Application Note

Title: **Crystal choice and frequency calculation for EM9301**

Product Family: **Wireless & Sensing**

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This document provides a description on the important parameters to be considered when choosing a crystal for EM9301 *Bluetooth*[1] low energy controller operation.

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[1] *Bluetooth* is a trademark owned by the *Bluetooth* Special Interest Group (SIG).

Foreword

The EM9301 is a low-voltage, low-power, fully-integrated, single-chip *Bluetooth*[1] Low Energy (BLE) controller designed to support both BLE master and slave roles according to the *Bluetooth* specification V4.0.
It integrates Xtal oscillator designed for a wide variety of low-cost and widely-spread 26MHz quartz crystals which provides the reference clock for the EM9301 logic and RF blocks then ensures *Bluetooth* timing requirements.
In so-called sleep mode this xtal block is switched off, and an internal RC oscillator is used in order to achieve a further current consumption reduction.
Therefore, and as shown in the EM9301 reference below, only one quartz crystal is necessary for the BLE operation with EM9301 in both master and sleep mode configurations. The requirements of this 26MHz quartz crystal will be discussed in details in this document.

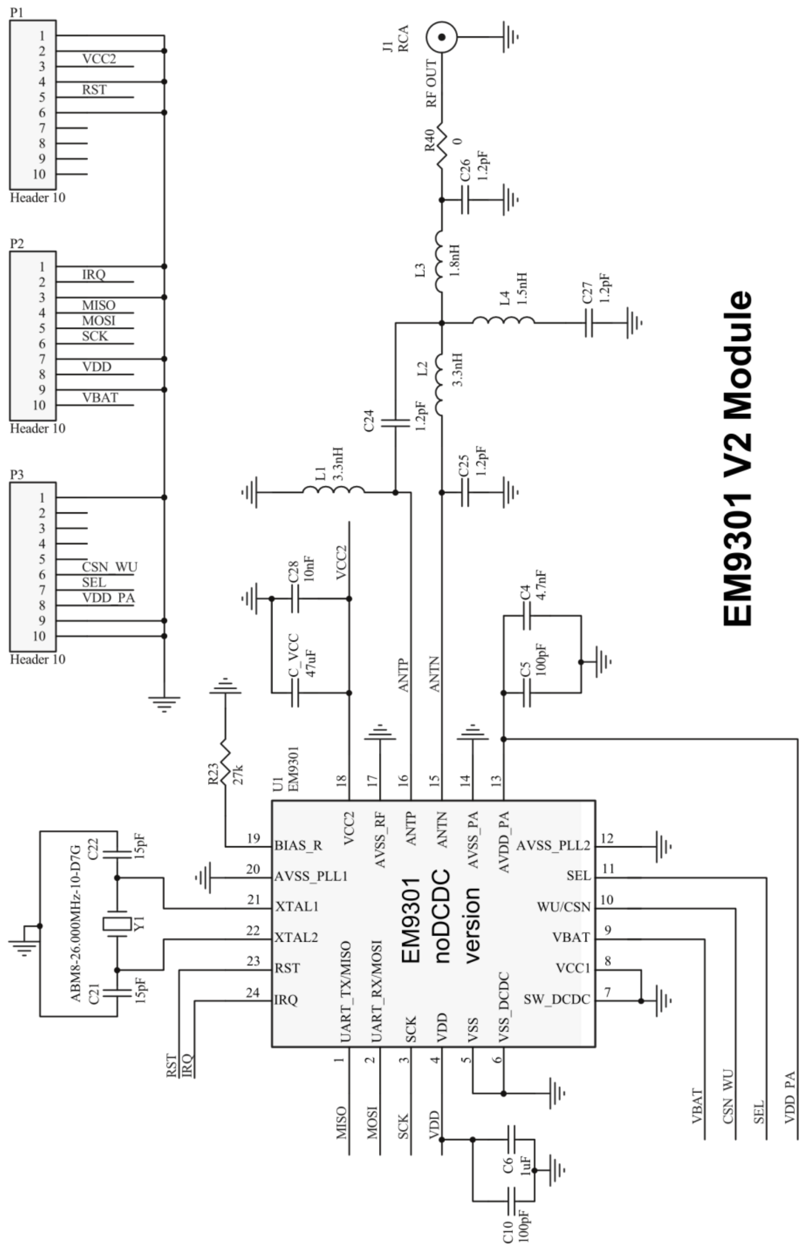

Figure 1: EM9301 reference design electrical schematic.

26MHz xtal oscillator

EM9301 integrates a low-power, low-noise, fast-starting crystal oscillator designed for using a wide variety of low-cost and widely-spread 26MHz quartz crystals. This flexibility is achieved by the integration of an amplitude-control circuit which ensures optimal low-power and low-noise operation. Figure 2 shows a simplified block diagram of the EM9301 Xtal oscillator.

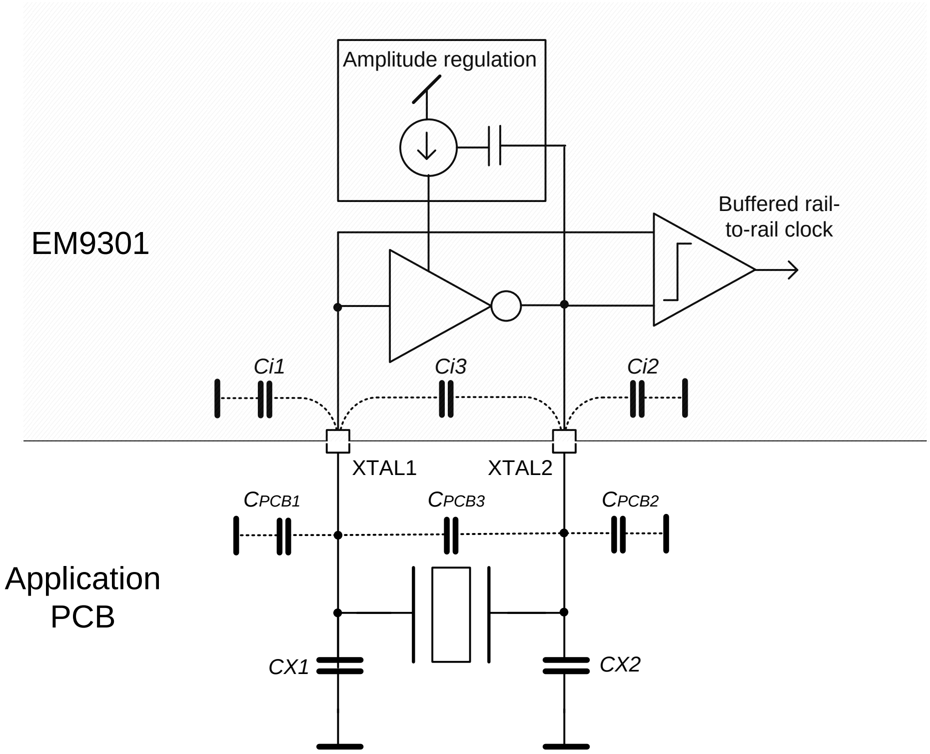

Figure 2: Xtal Block diagram

C_{i1} and C_{i2}, the internal capacitances on XTAL1 and XTAL2 pads, vary from 1.5 to 3pF, and C_{i3}, the shunt capacitance, from 0.4 to 0.9pF. C_{PBC1} and C_{PCB2} represent the parasitic capacitance on the XTAL1 and XTAL2 due to the application PCB, and C_{PCB3} the shunt capacitance on the PCB between those two pads. Of course those parasitic capacitance values might vary from one PCB design to another. Estimation is that on most of the PCBs, C_{PCB1} and C_{PCB2} vary from 0.7 to 1.5pF from 0.05 to 0.5pF. Special care has to be put during PCB design phase to reduce or at least control these parasitic capacitance.

This oscillator provides the reference clock for RF and digital operation on the EM9301 and meets low phase noise, low current consumption, fast start-up time, and *Bluetooth* frequency precision requirements. The first three requirements are guaranteed by the oscillator and post-amplifier architectures; the frequency precision depends on the tolerances of the specific quartz crystal and on the variations of the internal and external capacitances on the nodes XTAL1 and XTAL2.

26MHz crystal accuracy requirements

Bluetooth operation leads to a frequency precision of 50ppm and the specifications for the quartz crystal as well as for the external capacitors CX1 and CX2 are driven by this requirement.

The total possible frequency deviation will be the addition of the following possible tolerances:
1. Quartz frequency tolerance
2. Quartz frequency deviation with temperature
3. Quartz aging tolerance
4. Frequency deviation due to the tolerances of the external capacitances CX1 and CX2 and of the parasitic capacitances.

The first three influences can be specified when ordering the quartz crystal and the fourth one has to be calculated. The calculation is presented in the following section.

Frequency deviation calculation

Figure 3 shows an electrical model of a quartz crystal: L_m, R_m and C_m are respectively the so-called "motional" inductivity, resistivity and capacitance; C_0 is the packaging parasitic shunt capacitance. These parameters are strongly dependant on the quartz size and on the manufacturing technology.

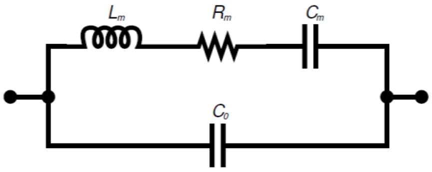

Figure3: Quartz crystal electrical model

The "motional" or series resonance frequency is defined as:

$$f_m = \frac{1}{2\pi\sqrt{C_m L_m}} \quad [\text{Hz}]$$

and the crystal quality factor as:

$$Q = \frac{2\pi f_m L_m}{R_m} = \frac{1}{2\pi f_m C_m R_m}$$

For the EM9301 oscillator, the oscillation frequency at a given equivalent parallel capacitive load C_P is approximately given by:

$$f \approx f_m \left[1 + \frac{C_m}{2(C_0 + C_P)} \right] \quad [\text{Hz}]$$

C_P can be calculated as:

$$C_P = \frac{1}{\frac{1}{Ci1 + C_{PCB1} + CX1} + \frac{1}{Ci2 + C_{PCB2} + CX2}} + Ci3 + C_{PCB3} \quad [\text{F}]$$

with $Ci1$, $Ci2$ and $Ci3$ the on-chip capacitances; C_{PCB1}, C_{PCB2} and C_{PCB3} the PCB parasitic capacitances; and $CX1$ and $CX2$ the external capacitances on the nodes XTAL1 and XTAL2.

C_m and C_0 will be mainly dependant on the crystal size: the smaller the crystal, the smaller the values of C_m and C_0.

The nominal load capacitance C_L has to be specified and the crystal manufacturer will cut the crystal quartz to obtain the specified nominal frequency f_0 when the equivalent parallel capacitance is equal to C_L:

$$f_0 \approx f_m \left[1 + \frac{C_m}{2(C_0 + C_L)} \right] \quad [\text{Hz}]$$

The frequency deviation with respect to the nominal oscillation frequency will then be given by:

$$\frac{\Delta f}{f_0} = \frac{f - f_0}{f_0} \approx \frac{1 + \frac{C_m}{2(C_0 + C_P)}}{1 + \frac{C_m}{2(C_0 + C_L)}} - 1$$

This formula allows to determine the maximal frequency deviations that can occur when using a given crystal and considering the variations of the equivalent parallel capacitance C_P.

Quartz crystal specifications

Table 1 shows the general specifications for the quartz crystals that can be used with the EM9301 Xtal oscillator. The particular specifications for each quartz crystal will depend on the available supplier options.

Parameter	Symbol	Min	Typ	Max	Unit
Resonance frequency with a parallel load C_L	f_0		26.000		MHz
Load Capacitance	C_L	8		18	pF
Series or “motional” resistance	R_m	10		200	Ohms
Quality factor	Q	10k		500k	
Operation mode			Fundamental		
Total oscillation frequency deviation	df/f_0	-50		+50	ppm

Table 1 Quartz general specifications

Two quartz specifications are given as reference: ABM8-26.000MHZ-10-D1G and ABM8-26.000-16-D7X from Abracon Corporation (www.abracon.com). The specifications for the former device are found in Table 2 and for the latter in Table 3. The EM9301 typical characteristics are measured using the ABM8-26.000MHZ-10-D1G quartz.

Parameter	symbol	Value	Unit
Parallel resonance frequency	f_0	26.000	MHz
Load Capacitance	C_L	10	pF
Series or “motional” resistance	R_m	5 - 50	Ohms
Shunt capacitance	C_0	0.7	pF
Center frequency tolerance	f_{0}_tol	+/-10	ppm
Frequency deviation with temperature	df_temp	+/-15	ppm
Frequency variation due to aging in 5 years	df_age	+/-5	ppm

Table 2 ABM8-26.000MHz-10-D1G Quartz specifications

Parameter	symbol	Value	Unit
Parallel resonance frequency	f_0	26.000	MHz
Load Capacitance	C_L	16	pF
Series or “motional” resistance	R_m	5 - 50	Ohms
Shunt capacitance	C_0	0.7	pF
Center frequency tolerance	f_{0}_tol	+/-15	ppm
Frequency deviation with temperature	df_temp	+/-20	ppm
Frequency variation due to aging in 5 years	df_age	+/-5	ppm

Table 3 ABM8-26.000MHz-16-D7X Quartz specifications

The specifications of these crystals indicate the initial frequency precision, and the impact of temperature and of the aging on the frequency accuracy. The influence of the crystal loading components has however to be calculated and taken into account. The calculation resulted and the impact on the overall frequency precision is presented below.

Global crystal accuracy

Table 4 and Table 5 show the maximal and minimal frequency deviations for the two reference crystals, the calculation is done using the equations presented in the previous section. Note that the load capacitance for the ABM8-26.000-16-D7X is higher that the one for the ABM8-26.000MHZ-10-D1G: this relaxes the specifications on the frequency tolerance and the deviation with the temperature for the crystal at the cost of higher oscillator current consumption and a longer start-up time.

		Min	Typ	Max	Units	
Crystal	f_0		26.000000		MHz	Nominal crystal frequency
	C_L		**10**		pF	Nominal load capacitance
	C_m		**3.0**		fF	Crystal motional capacitance
	C_0		**0.7**		pF	Crystal shunt capacitance
	f_0_tol.	**-10**		**10**	ppm	
	df_temp	**-15**		**15**	ppm	-40 deg. C to +85 deg. C
	df_age	**-5**		**5**	ppm	5 years
On-chip capacitances	*Ci1*	**1.5**		**3**	pF	Capacitance on XTAL1
	Ci2	**1.5**		**3**	pF	Capacitance on XTAL2
	Ci3	**0.4**		**0.9**	pF	Shunt capacitance
PCB	C_{PCB1}	**0.7**		**1.5**	pF	Capacitance on XTAL1
	C_{PCB2}	**0.7**		**1.5**	pF	Capacitance on XTAL2
	C_{PCB3}	**0.05**		**0.5**	pF	Shunt capacitance
Components	*CX1*	14.3	**15**	15.8	pF	**5%** Tolerance
	CX2	14.3	**15**	15.8	pF	**5%** Tolerance
Frequency	C_P	8.7		11.5	pF	Effective load capacitance
	TS	-17.5		19.8	ppm	Tuning sensitivity due to C_L *variations*
Frequency deviation		**-47.5**		**49.8**	**ppm**	Addition of all effects

Table 4 ABM8-26.000MHz-10-D1G Maximal and minimal frequency deviation

		Min	Typ	Max	Units	
Crystal	f_0		26.000000		MHz	Nominal crystal frequency
	C_L		**16**		pF	Nominal load capacitance
	C_m		**3.0**		fF	Crystal motional capacitance
	C_0		**0.7**		pF	Crystal shunt capacitance
	f_0_tol.	**-15**		**15**	ppm	
	df_temp	**-20**		**20**	ppm	-40 deg. C to +85 deg. C
	df_age	**-5**		**5**	ppm	5 years
On-chip capacitances	*Ci1*	**1.5**		**3**	pF	Capacitance on XTAL1
	Ci2	**1.5**		**3**	pF	Capacitance on XTAL2
	Ci3	**0.4**		**0.9**	pF	Shunt capacitance
PCB	C_{PCB1}	**0.7**		**1.5**	pF	Capacitance on XTAL1
	C_{PCB2}	**0.7**		**1.5**	pF	Capacitance on XTAL2
	C_{PCB3}	**0.05**		**0.5**	pF	Shunt capacitance
Components	*CX1*	25.7	**27**	28.4	pF	**5%** Tolerance
	CX2	25.7	**27**	28.4	pF	**5%** Tolerance
Frequency	C_P	14.4		17.8	pF	Effective load capacitance
	TS	-8.8		9.7	ppm	Tuning sensitivity due to C_L *variations*
Frequency deviation		**-48.8**		**49.7**	**ppm**	Addition of all effects

Table 5 ABM8-26.000MHz-16-D7X Maximal and minimal frequency deviation