEMENS

Microcontrollers

ApNote   AP242003

Crystal Oscillator of the
C500 and C166 Microcontroller Families

The microcontrollers of the C500/C166 Family include the active part of the oscillator. This document explains the quartz crystal oscillator functionality and gives recommendations how to get the right composition on external circuits.

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Actual Revision : 04.98 Previous Revision : 12.97		
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1   Introduction

This Application Note provides recommendations concerning the selection of quartz crystals and circuit composition for each oscillator. The cooperation between the IC oscillator and the quartz crystal is not always working properly because of a wrong composition on external circuits. Therefore **Siemens** (HL DC AT) and **Tele Quarz Group** built up a cooperation to support our customers with the appropriate knowledge to guarantee a problem-free operation of the oscillator.

2   Oscillator-Inverter

The microcontrollers of the C500/C166 Family include the active part of the oscillator (also called oscillator-inverter). Based on the history and evolution of the microcontrollers there are different oscillator-inverters implemented at the C500/C166 Family members. Due to the same reason, the meaning of XTAL1 and XTAL2 pins is different. In this Application Note and at the C166 family, XTAL1 is the oscillator-inverter input while XTAL2 is the output. At the C500 family it is recommended to have a closer look at the Data Sheet of each device.

The on-chip oscillator-inverter can either run with an external crystal and appropriate external oscillator circuitry (also called oscillator circuitry or 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 crystal. The oscillator provides an inverter and a feedback element. The resistance of the feedback element is in the range of 0.5 to 1 MΩ.

Depending on the type of oscillator-inverter the gain can be different between reset active and reset inactive. The recommendations in the appendix are seperated to the different oscillator-inverter types of the C500 and C166 family.

2.1   Oscillator Inverter Type_A, Type_B and Type_C

These types of inverters are implemented in C500 family derivatives. The gain of these types of oscillator-inverters is the same during reset active and reset inactive. These oscillators are optimized for operating frequencies in the range of 2.0 (3.5) to 20 MHz. For details reffer to appendix.

2.2   Oscillator Inverter Type_R

This type of inverter is implemented in most of the current C166 family derivatives. The gain of the Type_R oscillator-inverter is high during reset is active and is **R**educed by one-third when reset is inactive. This feature provides an excellent start-up behaviour and a reduced supply current for the oscillator during normal operation mode. The Type_R oscillator-inverter is optimized for an operating frequency range of 3.5 to 40 MHz.

2.3 Oscillator Inverter Type_LP1 and Type_LP2

This type of inverter is a **L**ow **P**ower oscillator, version 1 and version 2. Inverter Type_LP2 is the actual version and will be implemented in new derivatives of the C16x family. The Type_LP oscillator-inverter is a high sophisticated module with a high gain but low power consumption. The gain of the Type_LP oscillator-inverter is the same during reset active and reset inactive. This oscillator is optimized for an operating frequency range of 3.5 to 16 MHz. For input frequencies above 25 ... 30 MHz provided by an external oscillator the oscillator's output should be terminated with a 15 pF capacitance and a 3 kΩ resistor in series to XTAL2.

3 Fundamental Mode and 3rd Overtone

Depending on the system demands there are two different kind of oscillator modes available. The external quartz crystal can be prepared for fundamental mode or 3rd overtone mode.

The standard external oscillator circuitry for fundamental mode (see figure 1) includes the crystal, two low end capacitors and a series resistor R_{X2} to limit the current through the crystal. The series resistor R_{X2} is not often used in C500 family devices. A test resistor R_Q may be temporarily inserted to measure the oscillation allowance of the oscillator circuitry. How to check the start-up reliability will be explained in detail in Chapter 6.

For the 3rd overtone mode an additional inductance/capacitance combination (L_X/C_{X2}) is required to suppress oscillation in the fundamental mode and bias voltage (C_X) at the XTAL2 output. Fundamental mode is suppressed via phase shift and filter characteristics of the L_X/C_{X2} network. The formula f_{LXCX2} in chapter 5.3 calculates the frequency at which the inductive behaviour of the L_X/C_{X2} network changes to capacitive. The oscillation condition in 3rd overtone mode needs a capacitive behaviour for f_{3rd} and an inductive one for f_{fund}.

3rd overtone mode is often used in applications where the crystal has to be resistant against strong mechanical vibrations because 3rd overtone crystals have a higher mechanical stability than fundamental mode crystals with the same frequency.

In general, there are different possibilities to connect the L_X/C_X network for 3rd overtone to the oscillator circuit. The L_X/C_X network theoretically can be connected to C_{X1} or C_{X2}. This Application Note recommends the connection to C_{X2} (see figure 1) because a little variation of L_X caused by production deviation has more influence concerning the oscillator start-up behaviour at the XTAL1 input than at the XTAL2 output. Furthermore, the additional hardware for 3rd overtone mode receives additional electrical noise from the system. In a $C_{X1}/L_X/C_X$ combination the noise will be amplified via the oscillator inverter. In a $C_{X2}/L_X/C_X$ combination the noise will be damped by the quartz crystal. Depending on the quality of the Printed Circuit Board design, a $C_{X1}/L_X/C_X$ combination can have a bad influence on the start-up behaviour of the oscillator.

Note: There is no need of changing existing working designs which use the $C_{X1}/L_X/C_X$ combination when the safety factor SF is within the desired range.
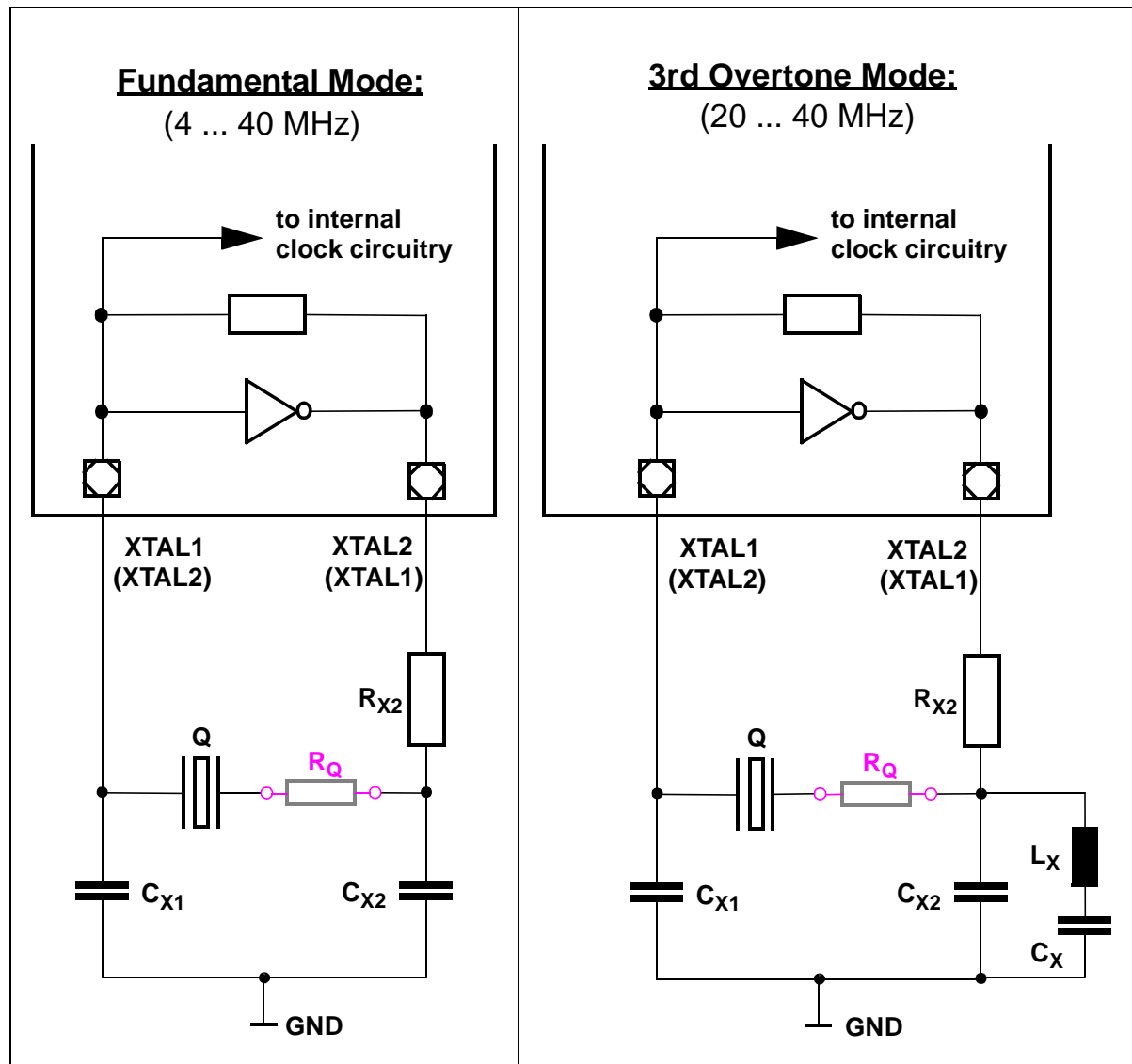
**Figure 1
Oscillator Modes**

Note: The operating frequency of the oscillator depends on the type of oscillator-inverter and the oscillation mode. For detailed information refer to appendix.

4 Oscillator Start-up Time

Based on small electrical system noise or thermic noise caused by resistors, the oscillation starts with a very small amplitude. Due to the amplification of the oscillator-inverter, the oscillation amplitude increases and reaches its maximum after a certain time period t_{st_up} (start-up time). Typical values of the start-up time are within the range of 0.1 msec $\leq t_{st\_up} \leq$ 5 msec. 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 real 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 a way that a total phase shift of 360° is performed. This can be achieved by a variation of C_{x1} and C_{x2}.

Note: The external hardware reset signal has to be active for a longer time period than the oscillator start-up time in order to prevent undefined effects.

Note: Because of the different gain of the Type_R oscillator-inverter during reset active and reset inactive it is recommended to consider the oscillation in both phases of the reset signal.

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

The definition of the oscillator start-up time is not a well defined value in literature. Generally it depends on the power supply rise time dVcc/dt at power on, on the electrical system noise and on the oscillation amplitude. For this application the oscillator start-up time t_{st_up} is defined from Vcc/2 to $0.9*V_{OSC\_max}$ of the stable oscillation, see figure 2.
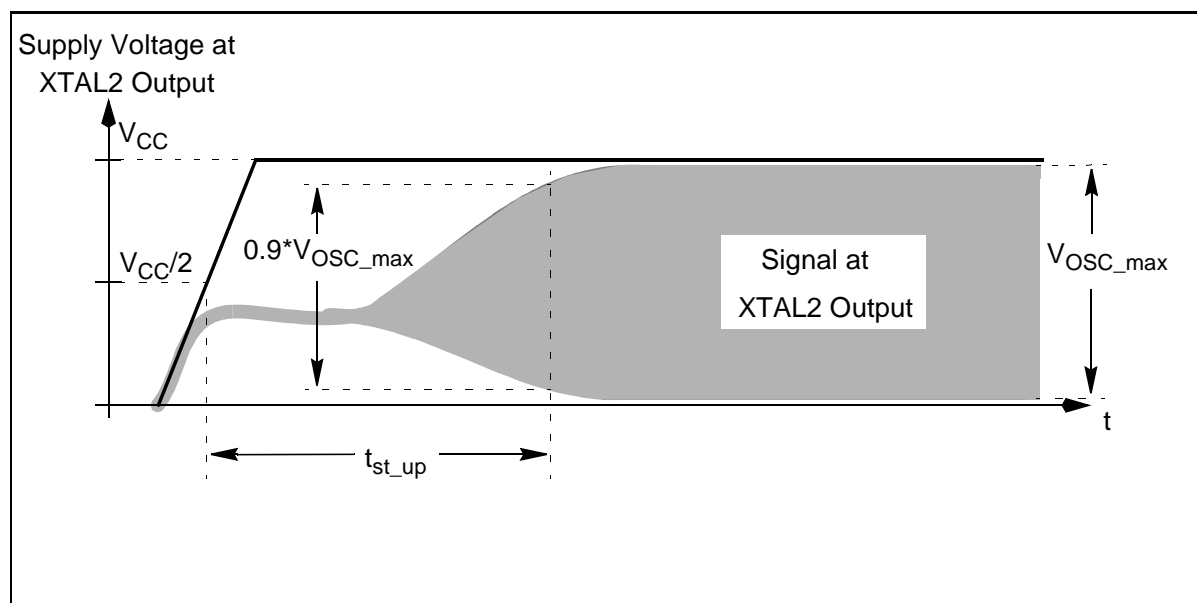
**Figure 2
Oscillator Start-up Time**

4.2 Definition of the Oscillator Off Time t_{off}

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

It is recommended to use a oscillation off time $t_{off} \geq 0.5$ sec, see figure 3.
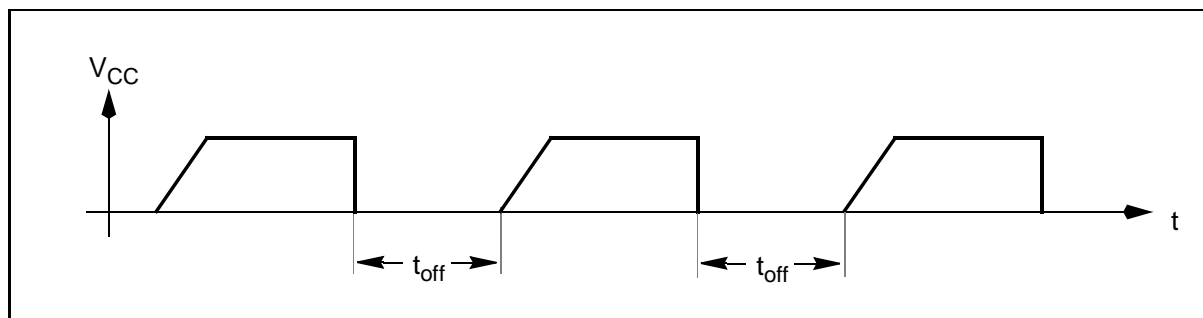
Figure 3
Oscillator Off Time

5   Drive Level

5.1   Measurement Method of Drive Current

The amplitude of mechanical vibration of the quartz crystal increases proportionally to the amplitude of the applied current. The power dissipated in the load resonance resistance R_L (in other technical descriptions 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, see figure 4. The drive level is calculated with the formulas shown in chapters 5.2 and 5.3. The drive level is mainly controlled via R_{X2} and C_{X1}, but C_{X2} also has an influence.
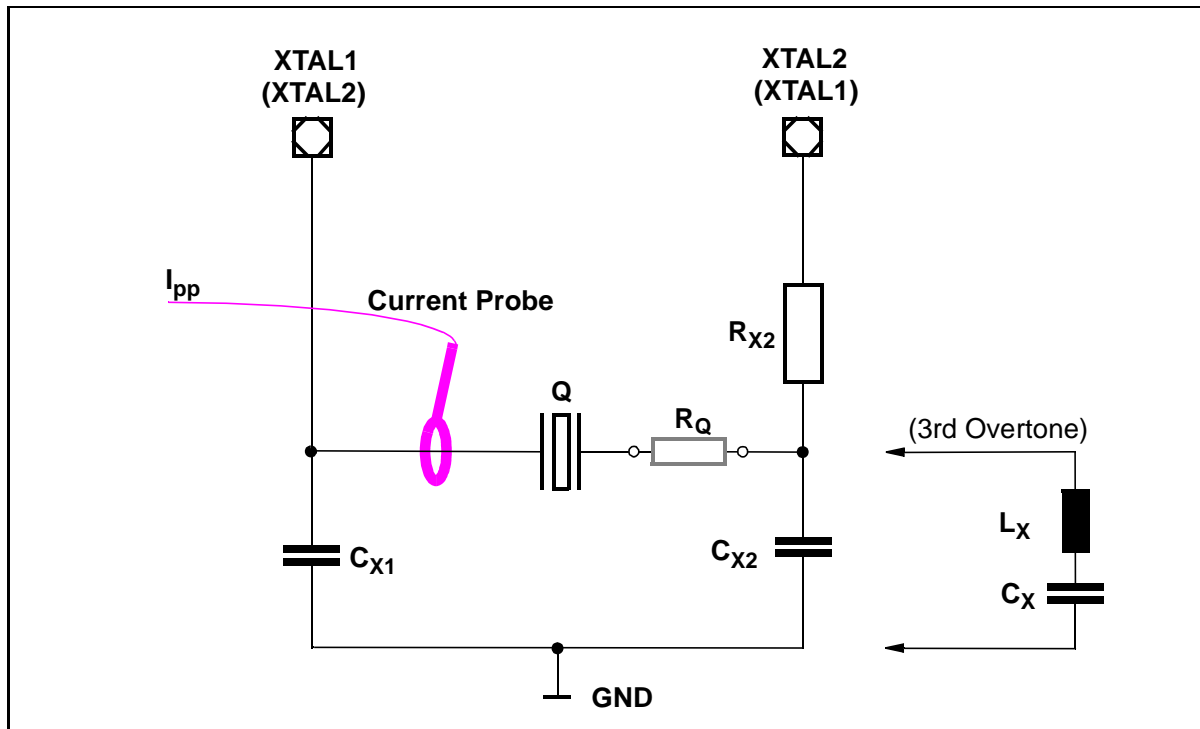
**Figure 4
Measurement Method of Drive Current with a Current Probe**

5.2   Drive Level Calculation for Fundamental Mode

The maximum and minimum allowed drive level depends on the used crystal and should be within the typical range of 50 µW $\leq P_W \leq$ 800 µW. For detailed information, the quartz crystal data sheet has to be regarded.

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 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.

Drive level:

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

Drive Current:

$$\boxed{I_Q = \frac{Ipp}{2 \cdot \sqrt{2}}}\text{ (for sine wave)}$$

Load Resonance Resistance:

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

Load Capacitance:

$$\boxed{C_L = \frac{C_{X1} \cdot C_{X2}}{(C_{X1} + C_{X2})} + C_S}$$

Note: The drive level calculation in systems with a Type_R oscillator-inverter should be done with the drive current (I_Q) measured during reset is inactive. Using an optimized external circuitry the difference of I_Q during reset active and reset inactive is very small.

5.3   Drive Level Calculation for 3rd Overtone Mode

The calculation of the drive level in 3rd overtone mode is equal to fundamental mode besides the calculation of the load capacitance. The formulas below show the relations between load capacitance, circuit components and frequencies in 3rd overtone.

Load Capacitance:

$$C_L = \frac{C_{X1} \cdot C_{X2rest}}{C_{X1} + C_{X2rest}} + C_S$$

C_{X2} rest Capacitance:

$$C_{X2rest} = C_{X2} - \frac{1}{(2\pi f_{3rd})^2 \cdot L_X}$$

Resonance Frequency of C_{X2} and L_X (Thomson Formula):

$$f_{LXCX2} = \frac{1}{2\pi \cdot \sqrt{L_X \cdot C_{X2}}}$$

Relation between f_{fund} and f_{3rd}:

$$f_{LXCX2} \approx \left(\frac{f_{fund} + f_{3rd}}{2} = 2 \cdot f_{fund} \right)$$

6 Start-up- and Oscillation Reliability

Most problems concerning the oscillator in a microcontroller system occur during the oscillation start-up time. During start-up time the drive level of the oscillation is very small and is increased up to the maximum. During that time the resistance of the crystal can reach very high values because crystals show resistance dips depending on the drive level. This effect is called drive level dependence (DLD). The DLD of a quartz crystal depends on the quality and can alter during production and during the life time of the crystal. If the resistance dips of the crystal increase in a range where the amplification of the oscillator is lower than one, than the oscillation cannot start. Therefore **it is strongly recommended to check the start-up and oscillation reliability**.

6.1 Measurement Method of Start-up- and Oscillation Reliability

As already mentioned before, the resistance of a crystal depends on the drive level. A simple method to check the start-up and oscillation reliability of the oscillator is to insert a test resistor R_Q in series into the quartz crystal, see figure 4.

The basic timing of Vcc during testing is equal to the described timing for testing the oscillation start-up time (see chapter 'oscillation start-up time'). The value of 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. Using a Type_R oscillator-inverter this procedure has to be considered during reset active and reset inactive. This final value of R_{Qmax} is used for further calculations of the safety factor SF.

Note: The series resistor R_Q should be an SMD device or a potentiometer which is suitable for RF (Radio Frequency). Depending on the RF behaviour 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 the one of 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 a SMD resistor.

Note: 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 which is used for mass production the consideration of start-up and oscillation reliability has to be done with or without a socket. The recommendations in the appendix are verified without socket.

Note: Depending on the system demands the verification of the start-up and oscillation reliability should be also done for variation of supply voltage and temperature.

**Table 1
Element Range for Test**

Element	Range
$C_{X1} = C_{X2}$	0 - 100 pF
R_{X2}	0 - 10 kΩ
3rd Overtone: L_X	1 - 15µH
3rd Overtone: C_X	1 - 10nF

The described measurement procedure for R_{Qmax} has to be performed for different values of R_{X2}, C_{X1} and C_{X2}. During 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 is shown in table 2. For the first test it is recommended to use $C_{X1} = C_{X2}$. A suggestion for the range is given in table 1. The range of the elements depends on the used quartz crystal and on the characteristics of the printed circuit board. After the test the measured values should be displayed in a diagram, see figure 6.

The measurement method of start-up and oscillation reliability for 3rd overtone mode needs more efforts than for fundamental mode. The relation between the values of L_X and C_{X2} is given via the formulas in chapter 5.3. When C_X lies within the recommended range it has theoretically no effect on the start-up behaviour of the oscillator, but in a system the parasitic inductive part of C_X can have a little influence. C_X is only needed in order to suppress bias voltage at XTAL2 output. Recommended values are shown in table 1.

**Table 2
Proposal for a Protocol Table**

R_{X2}= ... Ohm			
$C_{X1} = C_{X2}$	I_Q or P_w	R_{Qmax}	Comment
2.7 pF			
. . .			
10 pF			
. . .			
. . .			
. . .			
47 pF			

6.2   Safety Factor

The safety factor SF is the relation between maximum test resistance R_{Qmax}, which can be added in series to the quartz crystal but it is still oscillating, and the maximum load resonance resistance R_{Lmax}. It gives a feeling of how much the resistance of the passive part of the oscillator circuitry can be increased (caused by the drive level dependence of the crystal) until the oscillation does not start any more. Depending on production quality and long time behaviour of all parts of the oscillator circuitry, the safety factor needs a certain minimum value to grant a problem-free operation of the oscillator for mass production and during life time. The qualification of the safety factor shown in table 3 is based on the experience of the Tele Quarz Group.

Safety Factor:

$$SF = \frac{R_{Qmax}}{R_{Lmax}}$$

Load Resonance Resistance:

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

**Table 3
Qualification of the Safety Factor**

Safety Factor	Qualification
SF < 1.5	unsuitable
$1.5 \leq SF < 2$	risky
$2 \leq SF < 3$	suitable
$3 \leq SF < 5$	safe
$SF \geq 5$	very safe

Note: For oscillation frequencies higher than 24MHz it is strongly recommended to check whether the safety factor which can be achieved is sufficient for the system. In case the safety factor is not sufficient in fundamental mode, it is possible to use 3rd overtone mode (see appendix).

6.3 Trouble Shooting

For standard applications, the already described method to determine the safety factor by changing the load capacitors is sufficient and successful finding a appropriate safety factor. If the application system shows still problems, despite all information given in this application note was regarded then the following hints can solve the problem.

6.3.1 Pull down Resistor R_{X1}

An additional resistor R_{X1}, within the value 5 MΩ to 12 MΩ, in parallel to C_{X1} can also increase the safety factor, since the internal feedback resistor of the oscillator-inverter and the additional external resistor form a voltage divider at the input of the inverter, see figure 5. This combination decreases damping in the active part of the inverter. Therefore the start-up behaviour of the oscillation is improved, and the safety factor is increased. The additional resistor R_{X1} should only be used when the oscillation circuit is already optimized but the safety factor is not sufficient for the application.

6.3.2 Feedback Resistor R_f

An additional external feedback resistor with a value $R_f \sim 100$kΩ stabilizes the operating point (DC point) of the oscillator inverter input, see figure 5. This combination improves the start-up behaviour in an application system with much 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 to long or in a start-up time which is not stable. The additional external resistor R_f should only be used when the oscillation circuit is already optimized but the safety factor or start-up behaviour is not sufficient for the application.

Pull down Resistor R_{X1}

Feedback Resistor R_f

to internal
clock circuitry

XTAL1
(XTAL2)

XTAL2
(XTAL1)

R_{X2}

Q

R_{X1}

C_{X1}

C_{X2}

GND

to internal
clock circuitry

XTAL1
(XTAL2)

XTAL2
(XTAL1)

R_f

R_{X2}

Q

C_{X1}

C_{X2}

GND
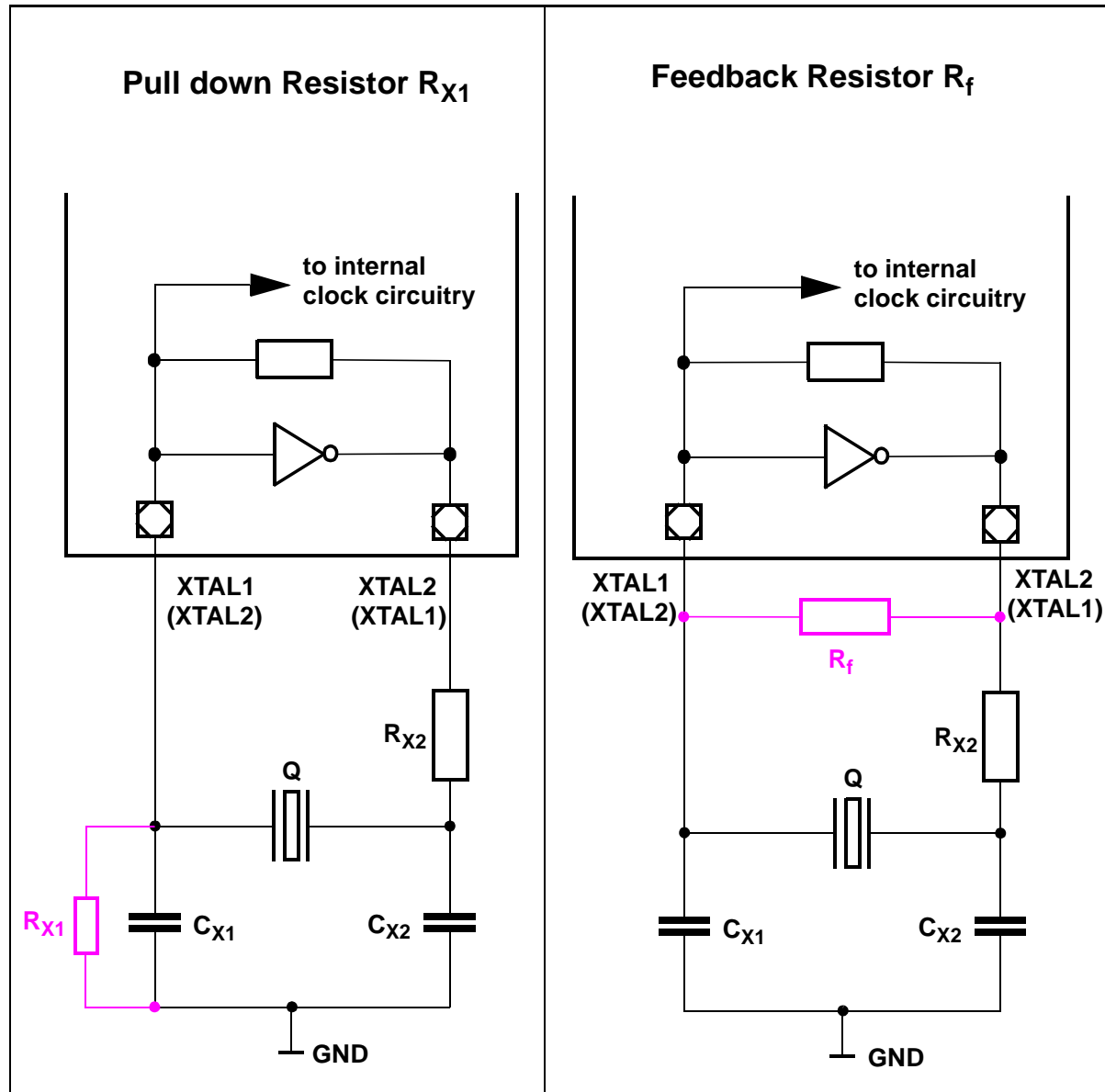
Figure 5
Pull down Resistor R_{X1} and Feedback Resistor R_f for Trouble shooting

6.4   Qualification of the Results

The basis for the evaluation of the measured results are the protocol tables. The results are displayed in evaluation diagrams shown in figure 6. For each protocol table with a fixed R_{X2} one evaluation diagram should be used. The evaluation diagram includes the characteristic curve for the safety factor SF and the drive level P_W. It is also possible to display the resistance of the test resistor R_Q and the crystal current I_Q.

In the evaluation diagram the specified minimum and maximum values of P_W (I_Q) of the used crystal can be marked. From it results a fixed range for the allowed capacitance of C_{X1} and C_{X2}. Depending on the circuit composition, the characteristic curve of SF (R_{Qmax}) includes very often a maximum for capacitance values in the C_{X1}/ C_{X2} range of 0 pF to 3 pF. The recommended range for SF (R_{Qmax}) should be in the falling area of the characteristic curve as marked in the diagram. Depending on the selected area for SF (R_{Qmax}) a specific range for C_{X1} and C_{X2} is given.

Now two areas for C_{X1} and C_{X2} are given, one by P_W (I_Q) and the other by SF (R_{Qmax}). The capacitive values which are available in both areas are allowed for the oscillator circuit (see marked area in the diagram). This analysis has to be done for every R_{X2} value. The final selection of the components should be done under consideration of the necessary safety level, frequency, quality of the start-up behaviour of the oscillator, start-up time of the oscillation and the specified load capacitance C_L of the crystal.

Note: It is not recommended to include the maximum of SF (R_{Qmax}) because in many cases the gradient of the characteristic curve between 0 pF and 3 pF is very high. If C_{X1} and C_{X2} were chosen in that area, small parameter variations of the used components during production could reduce the safety level very fast. The consequence could be that the oscillator does not work in this case.
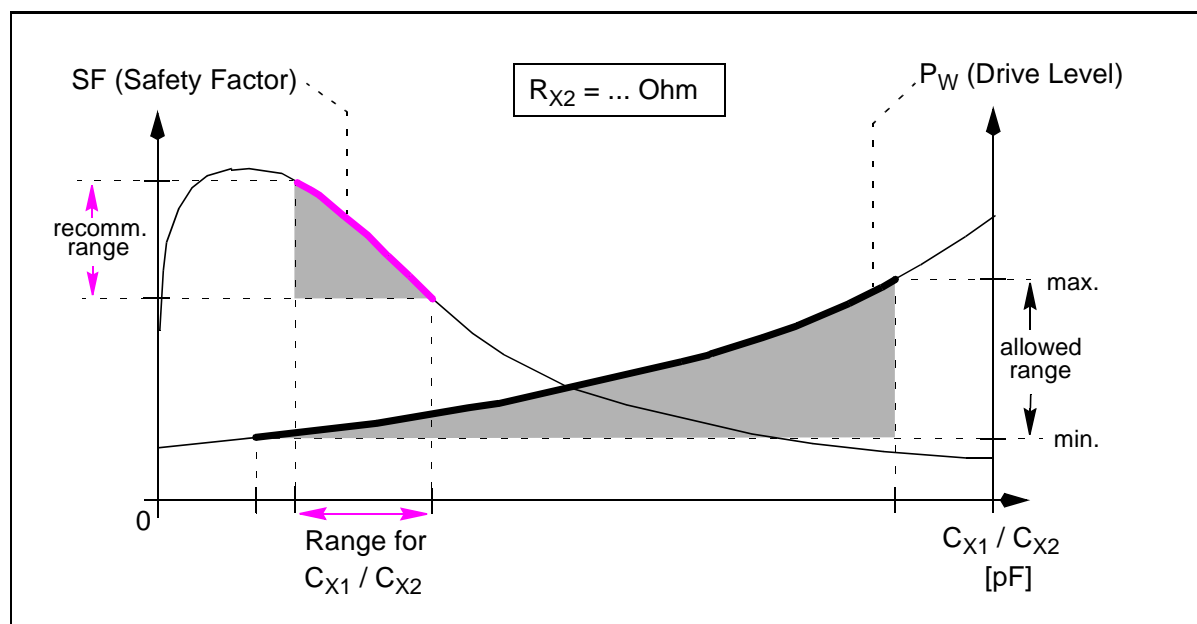
**Figure 6
Evaluation Diagram for C_{X1} and C_{X2}**

7   Oscillator Circuitry Layout Recommendations

The layout of the oscillator circuit is important for the RF and EMC behaviour of the design. The use of this recommendation can help to reduce problems caused by the layout. This design recommendation is optimized on EMC aspects.

For an optimal layout the following items have to be noted:

7.1   Avoidance of Capacitive Coupling

The crosstalk between oscillator signals and others has to be minimized. Sensitive inputs have to be separated from outputs with a high amplitude.

Note: The crosstalk between different layers also has to be analyzed.

7.2   Ground Connection of the Crystal Package

The connection of the crystal package to the ground plane directly underneath the crystal and to the ground layer via an interlayer connection has the following advantages:

- The crystal metal package reduces the electromagnetic emission.
- The mechanical stability of the crystal can be increased.

The ground layer and the additional ground plane underneath the crystal shield the oscillator. This shielding decouples all signals on the other PCB side.

7.3   Avoidance of 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 (also not on different layers!).

7.4   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 have to be avoided, because they are working like antennas.

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

7.5   Correct Module Placement

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

7.6   Layout Recommendation

**Figure 7
Layout Recommendation**

8   Recommendations of the Crystal Manufacturer Tele Quarz Group

The preceding chapters have shown a possibility of how to find the appropriate values for the circuit components of a crystal oscillator circuitry which ensure a problem-free operation. Similar tests were done in a cooperation between Siemens (HL DC AT) and Tele Quarz Group. This work is already performed for different Siemens microcontrollers. The specialists of Tele Quarz Group have done the analyses with the aid of the microcontroller development group of Siemens HL DC AT. The results of this cooperation are presented in the appendix of this Application Note. The cooperation will be continued and the results will be added to this Application Note step by step.

Note: The appendix shows recommendations for the appropriate circuit composition of the oscillator which run in most of all applications but they **do not release the system designer from a verification in the original system** 💣. It is mandatory to perform own investigations concerning the safety factor to get a problem-free operation of the oscillator. This is necessary because every design has a specific influence on the oscillator (noise, layout etc.).

9   Used Short Cuts

C_0 : Shunt capacitance of the quartz crystal (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 motional capacitance of the quartz crystal
C_L : Load capacitance of the system resp. quartz crystal
C_S : Stray capacitance of the system
C_{X1}, C_{X2} : Load capacitors
C_X : Capacitance to suppress bias voltage at XTAL2 output.
C_{X2rest} : Capacitance of C_{X2} in combination with L_X in 3rd overtone mode
C_B : Decoupling capacitance for V_{CC} and V_{SS} on the Printed Circuit Board (PCB).
Depending on the EMC behaviour the value should be in the range: 22nF to 100nF

f_{LXCX2} : Parallel resonance frequency of L_X and C_{X2}
f_{3rd} : Frequency of the 3rd overtone
f_{fund} : Frequency of the fundamental mode

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_X : Inductance for 3rd overtone mode

P_W : Drive level
Q : Quartz Crystal

R_1, R_r : Series resistance of the quartz crystal (resonance resistance) in other technical
descriptions also called: 'equivalent series resistance, ESR' or 'transformed
series resistance'). Mechanical equivalent is the moleculare friction, the damping
by mechanical mounting system and accustical damping by the gasfilled housing.
R_{1typ} : Typical value of the series resistance at room temperature
R_{1max} : Maximum value of the series resistance at room temperature
R_{1max} (TK) : Maximum value of the series resistance at the specified temperatur range.
This value ist the base for calculation of the SF in this application note.
R_{Ltyp}, R_{Lmax} : Typical and maximum load resonance resistor (in other technical descriptions
also called: 'effective resistance')
R_Q : Test resistor for calculation of safety level
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} : Resistor which controls the drive level (damping resistor)
R_f : Additional external feedback resistor to stabilize DC point (trouble shooting)

SF : Safety Factor
t_{st_up} : Start-up time of the oscillator
t_{off} : Oscillator off time for measurement of start-up behaviour
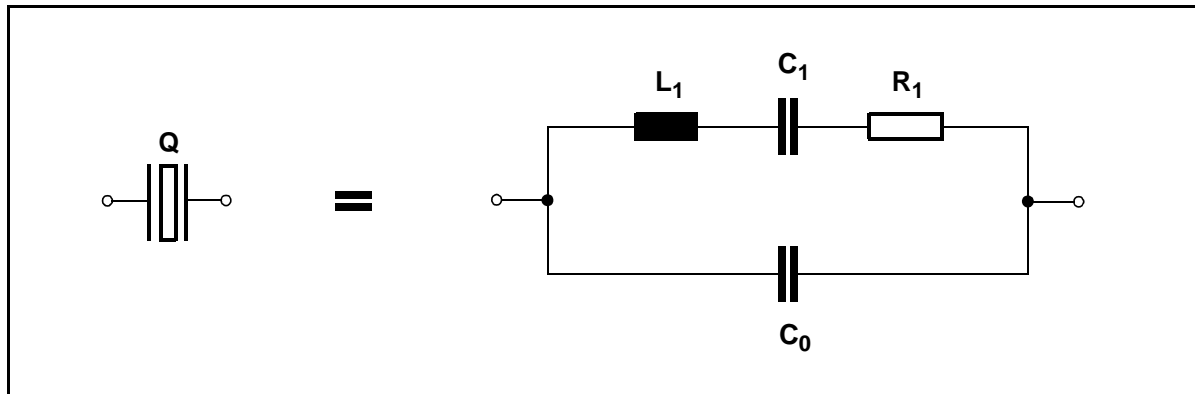
Figure 8
Equivalent Circuit of a Quartz Crystal

10 General Information using the Appendix

The Appendix includes recommendations for the right composition on external circuits for the C500 and C166 family. Each recommendation for the external circuits is only **one** of more different possibilities. The decision which composition is the right one, is not 'digital' (go or not go) but has to be done in a 'analog' way which offers more different results which fits to the system. The system designer has to decide which criterion of the application system concerning the oscillator has to be considered: safety factor, start-up behaviour, drive level, quartz crystal specification, frequency, EMC, layout demands etc. These facts are the base for the trade-off which external circuits fit best to the individual application system.

The most important topic of the oscillator is the safety factor which gives the system designer a feeling about the start-up quality of the oscillator. The recommendations in the appendix show one possibility for the external circuits which is optimized to the start-up behaviour respectively the safety factor and the used type of quartz crystal.

For microcontroller and quartz crystals which are not included in the tables please determine the safety factor in the target system as described in this Application Note.

11   Appendix C500 Family

All derivatives, steps and oscillator-inverter types of the C500 family shown in the table below are included in the recommendations of the following pages. For each type of oscillator-inverter there is given a proposal for the right composition on external circuits refered to different frequencies.

11.1 C500 Family: Relation between Oscillator-Inverter Type and Device Type

Table 4
C500 Family Derivatives and Oscillator-Inverter Type

Device	Step	Inverter
SAx-C505A-4E	AA	Type_A
SAx-C505C-2E	AA	Type_A
SAx-C505CA-4E	AA	Type_A
SAx-C513A-L / -R / -2R	BB	Type_A
SAx-C515C-L / -8R	AA	Type_B
SAx-80C517 SAx-80C537	DB	Type_B
SAx-C509L	DA, DB	Type_C

11.2 C500 Family: Type_A Oscillator-Inverter

The table below contains the recommendations for the external circuitry using a Type_A oscillator-inverter in fundamental mode. The quartz crystal data are included which are necessary for the calculation of the drive level (P_W) and safety factor (SF). The quartz crystal data are related to the quartz crystals of appendix Quartz Crystals. The measured values of R_{Qmax} and the calculated values of P_W and SF are based on these quartz crystals and the formulas presented in this ApNote.

**Table 5
C166 Family Derivatives including a Type_A Oscillator-Inverter**

Device	Step	Oscillator Frequency	XTAL1	XTAL2
SAx-C505A-4E	AA	2 - 20 MHz	Input	Output
SAx-C505C-2E	AA	2 - 20 MHz	Input	Output
SAx-C505CA-4E	AA	2 - 20 MHz	Input	Output
SAx-C513A-L / -R / -2R	BB	3,5 - 12 MHz	Input	Output

**Table 6
Recommendations for external circuitry used with a Type_A Oscillator-Inverter in Fundamental Mode**

Fundamental Mode:			Type_A Oscillator-Inverter							
	External Circuits			Quartz Crystal Data							
Frequency [MHz]	R_{X2} [Ω]	C_{X1} [pF] (Input)	C_{X2} [pF] (Output)	C_L [pF]	C_{0typ} [pF]	R_{1typ} [Ω]	R_{1max} [Ω]	R_{1max} (TK) [Ω]	P_W [μW] (@ 25°C, R_{1typ})	R_{Qmax} [Ω]	Safety Factor SF
20	56	8,2	15	10	4	20	60	80	230	560	3,57
18	56	8,2	18	14	4	20	60	80	356	560	4,23
16	100	8,2	22	13	4	20	60	80	310	560	4,09
12	100	8,2	33	13	4	30	70	90	190	820	5,33
10	150	10	33	14	3	30	80	100	160	820	5,56
8	150	10	33	15	3	35	80	100	150	1200	8,33
6	390	10	33	14	3	35	80	140	120	2700	13,08
5	390	12	33	18	3	35	80	140	50	3900	20,47
4	390	12	33	16	4	20	80	150	40	5600	23,89

11.3 C500 Family: Type_B Oscillator-Inverter

The table below contains the recommendations for the external circuitry using a Type_B oscillator-inverter in fundamental mode. The quartz crystal data are included which are necessary for the calculation of the drive level (P_W) and safety factor (SF). The quartz crystal data are related to the quartz crystals of appendix Quartz Crystals. The measured values of R_{Qmax} and the calculated values of P_W and SF are based on these quartz crystals and the formulas presented in this ApNote.

Table 7
C166 Family Derivatives including a Type_B Oscillator-Inverter

Device	Step	Oscillator Frequency	XTAL1	XTAL2
SAx-C515C-L / -8R	AA	2 - 10 MHz	Output (C_{X2})	Input (C_{X1})
SAx-80C517 SAx-80C537	DB	3,5 - 16 MHz	Input (C_{X1})	Output (C_{X2})

Table 8
Recommendations for external circuitry used with a Type_B Oscillator-Inverter in Fundamental Mode

Fundamental Mode:	Type_B Oscillator-Inverter										
	External Circuits			Quartz Crystal Data							
Frequency [MHz]	R_{X2} [Ω]	C_{X1} [pF] (Input)	C_{X2} [pF] (Output)	C_L [pF]	C_{0typ} [pF]	R_{1typ} [Ω]	R_{1max} [Ω]	R_{1max} (TK) [Ω]	P_W [µW] (@ 25°C, R_{1typ})	R_{Qmax} [Ω]	Safety Factor SF
16	0	6,8	12	13	4	20	60	80	333	560	4,09
12	56	10	18	13	4	30	70	90	249	560	3,64
10	100	10	27	14	3	30	80	100	190	680	4,61
8	100	10	27	15	3	35	80	100	160	820	5,69
6	150	10	33	14	3	35	80	140	133	1500	7,27
5	150	12	33	18	3	35	80	140	65	1800	9,45
4	150	12	33	16	4	20	80	150	45	3300	14,08

11.4 C500 Family: Type_C Oscillator-Inverter

The table below contains the recommendations for the external circuitry using a Type_C oscillator-inverter in fundamental mode. The quartz crystal data are included which are necessary for the calculation of the drive level (P_W) and safety factor (SF). The quartz crystal data are related to the quartz crystals of appendix Quartz Crystals. The measured values of R_{Qmax} and the calculated values of P_W and SF are based on these quartz crystals and the formulas presented in this ApNote.

**Table 9
C166 Family Derivatives including a Type_C Oscillator-Inverter**

Device	Step	Oscillator Frequency	XTAL1	XTAL2
SAx-C509L	DA, DB	3,5 - 16 MHz	Output (C_{X2})	Input (C_{X1})

**Table 10
Recommendations for external circuitry used with a Type_C Oscillator-Inverter in Fundamental Mode**

Fundamental Mode:	Type_C Oscillator-Inverter										
	External Circuits			Quartz Crystal Data							
Frequency [MHz]	R_{X2} [Ω]	C_{X1} [pF] (Input)	C_{X2} [pF] (Output)	C_L [pF]	C_{0typ} [pF]	R_{1typ} [Ω]	R_{1max} [Ω]	R_{1max} (TK) [Ω]	P_W [μW] (@ 25°C, R_{1typ})	R_{Qmax} [Ω]	Safety Factor SF
16	56	6,8	12	13	4	20	60	80	313	820	5,99
12	100	8,2	18	13	4	30	70	90	231	1000	6,50
10	100	10	27	14	3	30	80	100	210	1000	6,78
8	100	10	27	15	3	35	80	100	165	1500	10,42
6	150	10	33	14	3	35	80	140	150	1800	8,72
5	150	12	33	18	3	35	80	140	60	3300	17,32
4	150	12	33	16	4	20	80	150	50	3900	16,64

12   Appendix C166 Family

All derivatives, steps and oscillator-inverter types of the C166 family shown in the table below are included in the recommendations of the following pages. For each type of oscillator inverter there is given a proposal for the right composition on external circuits refered to different frequencies.

12.1   C166 Family: Relation between Oscillator-Inverter Type and Device Type

**Table 11
C166 Family Derivatives and Oscillator-Inverter Type**

Device	Step	Inverter
SAx-C163-LF	AB	Type_R
SAx-C165-LF	CA	Type_R
SAx-C165-LM	CA	Type_R
SAB-80C166(W)-M-Tx	CB, DA, DB, DC	Type_R
SAB-83C166(W)-M-Tx	CB, DA, DB, DC	Type_R
SAx-C167-LM	BA, BB, BC	Type_R
SAx-C167S-4RM	AA, AE, BA, BB, DA, DB	Type_R
SAx-C167SR-LM	AB, BA, CB, DA, DB	Type_R
SAx-C167CR-LM	AB, BA, BB, CA, CB, BE, DA, DB	Type_R
SAx-C167CR-4RM	AA, AB, AC, DA, DB	Type_R
SAx-C167CR-16RM	AA	Type_R
SAx C161RI	AA	Type_LP1
SAx C161CI	AA	Type_LP2 Type_RTC1
SAx C161RI	BA	Type_LP2
SAx C164CI	BA	Type_LP2

12.2   C166 Family: Type_R Oscillator-Inverter

The table below shows the derivatives including a Type_R oscillator-inverter. The tables on the next two pages include the recommendations for fundamental mode and 3rd overtone mode.

**Table 12
C166 Family Derivatives including a Type_R Oscillator-Inverter**

Device	Step	Oscillator Frequency
SAx-C163-LF	AB	3,5 - 24 (40) MHz
SAx-C165-LF	CA	3,5 - 24 (40) MHz
SAx-C165-LM	CA	3,5 - 24 (40) MHz
SAB-80C166(W)-M-Tx	CB, DA, DB, DC	3,5 - 24 (40) MHz
SAB-83C166(W)-M-Tx	CB, DA, DB, DC	3,5 - 24 (40) MHz
SAx-C167-LM	BA, BB, BC	3,5 - 24 (40) MHz
SAx-C167S-4RM	AA, AE, BA, BB, DA, DB	3,5 - 24 (40) MHz
SAx-C167SR-LM	AB, BA, CB, DA, DB	3,5 - 24 (40) MHz
SAx-C167CR-LM	AB, BA, BB, CA, CB, BE, DA, DB	3,5 - 24 (40) MHz
SAx-C167CR-4RM	AA, AB, AC, DA, DB	3,5 - 24 (40) MHz
SAx-C167CR-16RM	AA	3,5 - 24 (40) MHz

12.2.1 C166 Family: Type_R Oscillator-Inverter Fundamental Mode

The table below contains the recommendations for the external circuitry using a Type_R oscillator-inverter in fundamental mode. The quartz crystal data are included which are necessary for the calculation of the drive level (P_W) and safety factor (SF). The quartz crystal data are related to the quartz crystals of appendix Quartz Crystals. The measured values of R_{Qmax} and the calculated values of P_W and SF are based on these quartz crystals and the formulas presented in this ApNote.

Table 13
Recommendations for external circuitry used with a Type_R Oscillator-Inverter in Fundamental Mode

Fundamental Mode:	Type_R Oscillator-Inverter										
	External Circuits			Quartz Crystal Data							
Frequency [MHz]	R_{X2} [Ω]	C_{X1} [pF] (Input)	C_{X2} [pF] (Output)	C_L [pF]	C_{0typ} [pF]	R_{1typ} [Ω]	R_{1max} [Ω]	R_{1max} (TK) [Ω]	P_W [µW] (@ 25°C, R_{1typ})	R_{Qmax} [Ω]	Safety Factor SF
40	0	12	15	13	5	10	50	60	420	300	2,60
32	0	12	15	11	5	15	50	60	520	390	3,07
24	180	15	22	12	5	15	50	60	510	390	3,24
20	390	8,2	39	10	4	20	60	80	375	560	3,57
18	390	12	39	14	4	20	60	80	335	540	4,08
16	390	12	47	13	4	20	60	80	353	580	4,24
12	390	12	47	13	4	30	70	90	312	1000	6,50
10	390	15	47	14	3	30	80	100	216	1200	8,14
8	390	15	47	15	3	35	80	100	372	1800	12,50
6	390	15	47	14	3	35	80	140	100	2200	10,66
5	390	22	47	18	3	35	80	140	110	2700	14,17
4	390	22	47	16	4	20	80	150	46	3300	14,08

12.2.2 C166 Family: Type_R Oscillator-Inverter 3rd Overtone Mode

The table below contains the recommendations for the external circuitry using a Type_R oscillator-inverter in 3rd overtone mode. The quartz crystal data are included which are necessary for the calculation of the drive level (P_W) and safety factor (SF). The quartz crystal data are related to the quartz crystals of appendix Quartz Crystals. The measured value of R_{Qmax} and the calculated values of P_W and SF are based on these quartz crystals and the formulas presented in this ApNote.

**Table 14
Recommendations for external circuitry used with a Type_R Oscillator-Inverter in
3rd Overtone Mode**

3rd Overtone Mode:					Type_R Oscillator-Inverter							
	External Circuits					Quartz Crystal Data						
Frequency [MHz]	R_{X2} [Ω]	C_{X1} [pF] (Input)	C_{X2} [pF] (Output)	C_X [nF]	L_X [µH]	C_L [pF]	C_{0typ} [pF]	R_{1typ} [Ω]	R_{1max} [Ω]	R_{1max} (TK) [Ω]	P_W [µW] (@ 25°C , R_{1typ})	R_{Qmax} [Ω]	Safety Factor SF
40	100	5,6	10	10	4,7	7	5	12	35	40	700	560	4,76

12.3   C166 Family: Type_LP1 Oscillator-Inverter

The table below contains the recommendations for the external circuitry using a Type_LP1 oscillator-inverter in fundamental mode. The quartz crystal data are included which are necessary for the calculation of the drive level (P_W) and safety factor (SF). The quartz crystal data are related to the quartz crystals of appendix Quartz Crystals. The measured values of R_{Qmax} and the calculated values of P_W and SF are based on these quartz crystals and the formulas presented in this ApNote.

Table 15
C166 Family Derivatives including a Type_LP1 Oscillator-Inverter

Device	Step	Oscillator Frequency
SAx C161RI	AA	3,5 - 16 MHz

Table 16
Recommendations for external circuitry used with a Type_LP1 Oscillator-Inverter in Fundamental Mode

Fundamental Mode:	Type_LP1 Oscillator-Inverter										
	External Circuits			Quartz Crystal Data							
Frequency [MHz]	R_{X2} [Ω]	C_{X1} [pF] (Input)	C_{X2} [pF] (Output)	C_L [pF]	C_{0typ} [pF]	R_{1typ} [Ω]	R_{1max} [Ω]	R_{1max} (TK) [Ω]	P_W [μW] (@ 25°C, R_{1typ})	R_{Qmax} [Ω]	Safety Factor SF
16	0	4,7	4,7	13	4	20	60	80	270	8200	> 40
12	0	8,2	8,2	13	4	30	70	90	230	> 10000	> 40
10	0	10	12	14	3	30	80	100	121	> 10000	> 40
8	0	15	22	15	3	35	80	100	140	> 10000	> 40
6	0	15	22	14	3	35	80	140	170	> 10000	> 40
5	0	15	22	18	3	35	80	140	120	> 10000	> 40
4	0	15	22	16	4	20	80	150	80	> 10000	> 40

12.4 C166 Family: Type_LP2 Oscillator-Inverter

The table below contains the recommendations for the external circuitry using a Type_LP2 oscillator-inverter in fundamental mode. The quartz crystal data are included which are necessary for the calculation of the drive level (P_W) and safety factor (SF). The quartz crystal data are related to the quartz crystals of appendix Quartz Crystals. The measured values of R_{Qmax} and the calculated values of P_W and SF are based on these quartz crystals and the formulas presented in this ApNote.

Table 17
C166 Family Derivatives including a Type_LP2 Oscillator-Inverter

Device	Step	Oscillator Frequency
SAx C161CI	AA	3,5 - 16 MHz
SAx C161RI	BA	3,5 - 16 MHz
SAx C164CI	BA	3,5 - 16 MHz

Table 18
Recommendations for external circuitry used with a Type_LP2 Oscillator-Inverter in Fundamental Mode

Fundamental Mode:			Type_LP2 Oscillator-Inverter							
	External Circuits			Quartz Crystal Data						
Frequency [MHz]	R_{X2} [Ω]	C_{X1} [pF] (Input)	C_{X2} [pF] (Output)	C_L [pF]	C_{0typ} [pF]	R_{1typ} [Ω]	R_{1max} [Ω]	R_{1max} (TK) [Ω]	P_W [μW] (@ 25°C, R_{1typ})	R_{Qmax} [Ω]	Safety Factor SF
16	0	2,7	2,7	13	4	20	60	80	150	1200	8,77
12	0	3,3	4,7	13	4	30	70	90	110	2200	14,29
10	0	4,7	8,2	14	3	30	80	100	120	2200	14,92
8	0	5,6	12	15	3	35	80	100	100	3300	22,92
6	0	8,2	15	14	3	35	80	140	130	4700	22,77
5	0	10	18	18	3	35	80	140	80	5600	29,39
4	0	12	22	16	4	20	80	150	60	6800	29,01

12.5   C166 Family: Type_RTC1 Oscillator-Inverter

The table below contains the recommendations for the external circuitry using a Type_RTC1 oscillator-inverter in fundamental mode. The quartz crystal data are included which are necessary for the calculation of the safety factor (SF). The quartz crystal data are related to the quartz crystals of appendix Quartz Crystals. The measured value of R_{Qmax} and the calculated value of SF are based on these quartz crystals and the formulas presented in this ApNote.

**Table 19
C166 Family Derivatives including a Type_RTC1 Oscillator-Inverter**

Device	Step	Oscillator Frequency	XTAL3	XTAL4
SAx C161CI	AA	32,768 kHz	Input (C_{X1})	Output (C_{X2})

**Table 20
Recommendations for external circuitry used with a RTC1 Oscillator-Inverter in Fundamental Mode**

Fundamental Mode:		**Type_RTC1 Oscillator-Inverter**							
	External Circuits			**Quartz Crystal Data**					
Frequency [kHz]	R_{X2} [Ω]	C_{X1} [pF] (Input)	C_{X2} [pF] (Output)	C_L [pF]	C_{0typ} [pF]	R_{1typ} [Ω]	R_{1max} [Ω]	$R_{1max (TK)}$ [Ω]	R_{Qmax} [Ω]	Safety Factor SF
32,768	0	6,8	10	12,5	1	12000	35000	35000	330000	8,08

13   Quartz Crystals for the C500 and C166 Family

13.1   Fundamental Mode Quartz Crystal for Standard Temperature Range

Table 21
Quartz Crystals for all Oscillator-Inverter used in Fundamental Mode
Standard Temperature Range from - 20°C to 70°C

Quartz Crystal Specification for Fundamental Mode:			TELE QUARZ GROUP	
Frequency [MHz]	HC49		HC52	
	Can hight 6.6mm low profile SH66	Can hight 13.5mm SMD-Mounting with Clip CS20	Can hight 8.8mm Standard-Enclosure	Can hight 8.8mm SMD-Mounting with Clip CS10
40	C167CR40	C167CR40S	C167CR40A	C167CR40AS
32	C167CR32	C167CR32S	C167CR32A	C167CR32AS
24	C167CR24	C167CR24S	C167CR24A	C167CR24AS
20	C167CR20	C167CR20S	C167CR20A	C167CR20AS
18	C167CR18	C167CR18S	C167CR18A	C167CR18AS
16	C167CR16	C167CR16S	C167CR16A	C167CR16AS
12	C167CR12	C167CR12S	C167CR12A	C167CR12AS
10	C167CR10	C167CR10S	C167CR10A	C167CR10AS
8	C167CR08	C167CR08S	C167CR08A	C167CR08AS
6	C167CR06	C167CR06S	C167CR06A	C167CR06AS
5	C167CR05	C167CR05S	C167CR05A	C167CR05AS
4	---	C167CR04S	---	---
The specifications C167CRxxxx are for the use in standard temperature range from - 20°C to 70°C. For further information please contact your local Tele Quarz Group sales office.				

13.2 Fundamental Mode Quartz Crystal for Advanced Temperature Range

Table 22
Quartz Crystals for all Oscillator-Inverter used in Fundamental Mode
Advanced Temperature Range from - 40°C to 125°C for Automotive Applications

Quartz Crystal Specification for Fundamental Mode:			TELE QUARZ GROUP	
	HC49		**HC52**	
Frequency [MHz]	Can hight 6.6mm low profile SH66	Can hight 13.5mm SMD-Mounting with Clip CS20	Can hight 8.8mm Standard-Enclosure	Can hight 8.8mm SMD-Mounting with Clip CS10
20	KFZ0010	KFZ0010S	KFZ0010A	KFZ0010AS
18	KFZ0011	KFZ0011S	KFZ0011A	KFZ0011AS
16	KFZ0012	KFZ0012S	KFZ0012A	KFZ0012AS
12	KFZ0013	KFZ0013S	KFZ0013A	KFZ0013AS
10	KFZ0014	KFZ0014S	KFZ0014A	KFZ0014AS
8	KFZ0015	KFZ0015S	KFZ0015A	KFZ0015AS
6	KFZ0016	KFZ0016S	KFZ0016A	KFZ0016AS
5	KFZ0017	KFZ0017S	KFZ0017A	KFZ0017AS
4	---	KFZ0018S	---	---
The specifications KFZ00xxxx are for the use in advanced temperature range from - 40°C to 125°C for automotive applications. For further information please contact your local Tele Quarz Group sales office.				

13.3   3rd Overtone Mode Quartz Crystal for Standard Temperature Range

Table 23
Quartz Crystals for all Oscillator-Inverter used in 3rd Overtone Mode
Standard Temperature Range from - 20°C to 70°C

Quartz Crystal Specification for 3rd Overtone Mode:				
	HC49		**HC52**	
Frequency [MHz]	Can hight 6.6mm low profile SH66	Can hight 13.5mm SMD-Mounting with Clip CS20	Can hight 8.8mm Standard-Enclosure	Can hight 8.8mm SMD-Mounting with Clip CS10
40	---	C167CR403S	C167CR403A	C167CR403AS
The specifications C167CR403xx are for the use in standard temperature range from **- 20°C to 70°C**. For further information please contact your local Tele Quarz Group sales office.				

13.4   3rd Overtone Mode Quartz Crystal for Advanced Temperature Range

Table 24
Quartz Crystals for all Oscillator-Inverter used in 3rd Overtone Mode
Advanced Temperature Range from - 40°C to 125°C for Automotive Applications

Quartz Crystal Specification for 3rd Overtone Mode:				
	HC49		**HC52**	
Frequency [MHz]	Can hight 6.6mm low profile SH66	Can hight 13.5mm SMD-Mounting with Clip CS20	Can hight 8.8mm Standard-Enclosure	Can hight 8.8mm SMD-Mounting with Clip CS10
40	---	KFZ0009S	KFZ0009A	KFZ0009AS
The specifications KFZ0009xx are for the use in advanced temperature range from **- 40°C to 125°C** for automotive applications. For further information please contact your local Tele Quarz Group sales office.				

13.5   Real Time Clock Quartz Crystal

Table 25
Quartz Crystals for RTC Oscillator-Inverter used in Fundamental Mode
Standard Temperature Range from - 20°C to 70°C

Quartz Crystal Specification for Fundamental Mode:	
Frequency [kHz]	Ordering Code
32.768	TC38 12,5
For further information please contact your local Tele Quarz Group sales office.	

14   TELE QUARZ GROUP Sales Offices

For more information on TELE QUARZ GROUP
please call your local TELE QUARZ GROUP sales office.

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