Frequency Measurement Using PSoC® 4 BLE

Objective

The Frequency Measurement Using PSoC 4 BLE project demonstrates how to measure the frequency of an arbitrary signal using the PSoC 4 Bluetooth Low Energy (BLE) device. The measured frequency value is sent to the BLE central device i.e. CySmart PC Tool via BLE communication.

Overview

This project demonstrates how to convert an arbitrary input signal to a square wave using the opamps available in the PSoC 4 BLE device and measure the frequency of the input signal using the TCPWM and UDB components. The frequency value is sent to the CySmart PC tool via BLE communication. The BLE component in the PSoC 4 BLE device implements a custom profile to send the frequency data to the central device.

The project can measure input frequencies from 1 Hz to 10 MHz when the input is a square waveform and from 1 Hz to 500 KHz when the input signal is an arbitrary waveform.

Requirements

Design Tool: PSoC Creator 3.1 SP2, CySmart PC Tool 1.0 SP1

Programming Language: C (GCC 4.8.4 – included with PSoC Creator)

Associated Devices: All PSoC 4 BLE devices

Required Hardware: CY8CKIT-042-BLE Bluetooth® Low Energy (BLE) Pioneer Kit, Discrete Resistors and Capacitors

Device Operating Voltage: 5 V

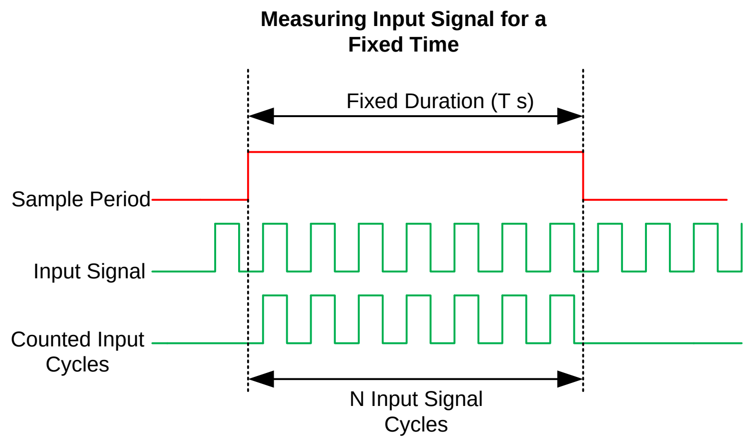
Basics of Frequency Measurement

Measuring a signal’s frequency is a common mixed-signal application. It may be the tachometer signal from a motor or an analog signal for tone detection. For all cases, it requires determining the rate of the signal’s oscillation. For mechanical systems, this rate is generally known as “revolutions per minute” (rpm). For electrical systems, it is better known as “cycles per second” or Hertz.

There are two classic methods for measuring frequency:

- **Measure the number of cycles in a fixed period of time:** In this method, the frequency of the input signal is measured by counting the number of input signal cycles for a fixed duration as shown below.

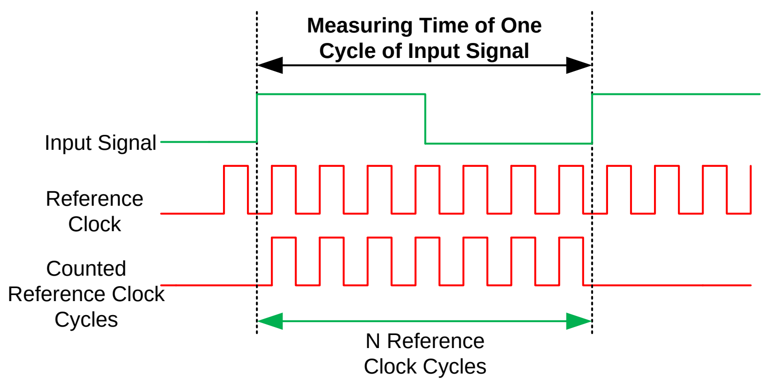
Figure 1. Measuring the Input Signal Cycles in a Fixed Duration



The input signal frequency for this method is given by $F_{INPUT} = \frac{N}{T}$. This method can be used to measure high frequency signal. At low frequencies, the measurement error will be very high.

- **Measure the time of one cycle:** In this method, the frequency of the input signal is measured by counting the number of reference clock cycles in a single cycle of the input signal as shown in Figure 2.

Figure 2. Measuring the Time Duration of One Input Signal Cycle



The input signal frequency for this method is given by $F_{INPUT} = \frac{F_{CLOCK}}{N}$. This method can be used to measure low frequency signal. At high frequency, the measurement error will be very high.

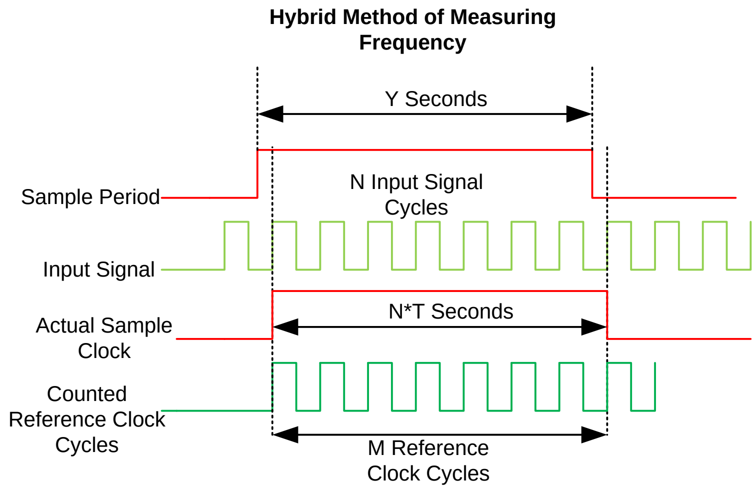
Each of the above methods has advantages and limitations of range and accuracy. Refer to AN2283: PSoC 1 – Measuring Frequency for a detailed explanation on the advantages and limitations of each of these methods. The application note also describes a hybrid method which combines both of the above methods to achieve a very high range and still ensure high accuracy.

This project demonstrates how to implement the hybrid method described in AN2283 by using the Analog and Digital blocks of PSoC 4 BLE device to measure the frequency of an arbitrary signal and send the frequency value over BLE communication to a central device.

Hybrid Method for Measuring Frequency

In the hybrid method, the sampling time of the input signal is not fixed. Instead, the sampling time is made such that it is an exact multiple of the input signal time period. During this sampling time, the reference clock signal is also counted as shown in Figure 3.

Figure 3. Hybrid Method of Measuring the Input Signal Frequency



In this method, the sample clock is synchronized with the rising edge of the input signal whose frequency should be measured. The actual sample clock duration will be N * T seconds instead of Y seconds.

Here, N is the number of input signal cycles counted by the counter and T is the time period of the input signal.

During the N*T seconds of the sample period, the counter also counts M reference clock cycles. The frequency of the input signal in this case is given by $F_{INPUT} = \frac{N * F_{CLOCK}}{M}$.

Where, M is the number of counts of reference clock cycles counted during the N*T seconds.

Relative Error Calculation of Hybrid Method

Differentiating the above equation we get

$$dF_{INPUT} = \frac{F_{CLOCK}}{M}\, dN - N\frac{F_{CLOCK}}{M^2}\, dM + \frac{N}{M} dF_{CLOCK}$$

We have $dN = 0$ and $dM = \pm 1$ and substituting $F_{INPUT} = \frac{N * F_{CLOCK}}{M}$ in the above equation we get:

$$dF_{INPUT} = \pm\frac{F_{INPUT}}{M} + \frac{F_{INPUT}}{F_{CLOCK}} dF_{CLOCK}$$

$$\frac{dF_{INPUT}}{F_{INPUT}} = \pm\frac{1}{M} + \frac{dF_{CLOCK}}{F_{CLOCK}}$$

The reference clock is generated using the External Crystal Oscillator (ECO). Therefore the relative $\frac{dF_{CLOCK}}{F_{CLOCK}}$ of the reference clock is very less. Therefore, the accuracy of the measured frequency of the input signal depends on the reference clock count M. Higher the count, higher is the accuracy of the measured frequency.

The hybrid method implemented using PSoC 4 BLE has a frequency range of **1 Hz to 10 MHz** when the input signal is a square wave. When the input signal is an arbitrary waveform, the Schmitt trigger can work only till **500 KHz** because of the slew rate limitation. Therefore, the frequency range for an arbitrary signal is **1 Hz to 500 KHz**.

Hardware Setup

Figure 4 below shows the block diagram of the test setup. The input signal can be an arbitrary signal from an external source (function generator) or it can be the square wave generated by the PSoC 4 BLE device. If the input signal is an arbitrary signal, it can be level shifted and converted to a square wave using the Schmitt trigger circuit built using the Opamp in PSoC 4 BLE device.

Figure 4: Block Diagram

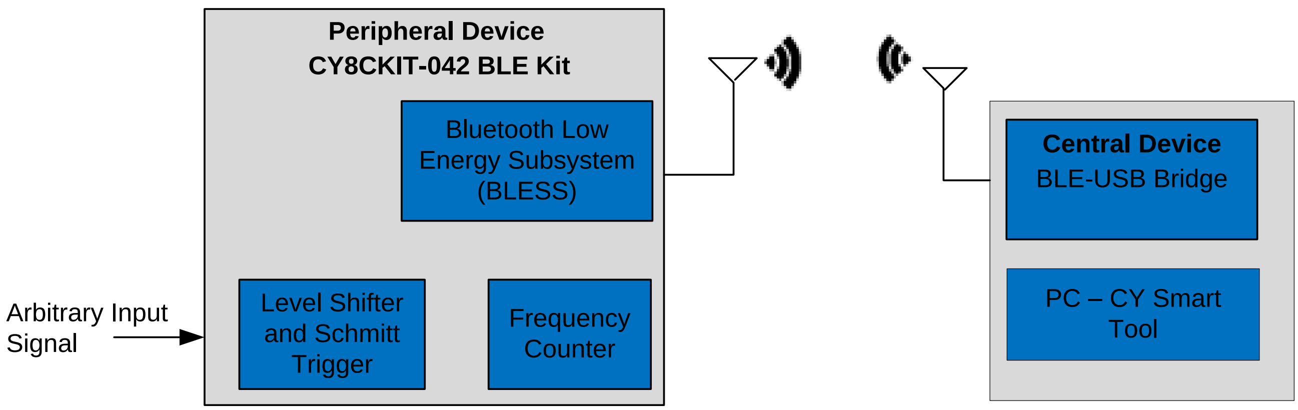
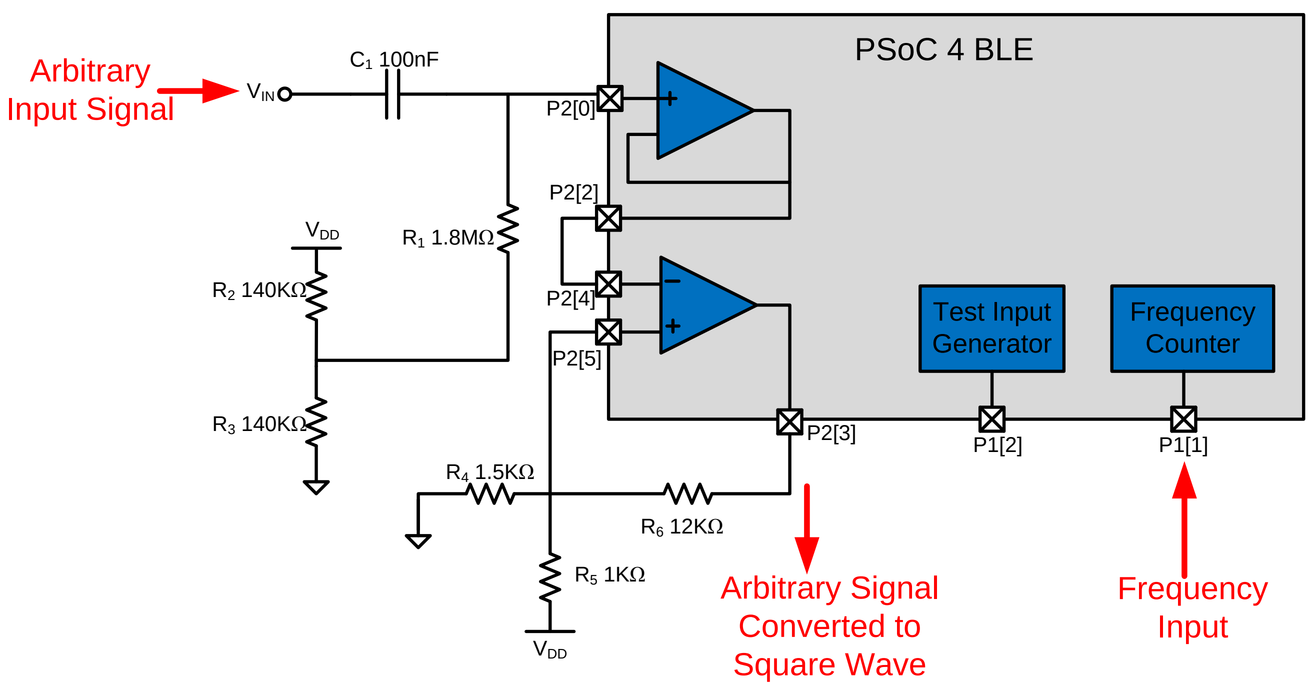


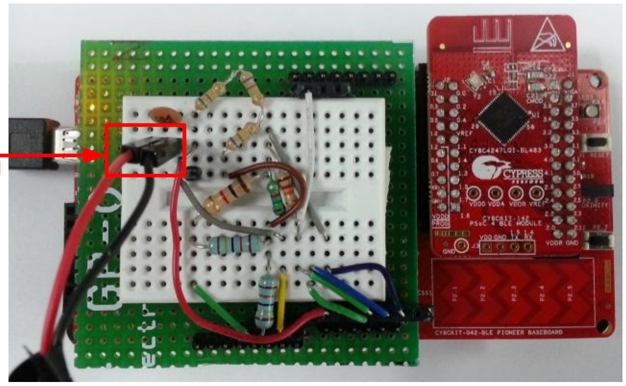
Figure 5 shows the required connections to measure the frequency of the input signal.

Figure 5. Hardware Connection for Measuring the Input Signal Frequency



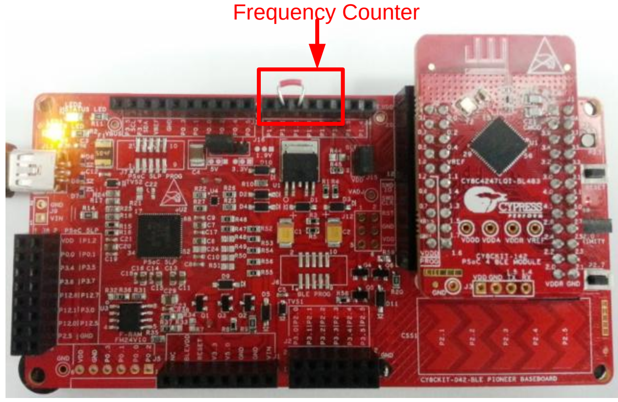
1. To measure the frequency of an arbitrary signal, connect the signal to V_{IN} as shown in Figure 6. The output of the Schmitt trigger i.e. pin P2[3] should be connected to the Frequency counter input i.e. P1[1].

Figure 6. Converting Arbitrary Signal to Square wave for Measuring Frequency



2. If the input signal is an externally generated square wave, you can directly connect the signal to the Frequency Counter input P1[1].
3. Alternately, the square wave can be generated using the PSoC 4 device. The project uses a clock component (buffered using T-Flipflop) to generate a square wave for testing the project. The clock output is routed to Pin P1[2]. This output can be connected to the Frequency Counter input P1[1] as shown in Figure 7.

Figure 7. Applying Clock Signal as Input to Frequency Counter



PSoC Creator Schematic

The PSoC Creator schematic is divided into 4 sections:

1. **Level Shifting & Schmitt Trigger** – The resistor-capacitor high pass filter is used to level shift the input signal with a reference of 2.5V (Project required V_{DD}= 5V). The Schmitt trigger circuit built using the Opamp converts the arbitrary input signal to square wave.
2. **Frequency Counter** – The PWM_2s component generates the sampling signal to compute the frequency. The input signal frequency is computed every once in 2s.

   The Input_Signal_Counter1 and Input_Signal_Counter2 is used to implement a 32-bit counter and it counts the number of input signal samples for a period of 1s. During the same interval, the Ref_Clock_Counter1 and Ref_Clock_Counter2 counts the 6MHz reference clock generated using the T-Flip-flop.

3. **Communication –** The BLE component sends the input signal frequency value to the CY Smart PC Tool.

   The UART component is used to view the project debug data in HyperTerminal.

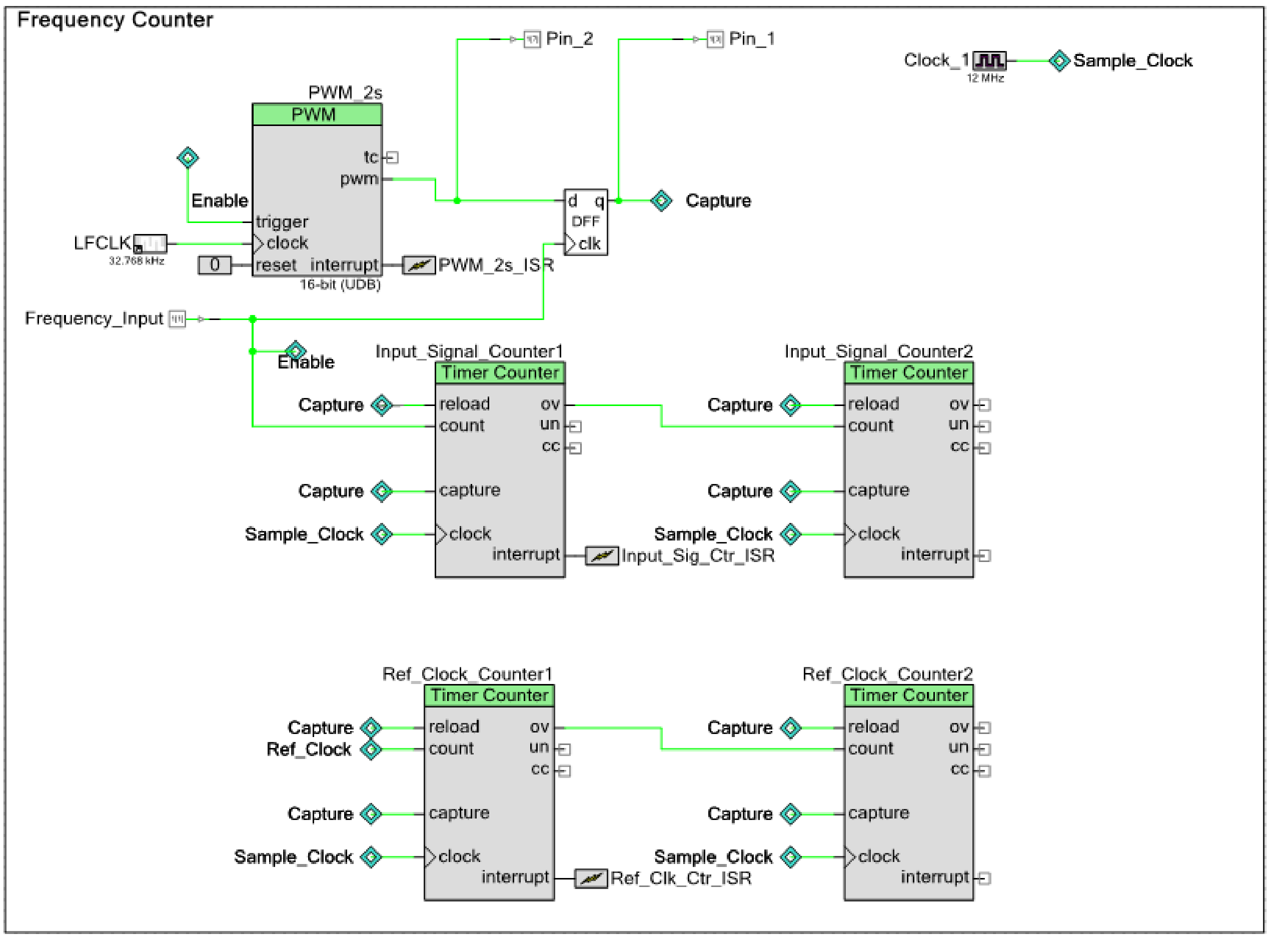
   The Status_LED is used to indicate the status of BLE communication.

4. **Reference clock and Test Signal generation:** The T-flipflop component is used to generate:

   a) Reference Clock for counting the number of reference clock during the frequency measurement interval

   b) Test input signal of 800 kHz for testing the project

Figure 8. PSoC Creator Schematic

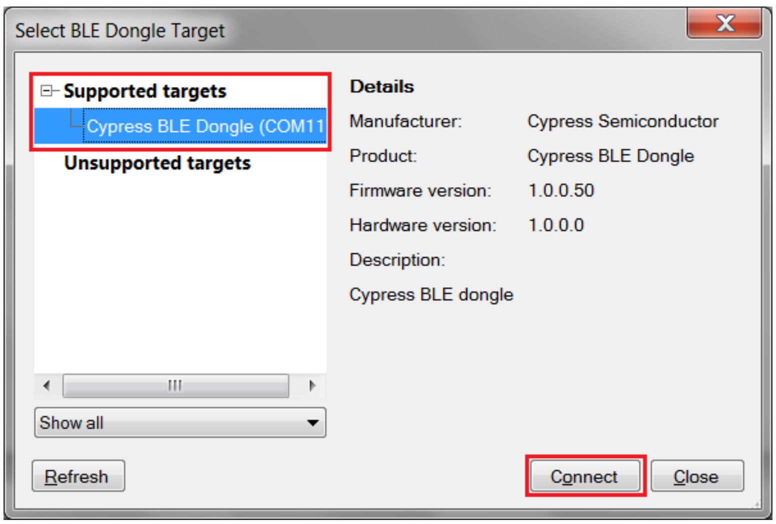


Testing

Testing with the CySmart BLE Test and Debug Utility for Windows PC:

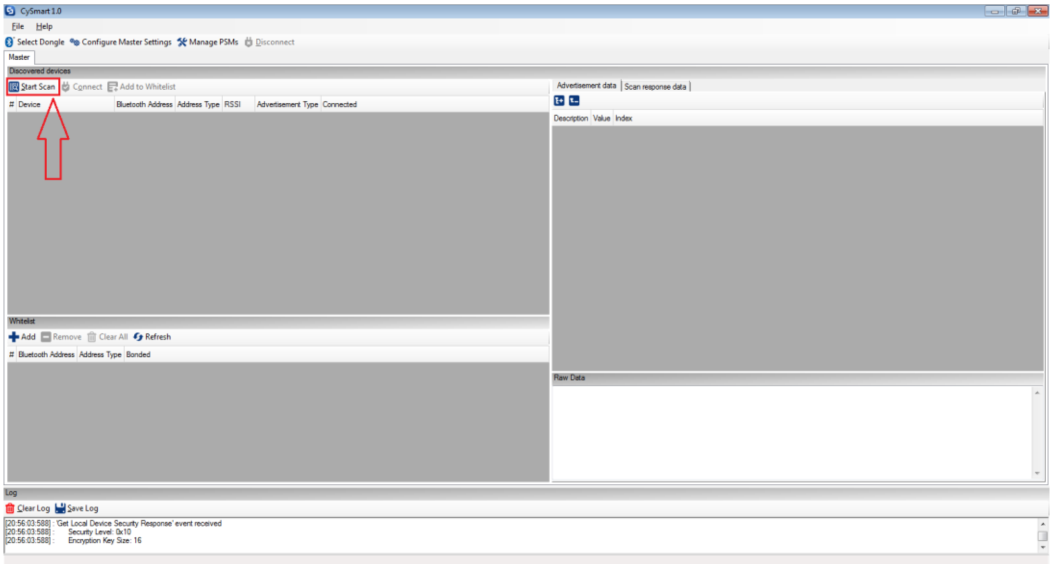
1. Depending on the input signal source (external source or internally generated test signal) connect the input signal to the PSoC 4 BLE device Frequency_Input pin as explained in the Hardware Setup section.
2. Program the PSoC 4 BLE device with the Frequency_Measurement_Using_PSoC4_BLE.hex file
3. Plug the BLE-USB Bridge (included with the BLE Pioneer Kit) in your computer's USB port.
4. On your computer, launch **CySmart 1.0**. It is located in the **All Programs -> Cypress -> CySmart** folder in the Windows start menu. The tool opens up and asks you to **Select BLE Dongle Target**. Select the **Cypress BLE Dongle (COMxx)** and click **Connect**, as shown in Figure 9.

Figure 9: CySmart: Select BLE Dongle Target



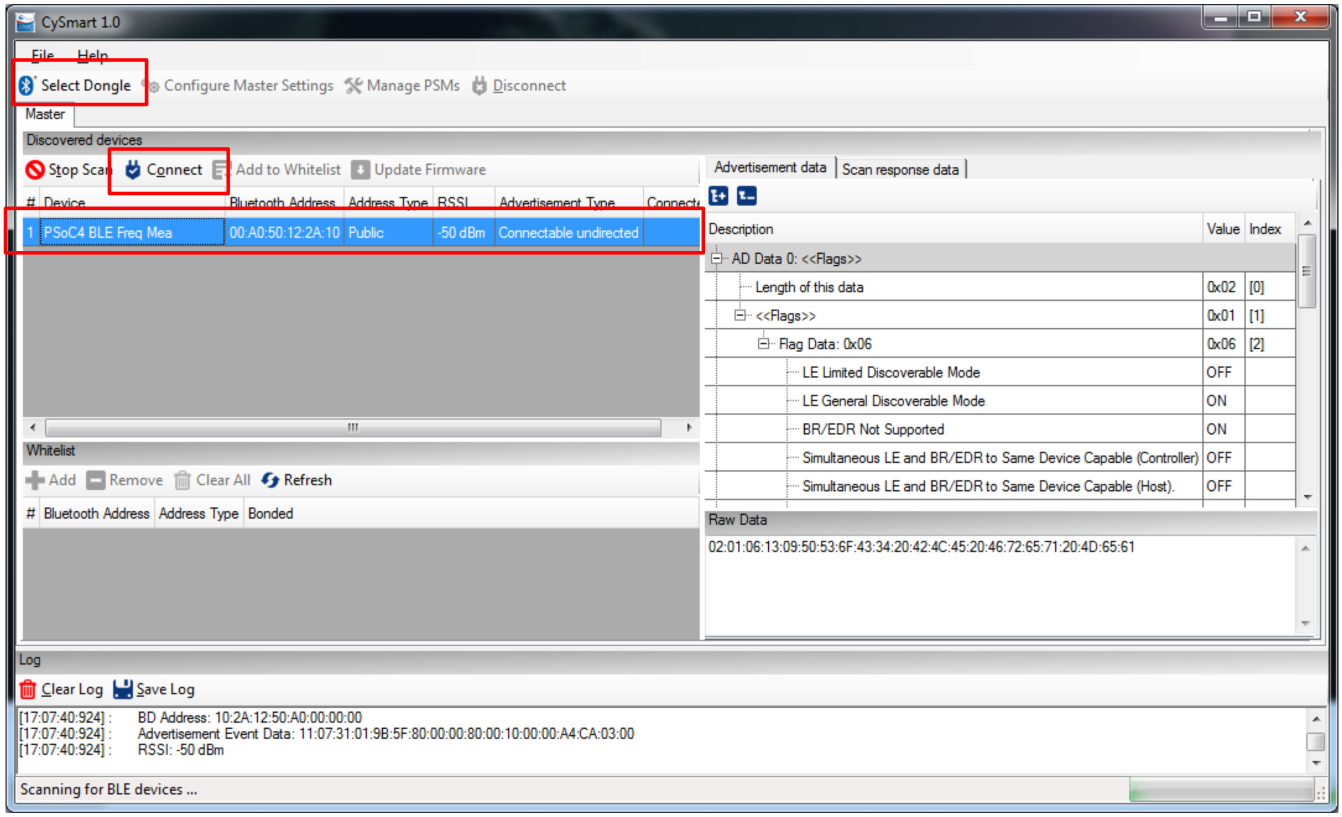
5. When the BLE-USB Bridge is connected, click on **Start Scan** to find your BLE device. See Figure 10.

Figure 10: Finding a BLE Device



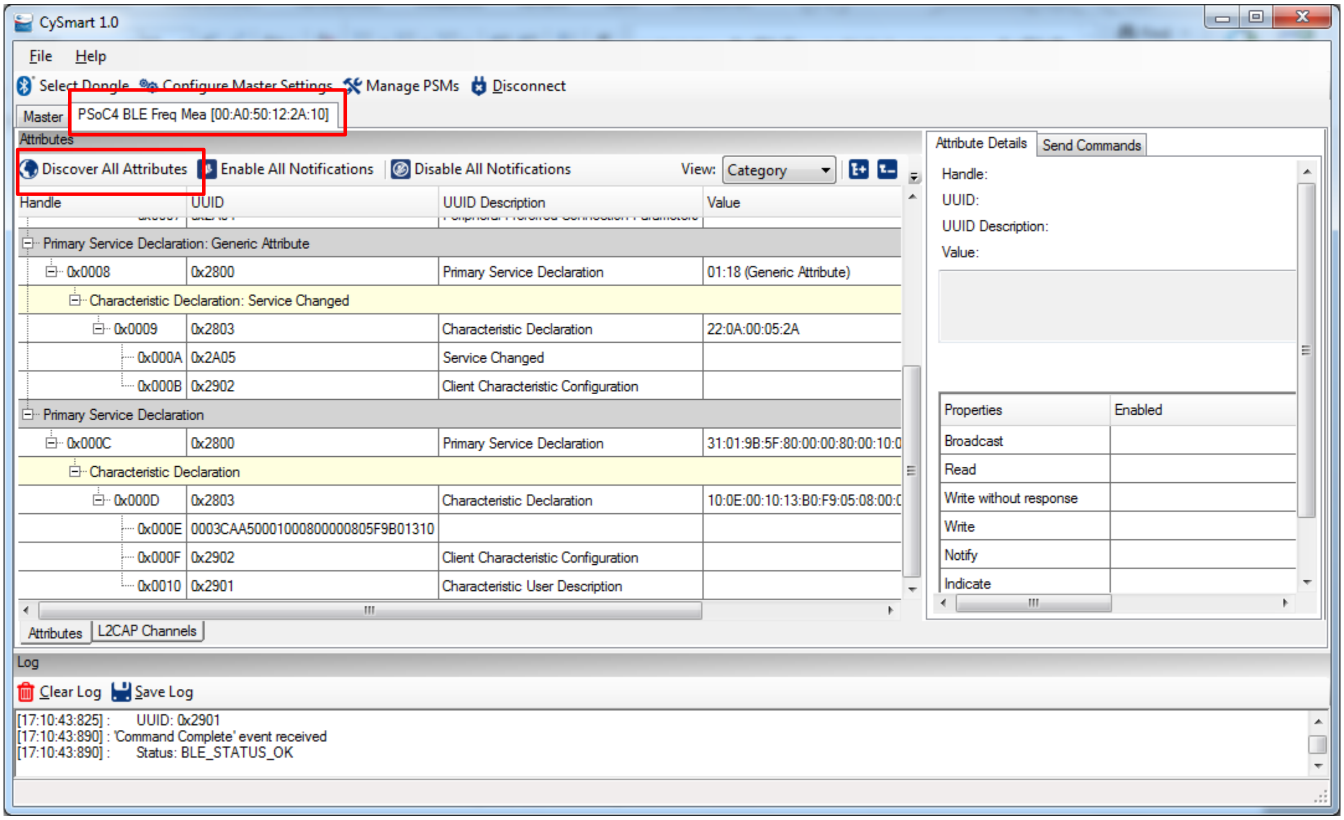
6. The scanning stops automatically once all the nearby devices are known. The tool lists all the nearby devices in the Discovered devices section.
7. Click on the “PSoC4 BLE Freq Mea” device name to see the Advertisement data and Scan response data packets on the right. See Figure 11.

Figure 11: Checking Discovery Details of a Connected BLE Device



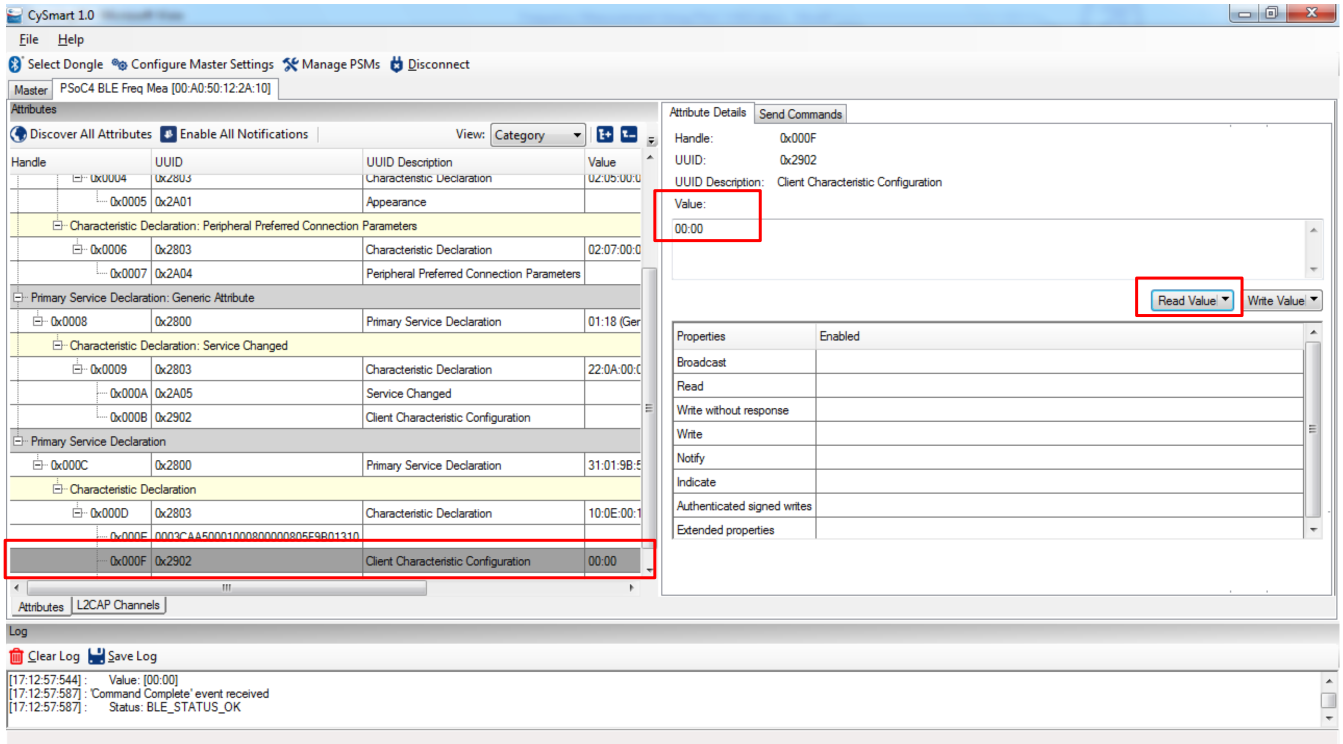
8. Click **Connect** as shown in Figure 11 to connect to the device.
9. The tool will now open a separate tab for the device. Click **Discover All Attributes** to list all the Attributes in the device, with their respective UUIDs and descriptions. See Figure 12.

Figure 12: Discovering Attributes of a Connected BLE Device



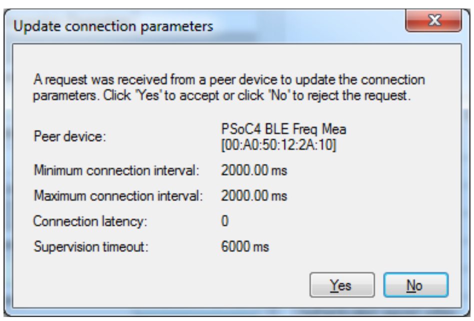
10. When all the attributes are listed, locate the Client Characteristic Configuration descriptor (UUID 0x2902) under Custom characteristic (UUID 0003CAA4-0000-1000-8000-00805F9B0131). Click Read Value to read the existing CCCD value as shown in Figure 13.

Figure 13: Reading Attribute Value



11. Modify the value field to '01:00' and click Write Value (Figure 16). Once the value is written, the CySmart Central Emulation Tool will display a message for the Update connection parameters. Select Yes, as shown in Figure 14.

Figure 14. Update Connection Parameter Option



12. This enables the notifications on the Custom characteristic to receive input signal frequency value (Frequency Value is indicated in the log file at the bottom of the CY Smart Tool as shown in Figure 16.
The frequency value is reported in the following format:

Figure 15. Frequency Data Format

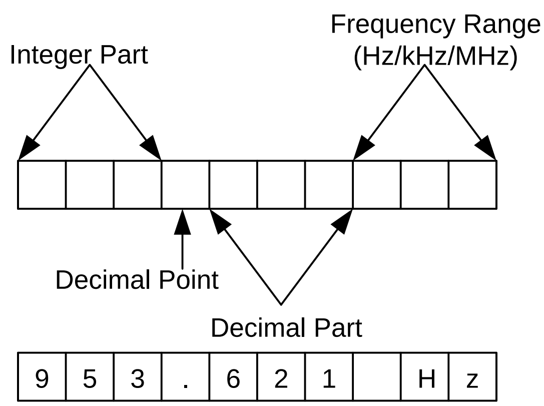
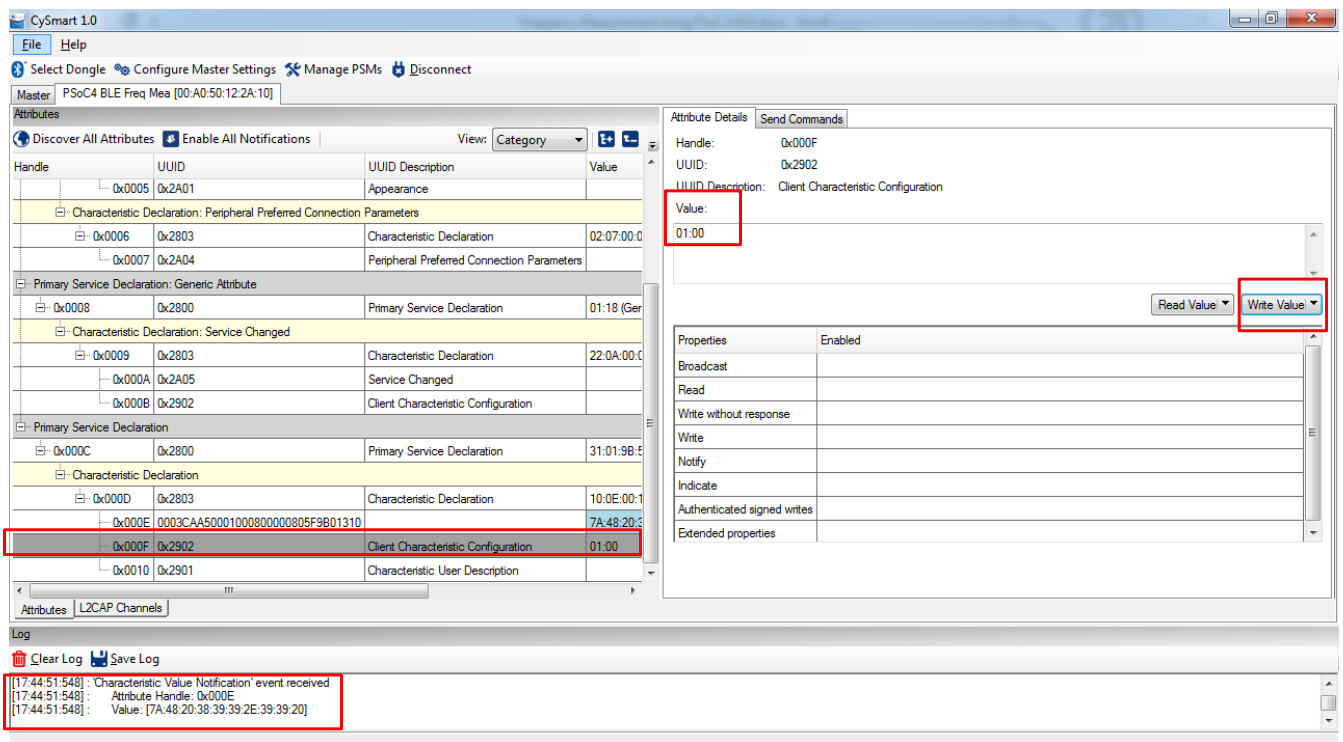
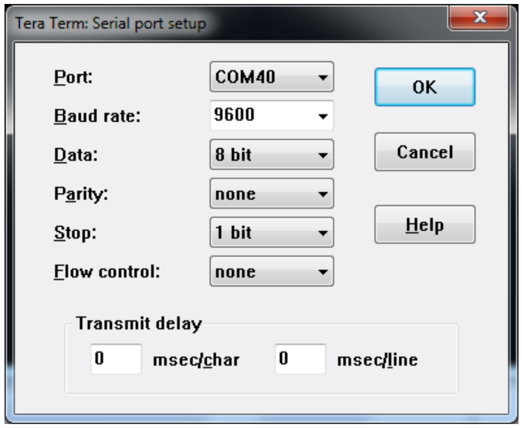


Figure 16: Writing Attribute Value



13. Alternately, the frequency value can also we viewed on hypertermial when UART debugging is enabled. To enable UART debugging, set the macro `UART_DEBUG_ENABLE` in the communication.h file to ‘1’ and program the kit.
14. Open the hyperterminal and select the kitprog COM port. Set the serial port setting as shown in Figure 17 and click OK. The UART debug data will be displayed in the format as shown in Figure 19 in Appendix section.

Figure 17. Serial Port Connection Parameter Values



Related Documents

Table 1 lists all relevant application notes, code examples, knowledge base articles, device datasheets, and Component / user module datasheets.

Table 1. Related Documents

Document	Title	Comment
AN91267	Getting Started with PSoC 4 BLE	Provides an introduction to PSoC 4 BLE device that integrates a Bluetooth Low Energy radio system along with programmable analog and digital resources.
AN2283	PSoC 1 Measuring Frequency	Explains how to measure frequency using PSoC 1 device.

Appendix

Figure 18. Level Shifter and Schmitt Trigger Waveform

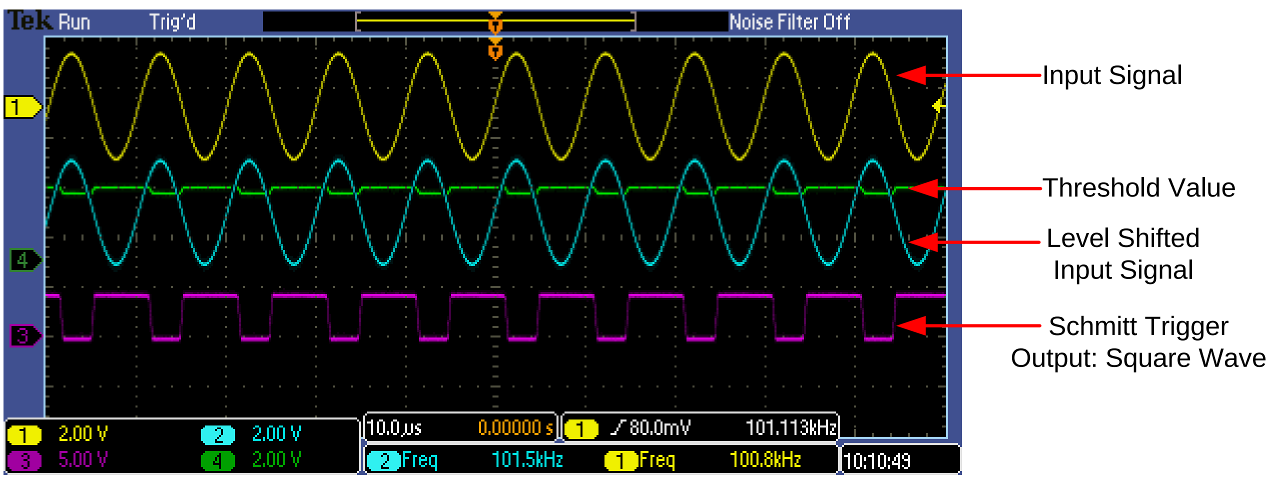


Figure 19. Debug Data Displayed on HyperTerminal