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48MHZ XTAL SELECTION

Product Family: **EM9304**

Part Number: EM9304, 48Mhz crystal, HFXTAL, 50ppm

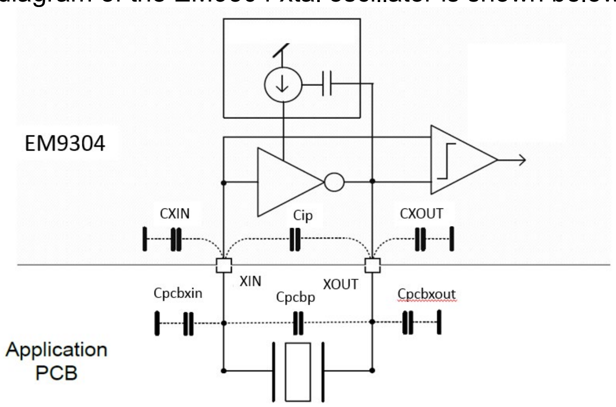
This document provides a description on the important parameters to be considered when choosing the HFXTAL for EM9304 BLE controller operation.

1. INTRODUCTION

The EMC9304 is a tiny, low-power, integrated circuit (IC) optimized for Bluetooth 5.0 low energy enabled product. It integrates an xtal oscillator designed for a variety of low-cost 48MHz quartz crystals which provide the reference clock for the EM9304 RF blocks ensuring Bluetooth timing requirements. For minimal external parts count the EM9304 integrates programmable xtal oscillator tuning caps on chip. In some systems a 48MHz reference clock that meets the ppm specifications if available can be used in place of a quartz crystal. For this app note we will only cover using the quartz crystal option.

2. 48MHZ XTAL OSCILLATOR

The EM9304 integrates a low-power, low-noise, fast-starting crystal oscillator designed for using a wide variety of low-cost quartz crystals. A simplified block diagram of the EM9304 xtal oscillator is shown below.



CXIN and CXOUT include the register trimmable on-chip tuning capacitors and the capacitances on XIN and XOUT pads. These caps have a 15% tolerance over PVT and can be set from 2.5pF-23pF. The onchip shunt capacitance between these pads can vary from 2.0pF-2.8pF. PCB capacitances can vary widely due to layout. Cpcbxin and Cpcbxout are estimated to be 1.1pF-1.3pF while the PCB shunt capacitor Cpcbp is estmated to be 0.1pF-0.3pF. Special care must be taken when laying out the PCB to reduce or at least control the parasitic capitances on the connections from the IC to the xtal.

The xtal oscillator provides the reference clock for RFoperation on the EM9304 and meets low phase noise, low current consumption, fast start-up time, and Bluetooth frequency precision requirements. The first three requiqrements are guaranteed by the oscillator block architecture; the frequency precision depends on the tolerances of the specific quartz crystal and on the variations of the internal and external capacitances on XIN and XOUT.

3. 48MHZ CRYSTAL ACCURACY REQUIREMENTS

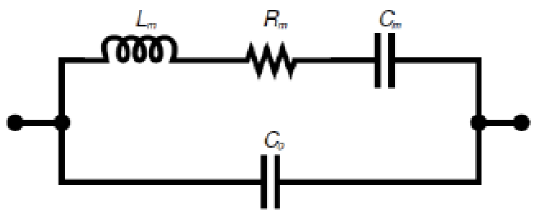
Bluetooth operation requires a frequency precision of 50ppm which dictates the specifications for the quartz crystal as well as the tuning and parasitic capacitances on the crystal terminals. The total possible frequency deviation will be the summation of the following possible tolerances:

1) Quartz frequency tolerance
2) Quartz frequency deviation with temperature
3) Quartz aging tolerance
4) Frequency deviation due to the tuning and parasitic capacitances on XIN and XOUT

The first three influences are specified when ordering the quartz crystal and the fourth one is calculated. This calculation is shown in the next section.

4. FREQUENCY DEVIATION CALC

The figure below shows an electrical model of a quartz crystal. L_m, R_m and C_m are the "motional" inductivity, resistivity and capacitance. C_0 is the packaging parasitic shunt capacitance. These parameters are strongly dependent on the quartz size and on the manufacturing technology.



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

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

The crystal quality factor is defined as:

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

Now given an equivalent parallel capacitive load C_P for the EM9304 oscillator we can approximate the oscillation frequency by:

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

We can calculate C_P given the capacitances shown on the schematic in section 2. This equation is

$$C_p = \frac{1}{\frac{1}{\text{Cpcbxin} + \text{CXIN}} + \frac{1}{\text{Cpcbxout} + \text{CXOUT}}} + \text{Cip} + \text{Cpcbp} \ [\text{F}]$$

CXIN, CXOUT and Cip are the on-chip capacitances while Cpcbxin, Cpcbxout and Cpcbp are the PCB parasitic capacitances.

C_m and C_0 will be mainly dependent on the crystal size. The smaller the size the smaller both these capacitances will be.

The nominal load capacitance C_L has to be specified and the manufacturer of the crystal will cut the 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 is 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 allows us to determine the maximum frequency deviation that can occur when using a given crystal along with the variations in the equivalent parallel capacitance C_P.

5. QUARTZ CRYSTAL SPECS

The following table are the requirements for the crystal to be used in systems with the EM9304.

Parameter	Symbol	Min	Typ	Max	Unit
Resonance frequency with a parallel load C_L	f_0		48.000		MHz
Operational mode			Fundamental		
Load Capacitance	C_L		10.0		pF
Equivalent series resistance	R_m			80	Ohms
Total oscillation frequency deviation	df/f_0	-50		50	ppm

The EM9304 data sheet recommends the NDK crystal NX1612SA which has the following specifications:

	Parameters	SYM.	Electrical Spec.				Notes
			min	typ	max	Units	
1	Nominal frequency	f_{nom}		48.000		MHz	
2	Overtone order	-		Fundamental		-	
3	Frequency tolerance	-	-10	-	+10	ppm	at +25°C
4	Frequency versus temperature characteristics	-	-15	-	+15	ppm	at -40~+85°C The reference temperature shall be +25°C
5	Equivalent resistance	-	-	21	80	Ω	IEC π-Network Series
6	Shunt capacitance	C_0	-30%	0.75	+30%	pF	Not grounded
7	Motional capacitance	C_1	-30%	2.05	+30%	fF	Not grounded
8	Motional inductance	L_1	-30%	5.40	+30%	mH	Not grounded
9	Load capacitance	C_L	-	10	-	pF	IEC π-Network
10	Level of drive	-	-	10	200	μW	
11	Pulling Sensitivity	PS	-30%	8.87	+30%	ppm/pF	CL=10pF/ Not grounded This value is calculated by following formula. $S=(C_1 \times 1{,}000)/\{2(C_0+C_L)^2\}$ [ppm/pF] Unit C_0:[pF], C_1:[fF], C_L:[pF]
12	Aging	-	-3	-	+3	ppm	1 year (at +25°C)
		-	-5	-	+5	ppm	5 years (at +25°C)
		-	-10	-	+10	ppm	10 years (at +25°C)
13	Insulation resistance	-	500	-	-	MΩ	When terminal to terminal and terminal to cover were applied at DC100V ±15V.
14	Operating temperature range	-	-40	-	+85	°C	
15	Storage temperature range	-	-40	-	+85	°C	
16	Recommended oscillation margin	-	500	-	-	Ω	When the circuit does not have enough value as above, please contact us.
17	Air-tightness	-	-	-	1.1×10^{-9}	Pa m³/s	Helium leak detector

The specifications of this crystal indicate the initial frequency precision, and the impact of temperature and of the aging for the frequency accuracy. The influence of the crystal loading components has to be calculated and taken into account in the overall frequency accuracy. A spreadsheet has been put together to tabulate contributors and calculate the overall accuracy for the EM9304 oscillator. This spreadsheet can be found on this forum under: Home → Resources → EM9304 Downloads → Tools → EM9304 48MHz frequency error calculator 0.1. The next section will show this spreadsheet used with the NDK NX1612SA quartz crystal.

6. GLOBAL CRYSTAL ACCURACY

The spreadsheet below uses the equations shown in section 4 and the manufactures specifications for the NDK NX1612SA crystal to calculate the global crystal accuracy for the EM9304 oscillator. The on-chip capacitors CXIN and CXOUT are set by a configuration register, and can be adjusted to better centre the total frequency deviation. This register is trimmed at wafer test and a nominal value is written to the EM9304's OTP memory. For crystals with different specifications this trim value may be changed which is discussed in a different app note.

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EM9304 xtal analysis

Date: 6/12/2018 10:54

		Min	Typ	Max	Units		
Crystal	f_0		**48.000000**		MHz	Nominal crystal frequency	
	C_L		**10.0**		pF	Nominal load capacitance	
	C_m		**2.05**		fF	Crystal motional capacitance	
	C_0	**0.53**	**0.75**	**0.98**	pF	Crystal shunt capacitance	
	R_m	**10.0**	**21.0**	**80.0**	Ω	Crystal motional resistance	
	f_0_tol.	**-10.0**		**10.0**	ppm	Tolerance @ 25 deg. C	
	df_temp	**-15.0**		**15.0**	ppm	Dev. over the operating temp. Range	
	df_age	**-5.0**		**5.0**	ppm	Ageing 5 years	
On-chip tuning capacitances	*CXIN*	11.5	**13.5**	15.5	pF	**15%** Tolerance	(2.5pF - 23pF)
	CXOUT	11.5	**13.5**	15.5	pF	**15%** Tolerance	(2.5pF - 23pF)
	Cip	2.3	2.7	3.1	pF	Shunt capacitance	
PCB	C_{PCBXIN}	**1.1**	**1.2**	**1.3**	pF	Capacitance on XIN	
	$C_{PCBXOUT}$	**1.1**	**1.2**	**1.3**	pF	Capacitance on XOUT	
	C_{PCBP}	**0.1**	**0.2**	**0.3**	pF	Shunt capacitance	
	C_P	8.7	10.3	11.8	pF	Effective load capacitance	
Frequency sensitivity	*TS*	-13.8	-2.2	13.3	ppm	Tuning sensitivity due to C_L *variations*	
Frequency deviation	df_0	**-43.8**	**-2.2**	**43.3**	**ppm**	Addition of all effects	
Drive Level	*DL*	**1.5**	**4.5**	**22.9**	**uW**	Crystal power dissipation	

7. QUARTZ CRYSTALS

The table below lists some crystals that have similar specifications to the one presented in section 5 for the 48.000MHz EM9304 oscillator. Cost, availability and package size may be other factors to drive the selection of a particular quartz crystal from a particular manufacturer. Each of the crystals below has been tested by EM on the DVK to meet EM9304 specifications.

Manufacturer	Size	Part Number
NDK America, Inc.	1.6mm X 1.2mm	NX1612SA-48MHZ-EXS00A-CS10127
NDK America, Inc.	2.0mm X 1.6mm	NX2016SA-48MHZ-EXS00A-CS08673
Hosonic	1.6mm X 1.2mm	ETAB48E007500E

8. PRODUCT VALIDATION

For a particular product, the crystal parameters must be checked with the particular PCB and other support components. Measurements across temperature and voltage with several samples must be done to guarantee operation of the product in the specified environment.

The quartz crystals in section 7 have been tested on the DVK module with an EM9304 in a QFN package. PCB trace layout between the crystal and the EM9304 will add to the parasitic capacitances on the crystal terminals, shifting the oscillation frequency. This can be adjusted for with the trim register that is discussed in a separate app note.

Validation tests suggested are: HFXTAL centre frequency, HFXTAL enable consumption, HFXTAL start-up time, etc. Other tests may be added to ensure high quantity production generates acceptable failure rates.