RX23W Group

Tuning procedure of Bluetooth dedicated clock frequency

Introduction

This document describes a tuning procedure of a clock frequency for RX23W Bluetooth® 5.0 (Core Specification v5.0) RF transceiver.

Target Device

RX23W Group

Note: The contents of this document are provided as a reference and do not guarantee the signal quality in the system.
When designing the actual system, thoroughly evaluate the product in the overall system and apply these contents on your own responsibility.

Contents

1. Overview

This document describes a tuning procedure to align Bluetooth dedicated clock frequency to 32MHz in RX23W group devices.

Because RX23W has load capacitors internally for the tuning of an oscillation frequency of 32MHz Bluetooth dedicated clock, the capacitors take contribution to reduce BoM cost and PCB area.

Bluetooth dedicated clock frequency varies not only due to RX23W device factor but also crystal oscillator and floating capacitance of PCB. Bluetooth dedicated clock frequency accuracy is specified within 50ppm including manufacturing irregularities, temperature drift, and aging deterioration of the crystal oscillator. If frequency tuning is not performed in PCB design, the PCB may not comply with the Bluetooth standard.

Note: An individual frequency tuning for each RX23W is unnecessary. However, the frequency tuning must be performed according to this document, when designing a new PCB, or changing the crystal oscillator model number or the PCB design around the oscillator.

1.1 Related documents

The following documents are related to this application note. Also refer to these documents when using this application note.

- RX23W User's Manual: Hardware (R01UH0823)
- Guidelines for Bluetooth Board Design (R01AN4534)
- Bluetooth Low Energy Protocol Stack Basic Package User's Manual (R01UW0205)

2. Bluetooth dedicated clock oscillator

Figure 2-1 shows circuitry of Bluetooth dedicated clock oscillator. The oscillator has two load capacitors (CL) internally for the tuning of an oscillation frequency of Bluetooth dedicated clock. The internal capacitors are connected to terminals XTAL1_RF and XTAL2_RF respectively. The capacitance of CL can be adjusted in the range of Table 2-1. The oscillation frequency error can be minimized with the appropriate capacitor setting (CLVAL).

The capacitance of line pattern between the crystal oscillator and RX23W or the parasitic capacitance of the pads for solder mount (Cp1, Cp2) will be factors of oscillation frequency variation. Therefore, the optimum capacitor setting will be vary depending on the PCB layout as well as the adopted crystal oscillator.

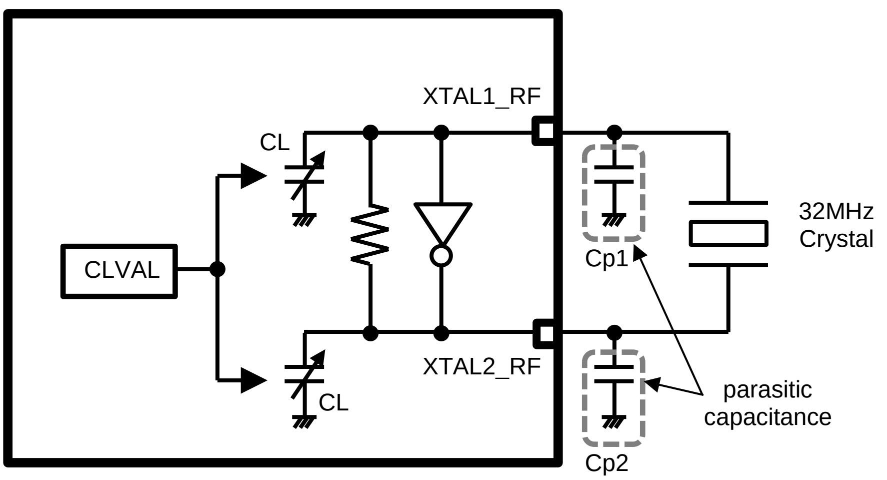

Figure 2-1. Circuitry of Bluetooth dedicated clock oscillator.

Table 2-1. Capacitance range of frequency tuning (CL)

Capacitance tuning range (Typ.)	Capacitance resolution (Typ.)
1.8pF~14.4pF	0.84pF (16 steps)

3. Frequency tuning procedure

This section describes a tuning procedure of Bluetooth dedicated clock frequency.
Firstly, get software for frequency tuning (refer 3.1). Next, build hardware setup(refer 3.2), and set RX23W to output mode of unmodulated signal (CW: Continuous Wave) from ANT port or clock signal from CLKOUT_RF port using operation program for calibration (refer 3.3). Then seek an optimal setting of minimum frequency error according to the tuning flow (refer 3.4).

3.1 Software

- RX23W firmware for frequency tuning
  - UART-HCI mode firmware
    Download a “Bluetooth Low Energy protocol stack basic package for RX23W” from Renesas website. Then compile a UART-HCI mode firmware which can be executed in a measurement environment.
- Operation program for calibration
  - CLVALTune.exe
    This software is included in “Bluetooth Low Energy protocol stack basic package for RX23W”.

3.2 Hardware setup

When frequency tuning of Bluetooth dedicated clock, a high precision frequency measurement system in ppm order is necessary. Considering combinations of monitor ports and connections, there are three hardware setups. Select one of the hardware setups according to the PCB mount condition.

3.2.1 Case of observing ANT output frequency with cable connection

In the setup of Figure 3-1, 2440MHz unmodulated signal is output from ANT port, and the signal frequency is observed with a coaxial cable connection. Because the high precision frequency measurement is needed, set the spectrum analyzer to the frequency count mode.

- Required environment
  - RX23W evaluation board (PCB)
  - Measuring instruments
    - Spectrum analyzer with frequency counter function (over 3GHz)
    - Coaxial cable
  - PC for evaluation
  - USB to UART cable

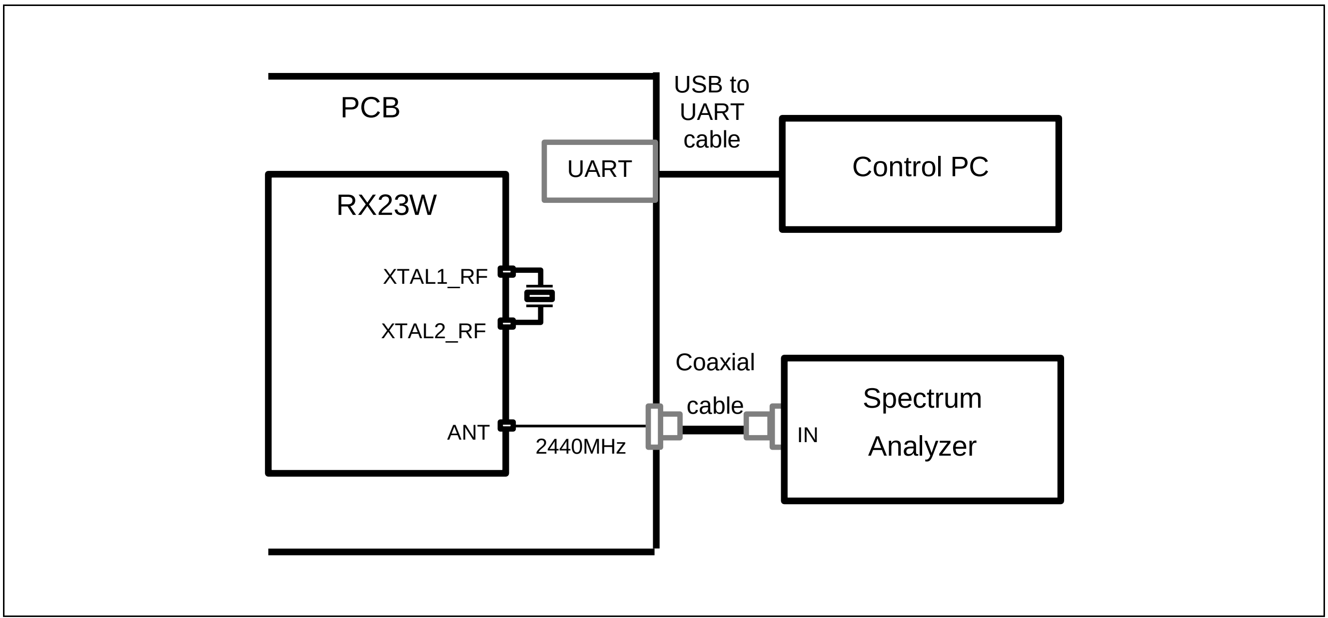

Figure 3-1. Measurement setup of ANT frequency (cable connection)

3.2.2 Case of observing ANT output frequency with wireless connection

In the setup of Figure 3-2, 2440MHz unmodulated signal is output from ANT port, and the signal frequency is observed with a wireless connection. Because the high precision frequency measurement is needed, set the spectrum analyzer to the frequency count mode.

When the wireless measurement setup is selected, measure the frequency in a noiseless environment not to immunity other 2.4GHz band signal. And bring close the antenna of RX23W up the antenna of the measuring instrument in order to enough input amplitude to the measuring instrument.

If the frequency measurement is unstable due to less input amplitude to the measuring instrument, solder a coaxial cable to signal line pattern of ANT directly and measure the frequency in the setup of 3.2.1.

- Required environment
  - — RX23W evaluation board (PCB)
  - — Measuring instruments
    - Spectrum analyzer with frequency counter function (over 3GHz)
    - Antenna for Bluetooth
  - — PC for evaluation
  - — USB to UART cable

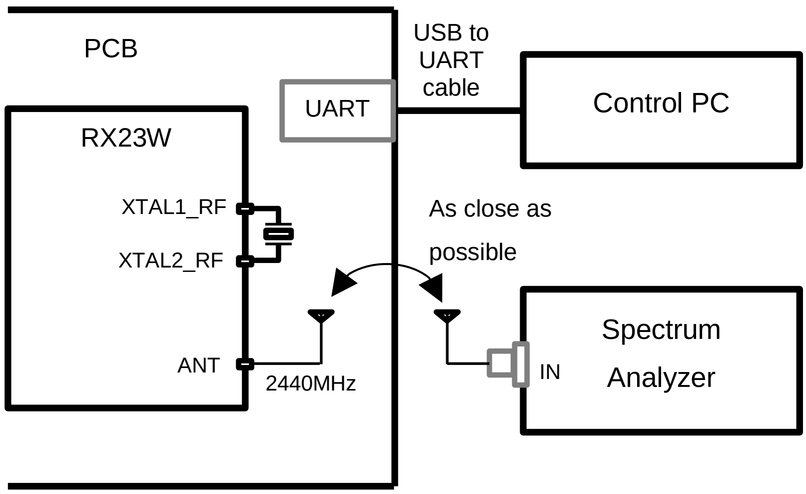

Figure 3-2. Measurement setup of ANT frequency (wireless connection)

3.2.3 Case of observing CLKOUT_RF output frequency

In the setup of Figure 3-3, 4MHz clock signal is output from CLKOUT_RF port, and the signal frequency is observed with the high precision universal frequency counter. This setup is effective when upper limit frequency of the measuring instrument is low. However, if the clock signal can't be output properly from CLKOUT_RF port, the setup can't be used.

- Required environment
  - — RX23W evaluation board (PCB)
  - — Measuring instruments
    - High precision universal frequency counter
    - High impedance probe
  - — PC for evaluation
  - — USB to UART cable

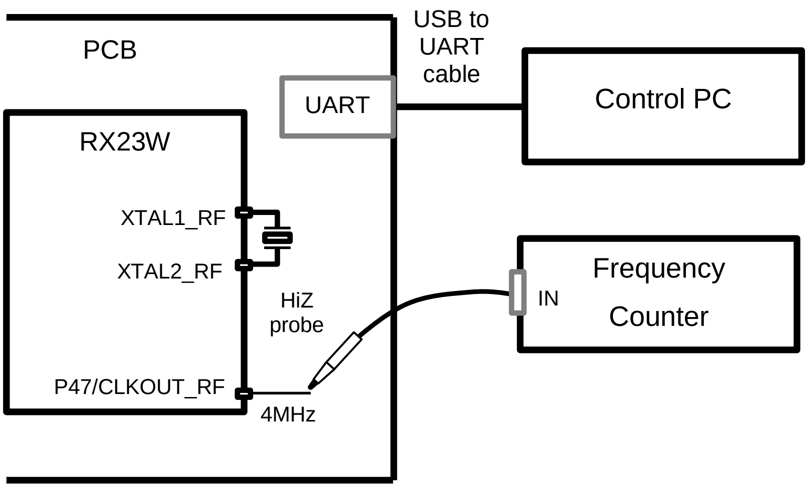

Figure 3-3. Measurement setup of CLKOUT_RF frequency

3.3 Operation program for calibration

The operation program for calibration is a dedicated software for frequency tuning of Bluetooth dedicated clock. When using software, UART-HCI mode firmware which can be executed in the measurement environment is necessary.

On the operation program, capacitor setting for frequency tuning (CLVAL) can be changed and 4MHz clock output or 2440MHz unmodulated signal output can be switched.

Note: When a UART port doesn't exist in the measurement environment, this software can't be used. In this case, it is necessary to repeat choosing one from 16 embedded firmwares for CLVAL setting and writing the firmware to RX23W, until determine an optimum CLVAL setting by the frequency tuning.

3.3.1 Case of observing ANT output frequency

Figure 3-4 shows the program setting in observing 2440MHz unmodulated signal from ANT port. The program setting is common for the cable and wireless connection.

COM port : Depends on PC configuration

Baudrate : Depends on UART-HCI mode firmware (default : 115200)

CLVAL : Capacitor setting for frequency tuning, select an arbitrary value from 0 to 15 (default : 5)

CLKOUT_RF : Select "No output"

Continuous Wave Tx : Select "19ch (2440MHz)"

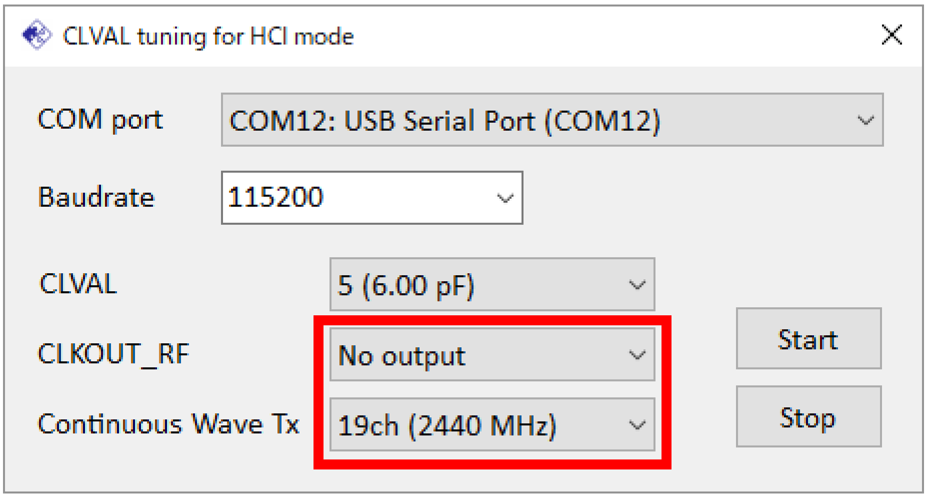

Figure 3-4. Program setting when frequency measurement on ANT port

3.3.2 Case of observing CLKOUT_RF output frequency

Figure 3-5 shows the program setting in observing 4MHz clock signal from CLKOUT_RF port. The program setting is common for the cable and wireless connection.

COM port : Depends on PC configuration

Baudrate : Depends on UART-HCI mode firmware (default : 115200)

CLVAL : Capacitor setting for frequency tuning, select an arbitrary value from 0 to 15 (default : 5)

CLKOUT_RF : Select “4MHz output”

Continuous Wave Tx : Select “Disable”

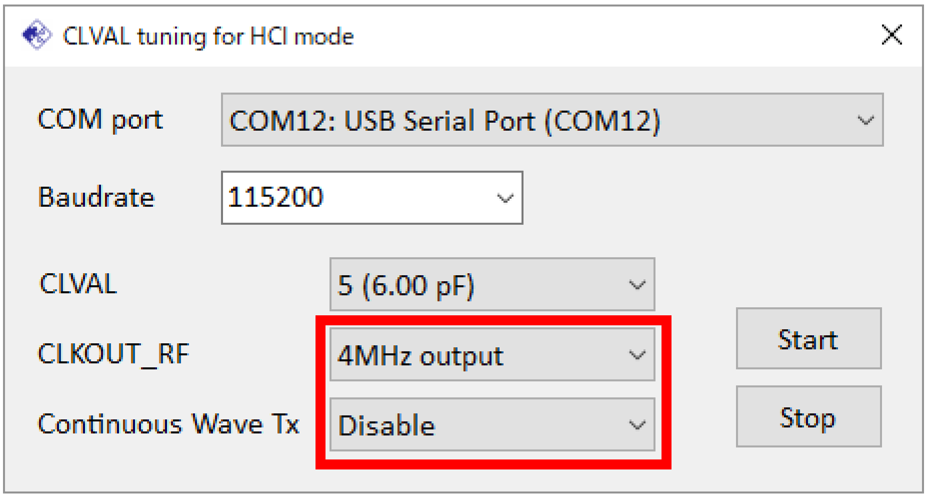

Figure 3-5. Program setting when frequency measurement on CLKOUT_RF port

3.4 Tuning procedure of Bluetooth dedicated clock frequency

A tuning procedure of Bluetooth dedicated clock frequency to determine an optimum capacitor setting (CLVAL) is as follows:

1. Build a hardware setup and set the measuring instrument to frequency count mode.
2. Download a firmware for frequency tuning to RX23W.
3. Run an operation program for calibration.
4. Select the program setting corresponding to the hardware setup, and an arbitrary CLVAL setting.
5. Click “Start” button. A signal outputs from ANT or CLKOUT_RF port.
6. Record the frequency count value on the measuring instrument display. Then click “Stop” button. The output signal from ANT or CLKOUT_RF port will stop.
7. When the measured frequency is lower than target frequency which is 2440MHz on ANT port or 4MHz on CLKOUT_RF port, change value of CLVAL to smaller. When the measured frequency is higher than target frequency, change value of CLVAL to larger.
8. Repeat steps from 5 to 7 until the difference between measurement and target frequency is minimized and determine an optimal CLVAL setting.

Set the determined CLVAL setting value by the procedure to the configuration parameter of Bluetooth Low Energy stack basic package in an application development. And build the application. Figure 3-6 shows an example of a description to configuration parameter.

```
/*********************************************************************************
  Capacity adjustment of 32MHz crystal resonator.
    0 to 15: Adjust according to board environment.
*********************************************************************************/
#define BLE_CFG_RF_CLVAL                (5)
```

Figure 3-6. Example of a description to configuration parameter

4. Crystal oscillator selection guide

4.1 Characteristic for crystal oscillator

Select the crystal oscillator model number based on the recommended parameters shown in Table 4-1.

Table 4-1. Recommended parameters of crystal oscillator

Parameter	Recommendation
Equivalent series resistance (ESR)	≤ 100ohm
Drive level	≤ 100uW
Load capacitance	≥ 5pF, ≤ 8pF

In addition, selecting a crystal oscillator with a small amount of frequency fluctuation for the load capacitance change, the requirement of the crystal oscillator frequency accuracy can be relaxed. The amount of frequency fluctuation for the load capacitance is different for each crystal oscillator, so please contact the crystal oscillator manufacturer for details.

4.2 Frequency accuracy requirement for crystal oscillator

This section explains the frequency accuracy requirement for the crystal oscillator. When selecting a crystal oscillator, make sure that the frequency accuracy of the crystal oscillator is within the required accuracy.

The way of thinking about the frequency accuracy requirement for the crystal oscillator is the following.

The factors of the Bluetooth dedicated clock frequency error can be classified into two: RX23W and crystal oscillator. The frequency accuracy requirement for the crystal oscillator is the value which can be obtained by subtracting the frequency error due to the RX23W from the required accuracy for the Bluetooth dedicated clock.

The frequency error based on RX23W are composed with initial adjustment error, manufacturing variation, temperature change and, aging change. These frequency error depends on the frequency fluctuation characteristic of the crystal oscillator for load capacitance change.

Table 4-2 shows an example of the frequency error budget. In this example, it is assumed which an optimum CL capacitance setting ($CLVAL_{opt}$) is 6 and the frequency variation (ΔF_{VAL}) is +/-8 ppm when changing +/-1 step (0.84 pF) from $CLVAL_{opt}$.

The initial adjustment error when performing the frequency tuning procedure shown in Chapter 3 is expected to be up to 0.5step*ΔF_{VAL} = 0.5*8ppm = +/-4 ppm.

In addition, the total error due to manufacturing variation, temperature change, and aging change of RX23W, corresponds to up to 0.22*$CLVAL_{opt}$ = 0.22*6 = 1.32step change. This change is translated to a frequency error of 0.22*$CLVAL_{opt}$*ΔF_{VAL} = 0.22*6*8ppm = +/-11 ppm. From the above, the maximum frequency error due to RX23W is +/-15 ppm in total.

Here, the accuracy of the Bluetooth dedicated clock is specified within +/- 50 ppm in the Bluetooth standard. Therefore, the frequency accuracy requirement for the crystal oscillator is within +/-35 ppm, including manufacturing variation, temperature change, and aging change.

Table 4-2. Example of frequency error budget ($CLVAL_{opt}$=6)

Parts	Error factor	Maximum error
RX23W	Initial tuning error	+/-4ppm (*1) (0.5 step)
	Summation of manufacturing variations, temperature changes, and aging change	+/-11ppm (*1) (1.32 step)
Crystal oscillator	Summation of manufacturing variations, temperature changes, and aging change	Requirement: within +/-35ppm (*1)
Total		within +/-50 ppm (*2)

*1) Assuming the frequency variation is +/-8 ppm when changing +/-1 step from optimum CL capacitance setting.

*2) Frequency accuracy requirement of Bluetooth dedicated clock

4.3 List of crystal oscillators

Table 4-3 is a list of crystal oscillators enforced in matching measurement. For details of the matching, please contact each crystal oscillator manufacturer.

Table 4-3. List of crystal oscillators

Manufacturer	**Parts number**	**SMD/Lead size code (in mm)**	**Frequency (MHz)**	**Frequency Tolerance** (ppm)	**Frequency** Stability (ppm)	**Equivalent** Series Resistance (ohm)	**Load Capacitance (pF)**
NDK	NX1612SA-32.000MHZ-CHP-CIS-3	1612	32.00	+/-10	+/-20	Max 100	6
NDK	NX1210AB-32.000MHZ-CHP-CIX-3	1210	32.00	Total +/-30		Max 100	6
Kyocera	CX1612DB32000 A0WPNC1	1612	32.00	Total +/-25		Max 100	5
Kyocera	CX1210SB32000 B0GPJC1	1210	32.00	Total +/-30		Max 80	6

5. Reference

5.1 Example of frequency tuning

An example is shown in which the ANT output signal frequency is observed with a cable connection using the configuration in Table 5-1, and the frequency tuning of the Bluetooth dedicated clock is performed.

Table 5-1. Environment of frequency tuning

Item	Composition content
DUT	RX23W 56pin QFN
Crystal oscillator	CX1612DB32000A0WPNC1 (Kyocera) Equivalent series resistance (ESR) : Max 100ohm Load capacitance: 5pF Frequency error : +/-25ppm (including temperature variation)
Measuring instrument	E4440A PSA spectrum analyzer (Keysight)
Monitor port	ANT with cable connection

The frequency error plot changing the CLVAL setting is shown in Figure 5-1. According to the plot, it can be seen that CLVAL setting ($CLVAL_{opt}$) which gives minimum frequency error is 6. And the oscillation frequency change (ΔF_{VAL}) is +/−8 ppm when the CLVAL setting is +/− 1step changed from $CLVAL_{opt}$.

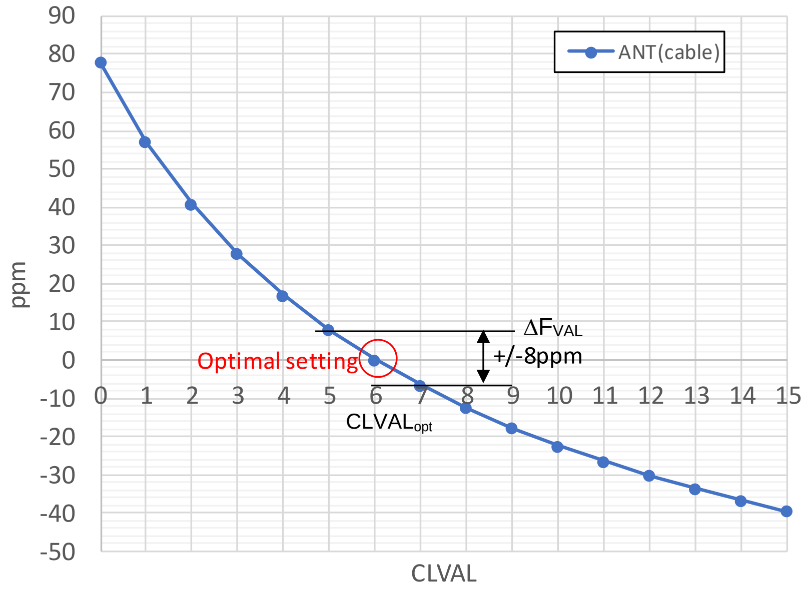

Figure 5-1. Frequency error versus CLVAL setting

Figure 5-2 is a frequency count display when CLVAL is set to 6 in this frequency tuning example. The frequency count value is 2439.9985MHz and initial frequency tuning error is (2439.9985−2440)/2440= −0.6ppm.

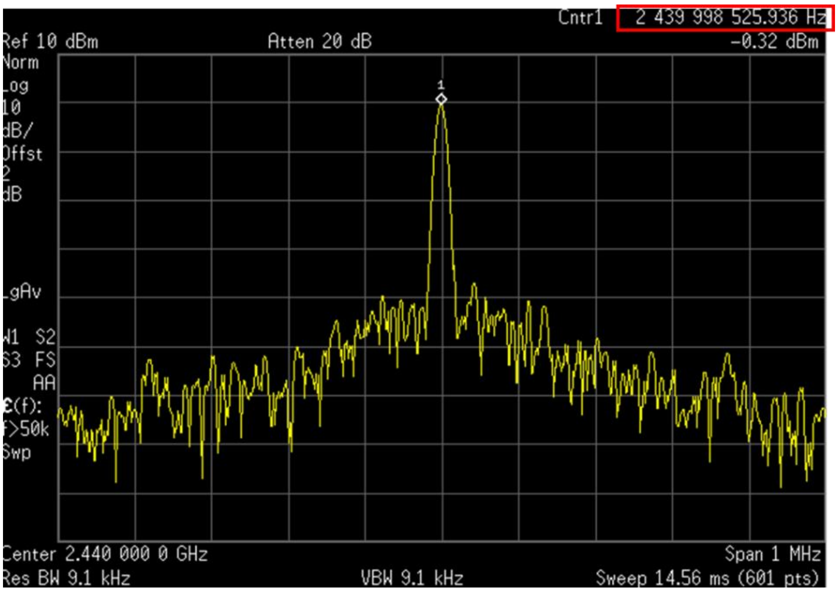

Figure 5-2. E4440A frequency count display (CLVAL=6)

With the optimum CLVAL setting ($CLVAL_{opt}$=6), the frequency change per step (+/−8 ppm), and the initial tuning error (−0.6 ppm), the frequency accuracy requirement for the crystal oscillator can be estimated by based on the explanation shown in section 4.2.

$$-50ppm+0.6ppm+0.22*6*8ppm \leq \text{required accuracy} \leq +50ppm+0.6ppm-0.22*6*8ppm$$

$$\Leftrightarrow \quad -38.8ppm \leq \text{required accuracy} \leq +40.0ppm$$

Because the nominal frequency error (+/−25 ppm) of the crystal oscillator (CX1612DB32000A0WPNC1) is within the required accuracy, the crystal oscillator on this RX23W evaluation board can support the Bluetooth standard on the viewpoint of frequency accuracy.

Revision History

Rev.	Date	Description	
		Page	Summary
1.00	Jun.24.19	—	First edition issued

General Precautions in the Handling of Microprocessing Unit and Microcontroller Unit Products

The following usage notes are applicable to all Microprocessing unit and Microcontroller unit products from Renesas. For detailed usage notes on the products covered by this document, refer to the relevant sections of the document as well as any technical updates that have been issued for the products.

1. Precaution against Electrostatic Discharge (ESD)

   A strong electrical field, when exposed to a CMOS device, can cause destruction of the gate oxide and ultimately degrade the device operation. Steps must be taken to stop the generation of static electricity as much as possible, and quickly dissipate it when it occurs. Environmental control must be adequate. When it is dry, a humidifier should be used. This is recommended to avoid using insulators that can easily build up static electricity. Semiconductor devices must be stored and transported in an anti-static container, static shielding bag or conductive material. All test and measurement tools including work benches and floors must be grounded. The operator must also be grounded using a wrist strap. Semiconductor devices must not be touched with bare hands. Similar precautions must be taken for printed circuit boards with mounted semiconductor devices.
2. Processing at power-on

   The state of the product is undefined at the time when power is supplied. The states of internal circuits in the LSI are indeterminate and the states of register settings and pins are undefined at the time when power is supplied. In a finished product where the reset signal is applied to the external reset pin, the states of pins are not guaranteed from the time when power is supplied until the reset process is completed. In a similar way, the states of pins in a product that is reset by an on-chip power-on reset function are not guaranteed from the time when power is supplied until the power reaches the level at which resetting is specified.
3. Input of signal during power-off state

   Do not input signals or an I/O pull-up power supply while the device is powered off. The current injection that results from input of such a signal or I/O pull-up power supply may cause malfunction and the abnormal current that passes in the device at this time may cause degradation of internal elements. Follow the guideline for input signal during power-off state as described in your product documentation.
4. Handling of unused pins

   Handle unused pins in accordance with the directions given under handling of unused pins in the manual. The input pins of CMOS products are generally in the high-impedance state. In operation with an unused pin in the open-circuit state, extra electromagnetic noise is induced in the vicinity of the LSI, an associated shoot-through current flows internally, and malfunctions occur due to the false recognition of the pin state as an input signal become possible.
5. Clock signals

   After applying a reset, only release the reset line after the operating clock signal becomes stable. When switching the clock signal during program execution, wait until the target clock signal is stabilized. When the clock signal is generated with an external resonator or from an external oscillator during a reset, ensure that the reset line is only released after full stabilization of the clock signal. Additionally, when switching to a clock signal produced with an external resonator or by an external oscillator while program execution is in progress, wait until the target clock signal is stable.
6. Voltage application waveform at input pin

   Waveform distortion due to input noise or a reflected wave may cause malfunction. If the input of the CMOS device stays in the area between V_{IL} (Max.) and V_{IH} (Min.) due to noise, for example, the device may malfunction. Take care to prevent chattering noise from entering the device when the input level is fixed, and also in the transition period when the input level passes through the area between V_{IL} (Max.) and V_{IH} (Min.).
7. Prohibition of access to reserved addresses

   Access to reserved addresses is prohibited. The reserved addresses are provided for possible future expansion of functions. Do not access these addresses as the correct operation of the LSI is not guaranteed.
8. Differences between products

   Before changing from one product to another, for example to a product with a different part number, confirm that the change will not lead to problems. The characteristics of a microprocessing unit or microcontroller unit products in the same group but having a different part number might differ in terms of internal memory capacity, layout pattern, and other factors, which can affect the ranges of electrical characteristics, such as characteristic values, operating margins, immunity to noise, and amount of radiated noise. When changing to a product with a different part number, implement a system-evaluation test for the given product.

Notice

1. Descriptions of circuits, software and other related information in this document are provided only to illustrate the operation of semiconductor products and application examples. You are fully responsible for the incorporation or any other use of the circuits, software, and information in the design of your product or system. Renesas Electronics disclaims any and all liability for any losses and damages incurred by you or third parties arising from the use of these circuits, software, or information.
2. Renesas Electronics hereby expressly disclaims any warranties against and liability for infringement or any other claims involving patents, copyrights, or other intellectual property rights of third parties, by or arising from the use of Renesas Electronics products or technical information described in this document, including but not limited to, the product data, drawings, charts, programs, algorithms, and application examples.
3. No license, express, implied or otherwise, is granted hereby under any patents, copyrights or other intellectual property rights of Renesas Electronics or others.
4. You shall not alter, modify, copy, or reverse engineer any Renesas Electronics product, whether in whole or in part. Renesas Electronics disclaims any and all liability for any losses or damages incurred by you or third parties arising from such alteration, modification, copying or reverse engineering.
5. Renesas Electronics products are classified according to the following two quality grades: “Standard” and “High Quality”. The intended applications for each Renesas Electronics product depends on the product’s quality grade, as indicated below.
   "Standard": Computers; office equipment; communications equipment; test and measurement equipment; audio and visual equipment; home electronic appliances; machine tools; personal electronic equipment; industrial robots; etc.
   "High Quality": Transportation equipment (automobiles, trains, ships, etc.); traffic control (traffic lights); large-scale communication equipment; key financial terminal systems; safety control equipment; etc.
   Unless expressly designated as a high reliability product or a product for harsh environments in a Renesas Electronics data sheet or other Renesas Electronics document, Renesas Electronics products are not intended or authorized for use in products or systems that may pose a direct threat to human life or bodily injury (artificial life support devices or systems; surgical implantations; etc.), or may cause serious property damage (space system; undersea repeaters; nuclear power control systems; aircraft control systems; key plant systems; military equipment; etc.). Renesas Electronics disclaims any and all liability for any damages or losses incurred by you or any third parties arising from the use of any Renesas Electronics product that is inconsistent with any Renesas Electronics data sheet, user’s manual or other Renesas Electronics document.
6. When using Renesas Electronics products, refer to the latest product information (data sheets, user’s manuals, application notes, “General Notes for Handling and Using Semiconductor Devices” in the reliability handbook, etc.), and ensure that usage conditions are within the ranges specified by Renesas Electronics with respect to maximum ratings, operating power supply voltage range, heat dissipation characteristics, installation, etc. Renesas Electronics disclaims any and all liability for any malfunctions, failure or accident arising out of the use of Renesas Electronics products outside of such specified ranges.
7. Although Renesas Electronics endeavors to improve the quality and reliability of Renesas Electronics products, semiconductor products have specific characteristics, such as the occurrence of failure at a certain rate and malfunctions under certain use conditions. Unless designated as a high reliability product or a product for harsh environments in a Renesas Electronics data sheet or other Renesas Electronics document, Renesas Electronics products are not subject to radiation resistance design. You are responsible for implementing safety measures to guard against the possibility of bodily injury, injury or damage caused by fire, and/or danger to the public in the event of a failure or malfunction of Renesas Electronics products, such as safety design for hardware and software, including but not limited to redundancy, fire control and malfunction prevention, appropriate treatment for aging degradation or any other appropriate measures. Because the evaluation of microcomputer software alone is very difficult and impractical, you are responsible for evaluating the safety of the final products or systems manufactured by you.
8. Please contact a Renesas Electronics sales office for details as to environmental matters such as the environmental compatibility of each Renesas Electronics product. You are responsible for carefully and sufficiently investigating applicable laws and regulations that regulate the inclusion or use of controlled substances, including without limitation, the EU RoHS Directive, and using Renesas Electronics products in compliance with all these applicable laws and regulations. Renesas Electronics disclaims any and all liability for damages or losses occurring as a result of your noncompliance with applicable laws and regulations.
9. Renesas Electronics products and technologies shall not be used for or incorporated into any products or systems whose manufacture, use, or sale is prohibited under any applicable domestic or foreign laws or regulations. You shall comply with any applicable export control laws and regulations promulgated and administered by the governments of any countries asserting jurisdiction over the parties or transactions.
10. It is the responsibility of the buyer or distributor of Renesas Electronics products, or any other party who distributes, disposes of, or otherwise sells or transfers the product to a third party, to notify such third party in advance of the contents and conditions set forth in this document.
11. This document shall not be reprinted, reproduced or duplicated in any form, in whole or in part, without prior written consent of Renesas Electronics.
12. Please contact a Renesas Electronics sales office if you have any questions regarding the information contained in this document or Renesas Electronics products.

(Note1) “Renesas Electronics” as used in this document means Renesas Electronics Corporation and also includes its directly or indirectly controlled subsidiaries.

(Note2) “Renesas Electronics product(s)” means any product developed or manufactured by or for Renesas Electronics.

(Rev.4.0-1 November 2017)

Corporate Headquarters

TOYOSU FORESIA, 3-2-24 Toyosu,
Koto-ku, Tokyo 135-0061, Japan
www.renesas.com

Trademarks

Renesas and the Renesas logo are trademarks of Renesas Electronics Corporation. All trademarks and registered trademarks are the property of their respective owners.

Contact information

For further information on a product, technology, the most up-to-date version of a document, or your nearest sales office, please visit: www.renesas.com/contact/.