Bluetooth® Low Energy Sensor Tag Hands On

1. Introduction

Thank you for purchasing a Texas Instruments (TI) *Bluetooth®* low energy (BLE) Sensor Tag Development Kit. The purpose of this document is to give an overview of the hardware and software included in the kit and to provide an introduction into BLE.

The information in this guide will get you up and running with the kit. For more detailed information on BLE technology and the TI BLE protocol stack, please consult the Texas Instruments *Bluetooth®* Low Energy Software Developer's Guide.

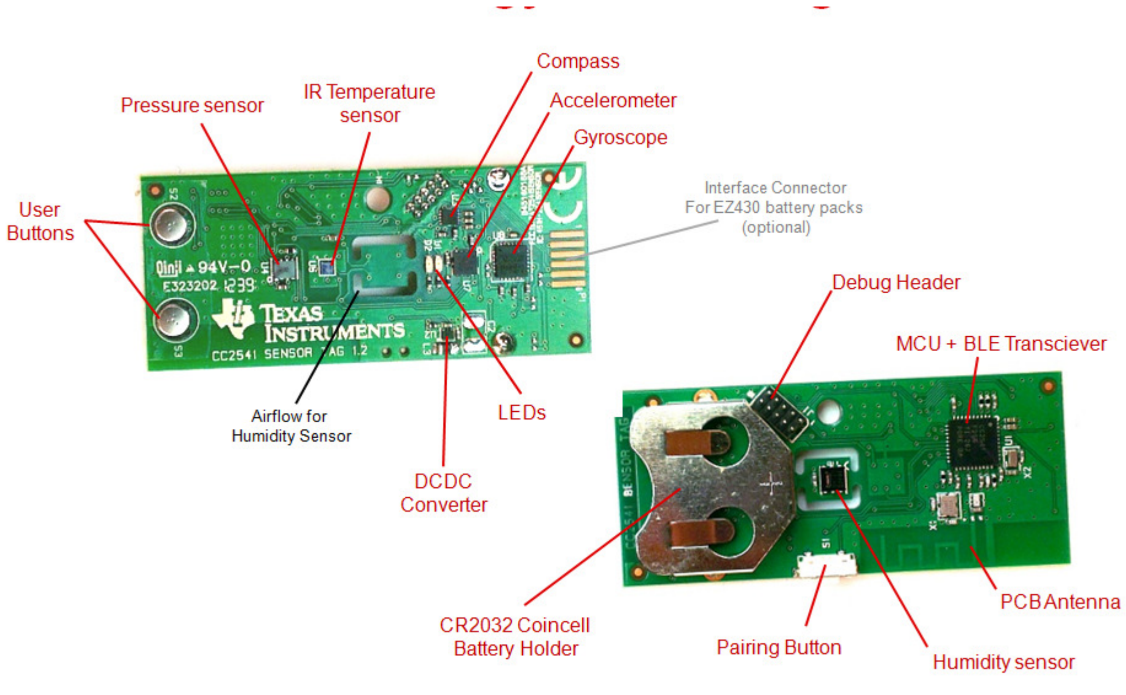
1.1 Kit Contents Overview

The kits contain the following hardware components including cables:

	CC2541 Sensor Tag	CC2540 Dongle	Plastic Case for Sensor Tag
Sensor Tag Kit	•	•	•

The **CC2541 Sensor Tag** is designed to act as a Peripheral Device (BLE Slave). Plastic casing for the sensor tag is also included. The sensor tag operates on a single CR2032 coin cell battery and includes a two-colored LED and the following sensors: temperature, humidity, pressure, accelerometer, gyroscope, and magnetometer.

The sensor tag uses I2C to interface to the different sensors. It is a FCC, IC, and ETSI certified solution. An overview of the sensor tag is shown below:



The **CC2540 USB Dongle** can be used to emulate any type of Bluetooth low energy behavior but is usually used as a Central Device (BLE Master). It connects to a Windows PC's USB Port, and is pre-loaded with the necessary software to receive commands from the PC tool BTool. That is, it acts as a network processor by default.

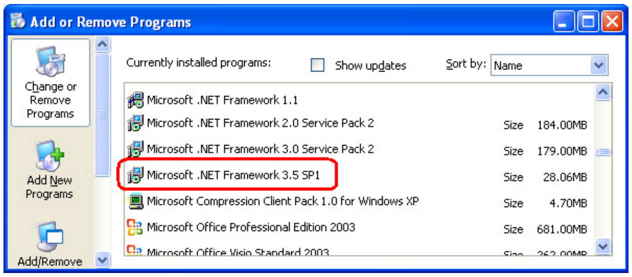
Caution! The kits include a non-rechargeable lithium battery. Always make sure the battery is removed from the CC2540/41 Sensor tag when it is connected to an external power source (Do not apply voltage > 3.6V). Dispose the battery properly and keep out of the reach of children. If swallowed, contact a physician immediately.

Caution! The kits contain ESD sensitive components. Handle with care to prevent permanent damage.

1.2 System Requirements

To use the TI BLE software, a PC running Microsoft Windows (XP or later) is required, as well as Microsoft .NET Framework 3.5 Service Pack 1 (SP1) or greater.

In order to check whether your system has the appropriate .NET Framework, open up the Windows Control Panel, and select “Add or Remove Programs”. Amongst the list of currently installed programs, you should see “Microsoft .NET Framework 3.5 SP1”, as shown in Figure 1:



Currently installed programs: □ Show updates Sort by: Name

Microsoft .NET Framework 1.1		
Microsoft .NET Framework 2.0 Service Pack 2	Size	184.00MB
Microsoft .NET Framework 3.0 Service Pack 2	Size	179.00MB
Microsoft .NET Framework 3.5 SP1	Size	28.06MB
Microsoft Compression Client Pack 1.0 for Windows XP	Size	4.70MB
Microsoft Office Professional Edition 2003	Size	681.00MB
Microsoft Office Visio Standard 2003	Size	262.00MB

Figure 1 System Requirements, .NET Framework 3.5 SP1

If you do not see it in the list, you can download the framework from Microsoft.

From a hardware standpoint, the Windows PC must contain one free USB port. An additional free USB port is required in order to use the CC Debugger and the USB Dongle simultaneously.

IAR Embedded Workbench for 8051 development environment is required in order to make changes to the sensor tag software. More information on IAR can be found in the Texas Instruments *Bluetooth*® Low Energy Software Developer’s Guide **Error! Reference source not found.**.

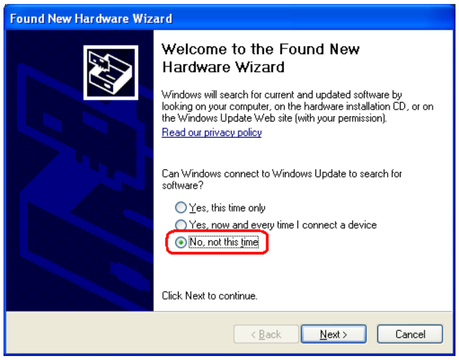
2. Getting Started

This section describes how to set up the software and get started with the Development Kit. It is assumed that the Sensor tag comes pre-programmed out of the box. If not, please see Chapter 4 for details on how to program the sensor tag with the latest firmware. In addition, this section assumes that the latest version of the TI BLE software (v1.3.1 as of the release of this document) has been installed. The latest BLE software can be downloaded at www.ti.com/ble-stack.

2.1 Associate Driver with USB Dongle

After the software installation is complete, the USB Dongle driver must be associated with the device in order to use the demo application. To associate the USB Dongle driver, first you must connect the USB Dongle to the PC's USB port, or to a USB hub that connects to the PC.

The first time that the dongle is connected to the PC, a message will most probably pop-up, indicating that Windows does not recognize the device.



Found New Hardware Wizard

Welcome to the Found New Hardware Wizard

Windows will search for current and updated software by looking on your computer, on the hardware installation CD, or on the Windows Update Web site (with your permission).

Read our privacy policy

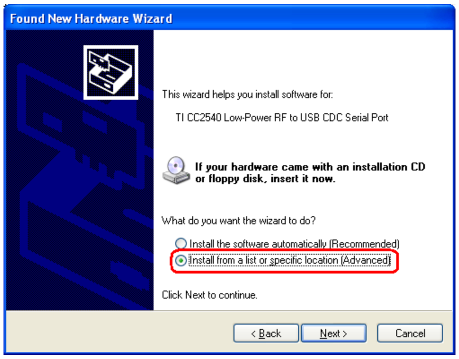
Can Windows connect to Windows Update to search for software?

○ Yes, this time only
○ Yes, now and every time I connect a device
● No, not this time

Click Next to continue.

Figure 2 PC, Found New Hardware

When prompted whether to use Windows Update search for software, select "No, not this time" and press the "Next" button. On the next screen, select the option "Install from a list or specific location (Advanced)", and press the "Next" button:



Found New Hardware Wizard

This wizard helps you install software for:

TI CC2540 Low-Power RF to USB CDC Serial Port

If your hardware came with an installation CD or floppy disk, insert it now.

What do you want the wizard to do?

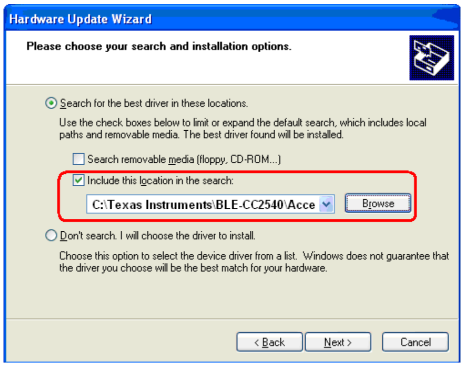
○ Install the software automatically (Recommended)
● Install from a list or specific location (Advanced)

Click Next to continue.

Figure 3 PC, Install Driver

On the next screen, click the checkbox labeled "Include this location in the search:", and click the "Browse" button. Select the following directory (assuming the default installation path was used):

C:\Texas Instruments\BLE-CC254x-1.3.1\Accessories\Drivers


Hardware Update Wizard

Please choose your search and installation options.

● Search for the best driver in these locations.

Use the check boxes below to limit or expand the default search, which includes local paths and removable media. The best driver found will be installed.

□ Search removable media (floppy, CD-ROM...)

☑ Include this location in the search:

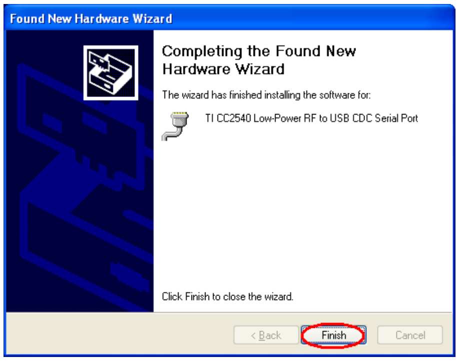
C:\Texas Instruments\BLE-CC2540\Acce

○ Don't search. I will choose the driver to install.

Choose this option to select the device driver from a list. Windows does not guarantee that the driver you choose will be the best match for your hardware.

Figure 4 PC, Select Driver

Click the “Next” button. This should install the driver. It will take a few seconds for the file to load. If the installation was successful, you should see the screen to the below. Click the “Finish” button to complete the installation.


Found New Hardware Wizard

Completing the Found New Hardware Wizard

The wizard has finished installing the software for:

TI CC2540 Low-Power RF to USB CDC Serial Port

Click Finish to close the wizard.

Figure 5 PC, CDC Driver Installation Complete

2.2 Determining the COM Port

Once the driver is installed, you need to determine which COM port Windows has assigned to the USB Dongle. After you have completed the USB Dongle driver association in section 2.1, right-click on the “Computer” icon on your Start and select “Properties”, as shown in Figure 5.

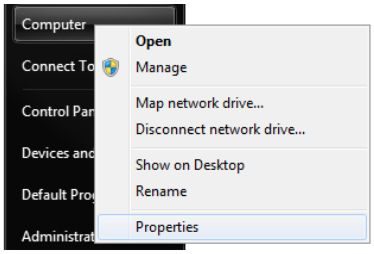
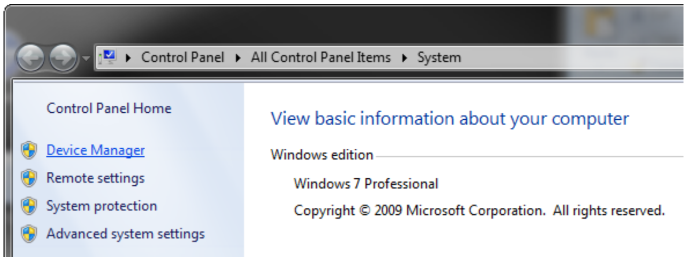


Figure 6 Win7 PC, Finding Computer Properties

The “System Properties” window should open up. Click “Device Manager as shown in Figure 7.



View basic information about your computer

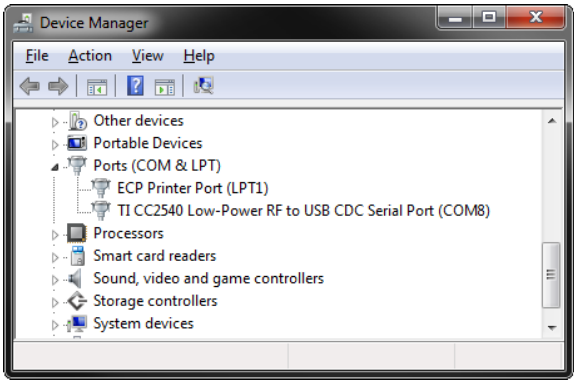
Windows edition

Windows 7 Professional

Copyright © 2009 Microsoft Corporation. All rights reserved.

Figure 7 Win7 PC, Finding Device Manager

A list of all hardware devices should appear. Under the section "Ports (COM & LPT)", the device "TI CC2540 Low-Power RF to USB CDC Serial Port" should appear. Next to the name should be the port number (for example, the CC2540USB Dongle uses COM8 in Figure 8).



- Other devices
- Portable Devices
- Ports (COM & LPT)
  - ECP Printer Port (LPT1)
  - TI CC2540 Low-Power RF to USB CDC Serial Port (COM8)
- Processors
- Smart card readers
- Sound, video and game controllers
- Storage controllers
- System devices

Figure 8 Win7 PC, Connected Ports List

Take note of this port number, as it will be needed in order to use BTool. You may close the device manager at this point.

3. Using BTool

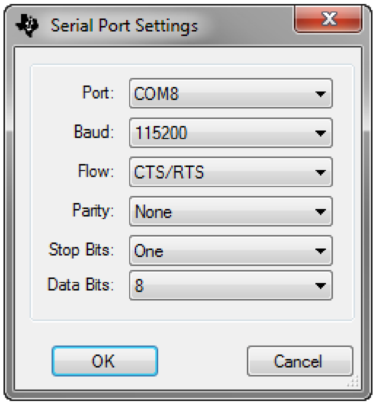
BTool is a PC Application that allows a user to form a connection between two BLE devices. BTool works by communicating with the CC2540 USB Dongle, acting as a network processor, by means of HCI vendor specific commands. The USB Dongle software (when running the HostTestRelease project) and driver create a virtual serial port over the USB interface. BTool, running on the PC, communicates with the USB Dongle through this virtual serial port.

More information on the network processor configuration and the HostTestRelease project can be found in the Texas Instruments *Bluetooth*® Low Energy Software Developer's Guide. More information on the HCI interface, as well as details on the HCI vendor specific commands that are used by the CC2540/41, can be found in the TI BLE Vendor Specific HCI Reference Guide. These documents can be found in the Documents folder of the stack install directory.

For this section, a PC running windows 7 has been used, but the procedures are essentially the same for other windows version, such as XP.

3.1 Starting the Application

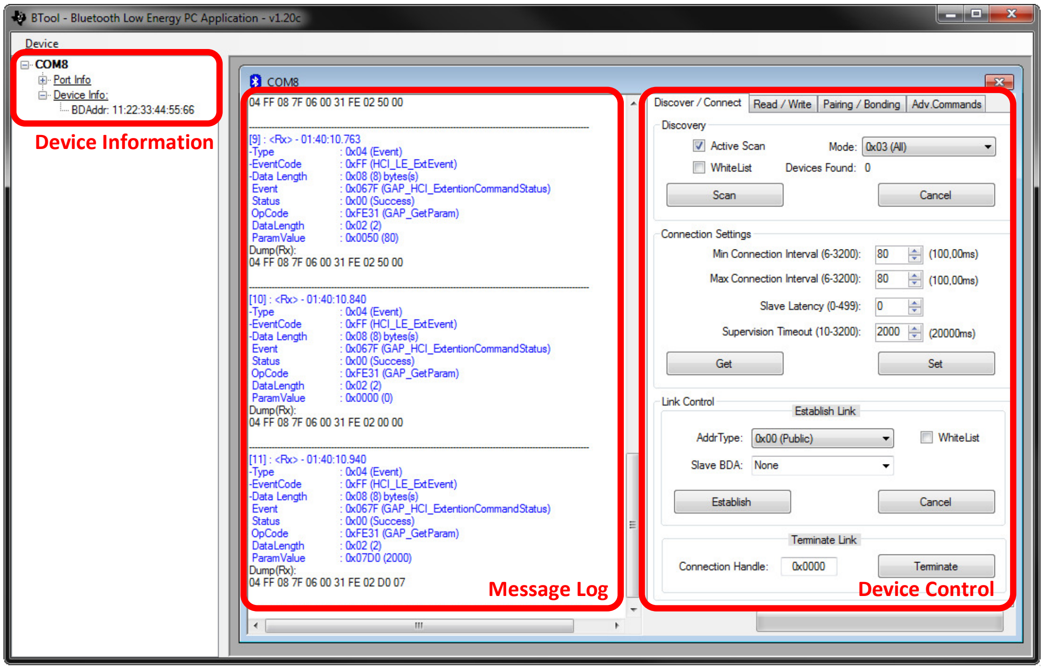
To start the application, go into your programs by choosing Start > Programs > Texas Instruments > BLE-CC254x-1.3.1 > BTool. On Start-up you should be able to set the Serial Port Settings. Set the "Port" value to the COM port earlier noted in Section 3.2. For the other settings, use the default values as shown in Figure 9. Press "OK" to connect to the CC2540 USB Dongle.


Serial Port Settings

Port: COM8
Baud: 115200
Flow: CTS/RTS
Parity: None
Stop Bits: One
Data Bits: 8

Figure 9 BTool, Serial Port settings

When connected you should see the screen presented in Figure 10. The screen indicates that you now have a serial port connection to the CC2540 USB Dongle. The screen is divided up into a few sections: the left sidebar contains information on the CC2540 USB Dongle status. The left side of the sub-window contains a log of all messages sent from the PC to the CC2540 USB Dongle and received by the PC from the CC2540 USB Dongle. The right side of the sub-window contains a GUI for control of the CC2540 USB Dongle. The bottom pane is the attribute explorer which we will discuss later on.



COM8
Port Info
Device Info:
BDAddr: 11:22:33:44:55:66

```
04 FF 08 7F 06 00 31 FE 02 50 00

------------------------------------------------------------
[9] : <Rx> - 01:40:10.763
-Type           : 0x04 (Event)
-EventCode      : 0xFF (HCI_LE_ExtEvent)
-Data Length    : 0x08 (8) bytes(s)
 Event          : 0x067F (GAP_HCI_ExtentionCommandStatus)
 Status         : 0x00 (Success)
 OpCode         : 0xFE31 (GAP_GetParam)
 DataLength     : 0x02 (2)
 ParamValue     : 0x0050 (80)
Dump(Rx):
04 FF 08 7F 06 00 31 FE 02 50 00

------------------------------------------------------------
[10] : <Rx> - 01:40:10.840
-Type           : 0x04 (Event)
-EventCode      : 0xFF (HCI_LE_ExtEvent)
-Data Length    : 0x08 (8) bytes(s)
 Event          : 0x067F (GAP_HCI_ExtentionCommandStatus)
 Status         : 0x00 (Success)
 OpCode         : 0xFE31 (GAP_GetParam)
 DataLength     : 0x02 (2)
 ParamValue     : 0x0000 (0)
Dump(Rx):
04 FF 08 7F 06 00 31 FE 02 00 00

------------------------------------------------------------
[11] : <Rx> - 01:40:10.940
-Type           : 0x04 (Event)
-EventCode      : 0xFF (HCI_LE_ExtEvent)
-Data Length    : 0x08 (8) bytes(s)
 Event          : 0x067F (GAP_HCI_ExtentionCommandStatus)
 Status         : 0x00 (Success)
 OpCode         : 0xFE31 (GAP_GetParam)
 DataLength     : 0x02 (2)
 ParamValue     : 0x07D0 (2000)
Dump(Rx):
04 FF 08 7F 06 00 31 FE 02 D0 07
```

Discovery

☑ Active Scan   Mode: 0x03 (All)

☐ WhiteList   Devices Found: 0

Connection Settings

Min Connection Interval (6-3200): 80 (100,00ms)

Max Connection Interval (6-3200): 80 (100,00ms)

Slave Latency (0-499): 0

Supervision Timeout (10-3200): 2000 (20000ms)

Link Control

Establish Link

AddrType: 0x00 (Public)   ☐ WhiteList

Slave BDA: None

Terminate Link

Connection Handle: 0x0000

Figure 10 BTool, Overview

3.2 Creating a BLE Connection between USB Dongle and Sensor tag

At this point the USB Dongle (central) is ready to discover other BLE devices that are advertising. The sensor tag should be preloaded with the sensor tag application. The full project and application source code files for the sensor tag are included in the BLE software development kit.

At this time you will want to insert the battery (or remove and re-insert the battery to reset the device) into the sensor tag (peripheral). You should also assemble the plastic and rubber portions of the kit to minimize ESD on the board.

In order to ensure that you are connecting to the correct device, **you need to know your sensor tag's address**. To save time for this tutorial, we have included your address on the bottom of the lid of your development kit. Alternatively, you can refer to section 5.3.2 for instructions to read the sensor tag's primary address.

3.2.1 Making the Sensor tag Discoverable

When the sensor tag powers up, it will not immediately go into a discoverable state. To enable advertising and make the sensor tag discoverable, press the "pairing button" on the side of the sensor tag once. This will turn advertisements on; making the device discoverable for 30 seconds (this value is defined in the *Specification of the Bluetooth System*). After that time, the device will return to standby mode. To make the device discoverable again, simply press the button once again. During discoverable mode, the LED will flash green.

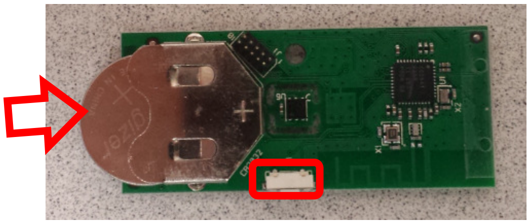
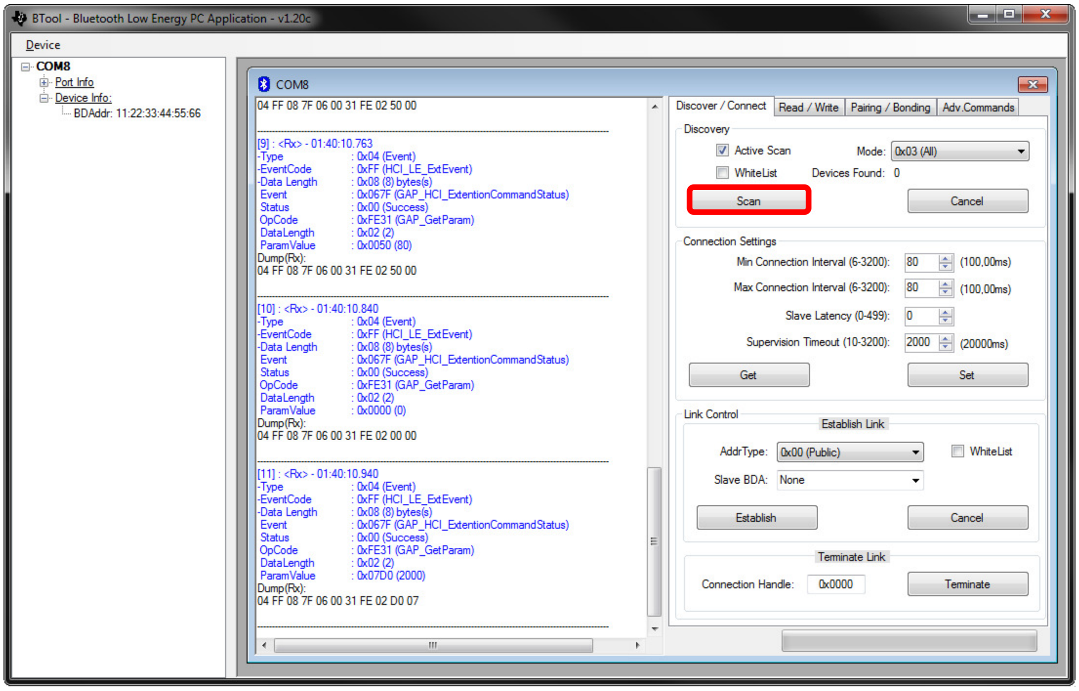


Figure 11 Press Side Button to Turn On Advertisements

3.2.2 Scanning for Devices

In BTool, Press the “Scan” button under the “Discover / Connect” tab, as shown in Figure 12.



BDAddr: 11:22:33:44:55:66

```
04 FF 08 7F 06 00 31 FE 02 50 00

------------------------------------------------------------------------
[9] : <Rx> - 01:40:10.763
-Type           : 0x04 (Event)
-EventCode      : 0xFF (HCI_LE_ExtEvent)
-Data Length    : 0x08 (8) bytes(s)
 Event          : 0x067F (GAP_HCI_ExtentionCommandStatus)
 Status         : 0x00 (Success)
 OpCode         : 0xFE31 (GAP_GetParam)
 DataLength     : 0x02 (2)
 ParamValue     : 0x0050 (80)
Dump(Rx):
04 FF 08 7F 06 00 31 FE 02 50 00

------------------------------------------------------------------------
[10] : <Rx> - 01:40:10.840
-Type           : 0x04 (Event)
-EventCode      : 0xFF (HCI_LE_ExtEvent)
-Data Length    : 0x08 (8) bytes(s)
 Event          : 0x067F (GAP_HCI_ExtentionCommandStatus)
 Status         : 0x00 (Success)
 OpCode         : 0xFE31 (GAP_GetParam)
 DataLength     : 0x02 (2)
 ParamValue     : 0x0000 (0)
Dump(Rx):
04 FF 08 7F 06 00 31 FE 02 00 00

------------------------------------------------------------------------
[11] : <Rx> - 01:40:10.940
-Type           : 0x04 (Event)
-EventCode      : 0xFF (HCI_LE_ExtEvent)
-Data Length    : 0x08 (8) bytes(s)
 Event          : 0x067F (GAP_HCI_ExtentionCommandStatus)
 Status         : 0x00 (Success)
 OpCode         : 0xFE31 (GAP_GetParam)
 DataLength     : 0x02 (2)
 ParamValue     : 0x07D0 (2000)
Dump(Rx):
04 FF 08 7F 06 00 31 FE 02 D0 07

------------------------------------------------------------------------
```

Discovery

☑ Active Scan　Mode: 0x03 (All)

☐ WhiteList　Devices Found: 0

Connection Settings

Min Connection Interval (6-3200): 80 (100,00ms)

Max Connection Interval (6-3200): 80 (100,00ms)

Slave Latency (0-499): 0

Supervision Timeout (10-3200): 2000 (20000ms)

Link Control

Establish Link

AddrType: 0x00 (Public)　☐ WhiteList

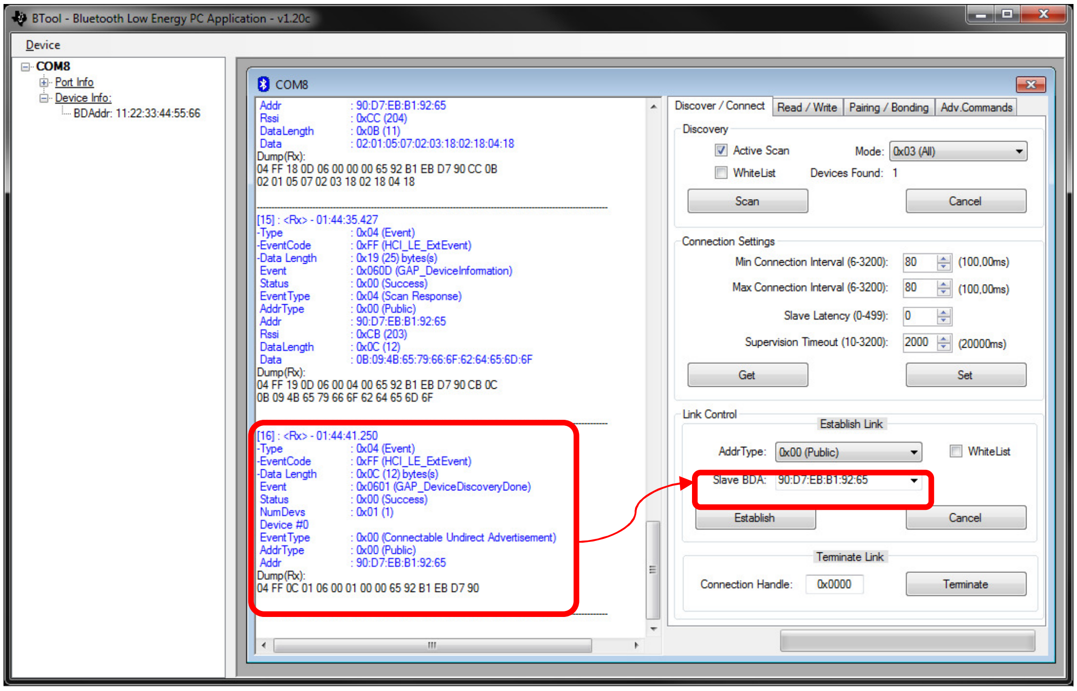
Slave BDA: None

Terminate Link

Connection Handle: 0x0000

Figure 12 BTool, Scan for Devices

The USB Dongle will begin search for other BLE devices. As devices are found, the log on the left side of the screen will display the devices discovered. After 10 seconds, the device discovery process will complete, and the USB Dongle will stop scanning. A summary of all the scanned devices will be displayed in the log window. In the example in Figure 13, one peripheral device was discovered while scanning. If you do not want to wait through the full 10 seconds of scanning, the “Cancel” button can be pressed alternatively, which will stop the device discovery process. The address of any scanned devices will appear in the “Slave BDA” section of the “Link Control” section in the bottom right corner of the sub-window.



BDAddr: 11:22:33:44:55:66

```
 Addr               : 90:D7:EB:B1:92:65
 Rssi               : 0xCC (204)
 DataLength         : 0x0B (11)
 Data               : 02:01:05:07:02:03:18:02:18:04:18
Dump(Rx):
04 FF 18 0D 06 00 00 00 65 92 B1 EB D7 90 CC 0B
02 01 05 07 02 03 18 02 18 04 18

------------------------------------------------------------------
[15] : <Rx> - 01:44:35.427
-Type               : 0x04 (Event)
-EventCode          : 0xFF (HCI_LE_ExtEvent)
-Data Length        : 0x19 (25) bytes(s)
 Event              : 0x060D (GAP_DeviceInformation)
 Status             : 0x00 (Success)
 EventType          : 0x04 (Scan Response)
 AddrType           : 0x00 (Public)
 Addr               : 90:D7:EB:B1:92:65
 Rssi               : 0xCB (203)
 DataLength         : 0x0C (12)
 Data               : 0B:09:4B:65:79:66:6F:62:64:65:6D:6F
Dump(Rx):
04 FF 19 0D 06 00 04 00 65 92 B1 EB D7 90 CB 0C
0B 09 4B 65 79 66 6F 62 64 65 6D 6F

------------------------------------------------------------------
[16] : <Rx> - 01:44:41.250
-Type               : 0x04 (Event)
-EventCode          : 0xFF (HCI_LE_ExtEvent)
-Data Length        : 0x0C (12) bytes(s)
 Event              : 0x0601 (GAP_DeviceDiscoveryDone)
 Status             : 0x00 (Success)
 NumDevs            : 0x01 (1)
 Device #0
 EventType          : 0x00 (Connectable Undirect Advertisement)
 AddrType           : 0x00 (Public)
 Addr               : 90:D7:EB:B1:92:65
Dump(Rx):
04 FF 0C 01 06 00 01 00 00 65 92 B1 EB D7 90

------------------------------------------------------------------
```

☑ Active Scan Mode: 0x03 (All)
☐ WhiteList Devices Found: 1

Min Connection Interval (6-3200): 80 (100,00ms)
Max Connection Interval (6-3200): 80 (100,00ms)
Slave Latency (0-499): 0
Supervision Timeout (10-3200): 2000 (20000ms)

AddrType: 0x00 (Public) ☐ WhiteList
Slave BDA: 90:D7:EB:B1:92:65

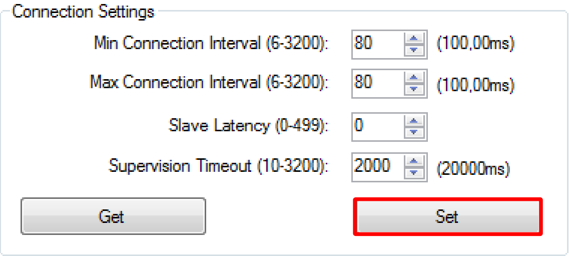
Connection Handle: 0x0000

Figure 13 BTool, Slave Address

3.2.3 Selecting Connection Parameters

Before establishing a connection, you can set up the desired connection parameters. The default values of 100ms connection interval, 0 slave latency, and 20s supervision timeout should serve as a good starting point; however for different applications you may want to experiment with these values.

Once the desired values have been set, be sure to click the "Set" button; otherwise the settings will not be saved. Note that the connection parameters must be set before a connection is established; changing the values and clicking the "Set" button while a connection is active will not change the settings of an active connection. The connection must be terminated and re-established to use the new parameters. (The *Bluetooth* specification does support connection parameter updates while a connection is active; however this must be done using either an L2CAP connection parameter update request, or using a direct HCI command. More information can be found in the *Specification of the Bluetooth System*)

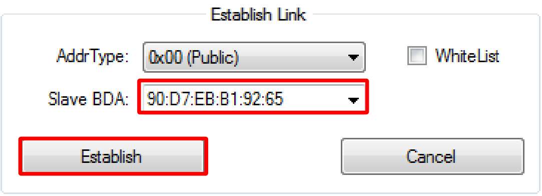


Min Connection Interval (6-3200): 80 (100,00ms)
Max Connection Interval (6-3200): 80 (100,00ms)
Slave Latency (0-499): 0
Supervision Timeout (10-3200): 2000 (20000ms)

Figure 14 BTool, Connection Settings

3.2.4 Establishing a Connection

To establish a connection with the sensor tag, select the address of the device to connect with and click the "Establish" button as shown in Figure 15.


Establish Link

AddrType: 0x00 (Public)

☐ WhiteList

Slave BDA: 90:D7:EB:B1:92:65

Figure 15 BTool, Establish Connection

If the sensor tag is still in discoverable mode, a connection should be established (if more than 30 seconds have passed since the device was previously made discoverable, press the right button on the sensor tag once again). Once a connection is established, the message window will return a “GAP_EstablishLink” event message with a “Status” value of “0x00 (Success)” as shown in Figure 16.

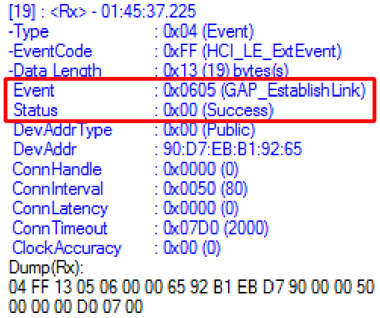

```
[19] : <Rx> - 01:45:37.225
-Type           : 0x04 (Event)
-EventCode      : 0xFF (HCI_LE_ExtEvent)
-Data Length    : 0x13 (19) bytes(s)
 Event          : 0x0605 (GAP_EstablishLink)
 Status         : 0x00 (Success)
 DevAddrType    : 0x00 (Public)
 DevAddr        : 90:D7:EB:B1:92:65
 ConnHandle     : 0x0000 (0)
 ConnInterval   : 0x0050 (80)
 ConnLatency    : 0x0000 (0)
 ConnTimeout    : 0x07D0 (2000)
 ClockAccuracy  : 0x00 (0)
Dump(Rx):
04 FF 13 05 06 00 00 65 92 B1 EB D7 90 00 00 50
00 00 00 D0 07 00
```

Figure 16 BTool Log, Link Established

In BTool, you can see your connected peripheral device in the Device Information field, as shown in Figure 17.

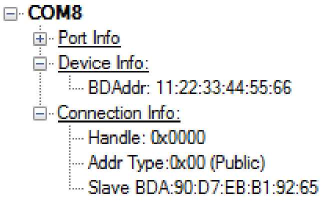

```
⊟ COM8
   ⊞ Port Info
   ⊟ Device Info:
        BDAddr: 11:22:33:44:55:66
   ⊟ Connection Info:
        Handle: 0x0000
        Addr Type:0x00 (Public)
        Slave BDA:90:D7:EB:B1:92:65
```

Figure 17 BTool, Device Information

3.3 Using the Sensor Tag’s GATT Profiles

We will now begin investigating the sensor tag’s GATT profiles. Besides the standard GAP, GATT, and device information services, the sensor tag contains the following GATT services: temperature, accelerometer, humidity, magnetometer, barometer, gyroscope, simple keys, and test. You will find the sensor tag complete attribute below and it can be used as a reference. Services are shown in yellow, characteristics are shown in blue, and characteristic values / descriptors are shown in grey.

Services are constructed of characteristics, each of which have, at minimum, a declaration and a value, and may have a client configuration and/or a user description. The actual payload data is stored with the characteristic values. All application data that is being sent or received in Bluetooth low energy must be contained within characteristic values. This section details a step-by-step process that demonstrates several processes for reading, writing, discovering, and notifying GATT characteristic values using BTool.

In a *Bluetooth* low energy system, upon connection, the Central Device (GATT Client) performs a service discovery on the Peripheral device (GATT server) to build up an attribute table. This attribute table will provide handles (internal addresses of the characteristics) which can be used by the Client to access the data located in the Server. The service discovery is typically an automated process that can be started with a single command. In BTool however, the automated service discovery is not implemented (although it’s still possible to perform it manually). To simplify the evaluation of the sensor tag, the attribute table will be known and is shown below so it is possible to use handles directly to read out data.

Sensor Tag Application: Complete Attribute Table

TI Base UUID: F000XXXX-0451-4000-B000-000000000000. 128-but UUIDs are typed 'bold'

handle (hex)	handle (dec)	Type (hex)	Type (#DEFINE)	Hex / Text Value (default)	GATT Server Permissions	Notes
0x1	1	0x2800	GATT_PRIMARY_SERVICE_UUID	0x1800 (GAP_SERVICE_UUID)	GATT_PERMIT_READ	Start of GAP Service (Mandatory)
0x2	2	0x2803	GATT_CHARACTER_UUID	02 (properties: read only) 03 00 (handle: 0x0003) 00 2A (UUID: 0x2A00)	GATT_PERMIT_READ	Device Name characteristic declaration
0x3	3	0x2A00	GAP_DEVICE_NAME_UUID	"Sensor Tag"	GATT_PERMIT_READ	Device Name characteristic value
0x4	4	0x2803	GATT_CHARACTER_UUID	02 (properties: read only) 05 00 (handle: 0x0005) 01 2A (UUID: 0x2A01)	GATT_PERMIT_READ	Appearance characteristic declaration
0x5	5	0x2A01	GAP_APPEARANCE_UUID	0x0000	GATT_PERMIT_READ	Appearance characteristic value
0x6	6	0x2803	GATT_CHARACTER_UUID	0A (properties: read/write) 07 00 (handle: 0x0007) 02 2A (UUID: 0x2A02)	GATT_PERMIT_READ	Peripheral Privacy Flag characteristic declaration
0x7	7	0x2A02	GAP_PERI_PRIVACY_FLAG_UUID	0x00 (GAP_PRIVACY_DISABLED)	GATT_PERMIT_READ | GATT_PERMIT_WRITE	Peripheral Privacy Flag characteristic value
0x8	8	0x2803	GATT_CHARACTER_UUID	0A (properties: read/write) 09 00 (handle: 0x0009) 03 2A (UUID: 0x2A03)	GATT_PERMIT_READ	Reconnection address characteristic declaration
0x9	9	0x2A03	GAP_RECONNECT_ADDR_UUID	00:00:00:00:00:00	GATT_PERMIT_READ | GATT_PERMIT_WRITE	Reconnection address characteristic value
0xA	10	0x2803	GATT_CHARACTER_UUID	02 (properties: read only) 0B 00 (handle: 0x000B) 04 2A (UUID: 0x2A04)	GATT_PERMIT_READ	Peripheral Preferred Connection Parameters characteristic declaration
0xB	11	0x2A04	GAP_PERI_CONN_PARAM_UUID	50 00 (100ms preferred min connection interval) A0 00 (200ms preferred max connection interval) 00 00 (0 preferred slave latency) E8 03 (10000ms preferred supervision timeout)	GATT_PERMIT_READ	Peripheral Preferred Connection Parameters characteristic declaration
0xC	12	0x2800	GATT_PRIMARY_SERVICE_UUID	0x1801 (GATT_SERVICE_UUID)	GATT_PERMIT_READ	Start of GATT Service (mandatory)
0xD	13	0x2803	GATT_CHARACTER_UUID	20 (properties: indicate only) 0E 00 (handle: 0x000E) 05 2A (UUID: 0x2A05)	GATT_PERMIT_READ	Service Changed characteristic declaration
0xE	14	0x2A05	GATT_SERVICE_CHANGED_UUID	(null value)	(none)	Service Changed characteristic value
0xF	15	0x2902	GATT_CLIENT_CHAR_CFG_UUID	00:00 (2 bytes)	GATT_PERMIT_READ | GATT_PERMIT_WRITE	Write "01:00" to enable notifications, "00:00" to disable
0x10	16	0x2800	GATT_PRIMARY_SERVICE_UUID	0x180A (DEVINFO_SERV_UUID)	GATT_PERMIT_READ	Start of Device Information Service
0x11	17	0x2803	GATT_CHARACTER_UUID	02 (read permissions) 11 00 (handle 0x0011) 23 2A (UUID 0x2A23)	GATT_PERMIT_READ	System ID characteristic declaration
0x12	18	0x2A23	DEVINFO_SYSTEM_ID_UUID	xx xx xx 00 00 xx xx xx (xx's are IEEE address)	GATT_PERMIT_READ	System ID
0x13	19	0x2803	GATT_CHARACTER_UUID	02 (read permissions) 13 00 (handle 0x0013) 24 2A (UUID 0x2A24)	GATT_PERMIT_READ	Model Number String characteristic declaration
0x14	20	0x2A24	DEVINFO_MODEL_NUMBER_UUID	"Model Number"	GATT_PERMIT_READ	Model Number String
0x15	21	0x2803	GATT_CHARACTER_UUID	02 (read permissions) 15 00 (handle 0x0015) 25 2A (UUID 0x2A25)	GATT_PERMIT_READ	Serial Number String characteristic declaration
0x16	22	0x2A25	DEVINFO_SERIAL_NUMBER_UUID	"Serial Number"	GATT_PERMIT_READ	Serial Number String
0x17	23	0x2803	GATT_CHARACTER_UUID	02 (read permissions) 17 00 (handle 0x0017) 26 2A (UUID 0x2A26)	GATT_PERMIT_READ	Firmware Revision String characteristic declaration
0x18	24	0x2A26	DEVINFO_FIRMWARE_REV_UUID	"Firmware Revision"	GATT_PERMIT_READ	Firmware Revision String
0x19	25	0x2803	GATT_CHARACTER_UUID	02 (read permissions) 19 00 (handle 0x0019) 27 2A (UUID 0x2A27)	GATT_PERMIT_READ	Hardware Revision String characteristic declaration
0x1A	26	0x2A27	DEVINFO_HARDWARE_REV_UUID	"Hardware Revision"	GATT_PERMIT_READ	Hardware Revision String
0x1B	27	0x2803	GATT_CHARACTER_UUID	02 (read permissions) 1B 00 (handle 0x001B) 28 2A (UUID 0x2A28)	GATT_PERMIT_READ	Software Revision String characteristic declaration
0x1C	28	0x2A28	DEVINFO_SOFTWARE_REV_UUID	"Software Revision"	GATT_PERMIT_READ	Software Revision String
0x1D	29	0x2803	GATT_CHARACTER_UUID	02 (read permissions) 1D 00 (handle 0x001D) 29 2A (UUID 0x2A29)	GATT_PERMIT_READ	Manufacturer Name String characteristic declaration
0x1E	30	0x2A29	DEVINFO_MANUFACTURER_NAME_UUID	"Manufacturer Name"	GATT_PERMIT_READ	Manufacturer Name String
0x1F	31	0x2803	GATT_CHARACTER_UUID	02 (read permissions) 1F 00 (handle 0x001F) 2A 2A (UUID 0x2A2A)	GATT_PERMIT_READ	IEEE 11073-20601 Regulatory Certification Data List characteristic declaration
0x20	32	0x2A2A	DEVINFO_11073_CERT_DATA_UUID	FE 00 65 78 70 65 72 69 6D 65 6E 74 61 6C	GATT_PERMIT_READ	IEEE 11073-20601 Regulatory Certification Data List
0x21	33	0x2803	GATT_CHARACTER_UUID	02 (read permissions) 22 00 (handle 0x0022) 50 2A (UUID 0x2A50)	GATT_PERMIT_READ	PnP ID characteristic declaration
0x22	34	0x2A2A	PNPID_DATA_UUID	FE 00 65 78 70 65 72 69 6D 65 6E 74 61 6C	GATT_PERMIT_READ	PnP ID

0x23	35	0x2800	GATT_PRIMARY_SERVICE_UUID	**0xAA00** (IRTEMPERATURE_SERV_UUID)	GATT_PERMIT_READ	Start of Sensor Profile Temperature Service
0x24	36	0x2803	GATT_CHARACTER_UUID	12 (properties: read/notify) 25 00 (handle: 0x0025) 01 AA (UUID: **0xAA01**)	GATT_PERMIT_READ	
0x25	37	**0xAA01**	IRTEMPERATURE_DATA_UUID	00:00:00:00 (4 bytes)	GATT_PERMIT_READ	ObjectLSB:ObjectMSB:AmbientLSB:AmbientMSB
0x26	38	0x2902	GATT_CLIENT_CHAR_CFG_UUID	00:00 (2 bytes)	GATT_PERMIT_READ | GATT_PERMIT_WRITE	Write "01:00" to enable notifications, "00:00" to disable
0x27	39	0x2901	GATT_CHAR_USER_DESC_UUID	"IR Temp. Data" (14 bytes)	GATT_PERMIT_READ	
0x28	40	0x2803	GATT_CHARACTER_UUID	0A (properties: read/write) 29 00 (handle: 0x0029) 02AA (UUID: **0xAA02**)	GATT_PERMIT_READ	
0x29	41	**0xAA02**	IRTEMPERATURE_CONF_UUID	1 (1 byte)	GATT_PERMIT_READ | GATT_PERMIT_WRITE	Write "01" to start Sensor and Measurements, "00" to put to sleep
0x2A	42	0x2901	GATT_CHAR_USER_DESC_UUID	"IR Temp. Conf." (15 bytes)	GATT_PERMIT_READ	
0x2B	43	0x2800	GATT_PRIMARY_SERVICE_UUID	**0xAA10** (ACCELEROMETER_SERV_UUID)	GATT_PERMIT_READ	Start of Sensor Profile Accelerometer Service
0x2C	44	0x2803	GATT_CHARACTER_UUID	12 (properties: read/notify) 2D 00 (handle: 0x002D) 11 AA (UUID: **0xAA11**)	GATT_PERMIT_READ	
0x2D	45	**0xAA11**	ACCELEROMETER_DATA_UUID	00:00:00 (3 bytes)	GATT_PERMIT_READ	X : Y : Z Coordinates
0x2E	46	0x2902	GATT_CLIENT_CHAR_CFG_UUID	00:00 (2 bytes)	GATT_PERMIT_READ | GATT_PERMIT_WRITE	Write "01:00" to enable notifications, "00:00" to disable
0x2F	47	0x2901	GATT_CHAR_USER_DESC_UUID	"Accel. Data" (14 bytes)	GATT_PERMIT_READ	
0x30	48	0x2803	GATT_CHARACTER_UUID	0A (properties: read/write) 31 00 (handle: 0x0031) 12 AA (UUID: **0xAA12**)	GATT_PERMIT_READ	
0x31	49	**0xAA12**	ACCELEROMETER_CONF_UUID	1 (1 byte)	GATT_PERMIT_READ | GATT_PERMIT_WRITE	Write "01" to start Sensor and Measurements, "00" to put to sleep
0x32	50	0x2901	GATT_CHAR_USER_DESC_UUID	"Accel. Conf." (15 bytes)	GATT_PERMIT_READ	
0x33	51	0x2803	GATT_CHARACTER_UUID	0A (properties: read/write) 34 00 (handle: 0x0034) 13 AA (UUID: **0xAA13**)	GATT_PERMIT_READ	
0x34	52	**0xAA13**	ACCELEROMETER_PERI_UUID	1 (1 byte)	GATT_PERMIT_READ | GATT_PERMIT_WRITE	Period = [Input*10] ms, default 1000 ms, lower limit 100 ms
0x35	53	0x2901	GATT_CHAR_USER_DESC_UUID	"Acc. Period" (12 bytes)	GATT_PERMIT_READ	
0x36	54	0x2800	GATT_PRIMARY_SERVICE_UUID	**0xAA20** (HUMIDITY_SERV_UUID)	GATT_PERMIT_READ	Start of Sensor Profile Humidity Service
0x37	55	0x2803	GATT_CHARACTER_UUID	12 (properties: read/notify) 38 00 (handle: 0x0038) 21 AA (UUID: **0xAA21**)	GATT_PERMIT_READ	
0x38	56	**0xAA21**	HUMIDITY_DATA_UUID	00:00:00:00 (4 bytes)	GATT_PERMIT_READ	TempLSB:TempMSB:HumidityLSB:HumidityMSB
0x39	57	0x2902	GATT_CLIENT_CHAR_CFG_UUID	00:00 (2 bytes)	GATT_PERMIT_READ | GATT_PERMIT_WRITE	Write "01:00" to enable notifications
0x3A	58	0x2901	GATT_CHAR_USER_DESC_UUID	"Humid. Data" (14 bytes)	GATT_PERMIT_READ	
0x3B	59	0x2803	GATT_CHARACTER_UUID	0A (properties: read/write) 3C 00 (handle: 0x003C) 22 AA (UUID: **0xAA22**)	GATT_PERMIT_READ	
0x3C	60	**0xAA22**	HUMIDITY_CONF_UUID	1 (1 byte)	GATT_PERMIT_READ | GATT_PERMIT_WRITE	Write "01" to start Sensor and Measurements, "00" to put to sleep
0x3D	61	0x2901	GATT_CHAR_USER_DESC_UUID	"Humid. Conf." (15 bytes)	GATT_PERMIT_READ	
0x3E	62	0x2800	GATT_PRIMARY_SERVICE_UUID	**0xAA30** (MAGNETOMETER_SERV_UUID)	GATT_PERMIT_READ	Start of Sensor Profile Magnetometer Service
0x3F	63	0x2803	GATT_CHARACTER_UUID	12 (properties: read/notify) 40 00 (handle: 0x0040) 31 AA (UUID: **0xAA31**)	GATT_PERMIT_READ	
0x40	64	**0xAA31**	MAGNETOMETER_DATA_UUID	00:00:00:00:00:00 (6 bytes)	GATT_PERMIT_READ	XLSB:XMSB:YLSB:YMSB: ZLSB:ZMSB Coordinates
0x41	65	0x2902	GATT_CLIENT_CHAR_CFG_UUID	00:00 (2 bytes)	GATT_PERMIT_READ | GATT_PERMIT_WRITE	Write "01:00" to enable notifications, "00:00" to disable
0x42	66	0x2901	GATT_CHAR_USER_DESC_UUID	"Mag. Data" (10 bytes)	GATT_PERMIT_READ	
0x43	67	0x2803	GATT_CHARACTER_UUID	0A (properties: read/write) 44 00 (handle: 0x0044) 32 AA (UUID: 0xAA32)	GATT_PERMIT_READ	
0x44	68	**0xAA32**	MAGNETOMETER_CONF_UUID	1 (1 byte)	GATT_PERMIT_READ | GATT_PERMIT_WRITE	Write "01" to start Sensor and Measurements, "00" to put to sleep
0x45	69	0x2901	GATT_CHAR_USER_DESC_UUID	"Mag. Conf." (11 bytes)	GATT_PERMIT_READ	
0x46	70	0x2803	GATT_CHARACTER_UUID	0A (properties: read/write) 47 00 (handle: 0x0047) 33 AA (UUID: **0xAA33**)	GATT_PERMIT_READ	
0x47	71	**0xAA33**	MAGNETOMETER_PERI_UUID	1 (1 byte)	GATT_PERMIT_READ | GATT_PERMIT_WRITE	Period = [Input*10]ms, default 2000ms, lower limit 100 ms
0x48	72	0x2901	GATT_CHAR_USER_DESC_UUID	"Mag. Period" (12 bytes)	GATT_PERMIT_READ	

0x49	73	0x2800	GATT_PRIMARY_SERVICE_UUID	**0xAA40** (BAROMETER_SERV_UUID)	GATT_PERMIT_READ	Start of Sensor Profile Barometer Service
0x4A	74	0x2803	GATT_CHARACTER_UUID	12 (properties: read/notify) 4B 00 (handle: 0x004B) 41 AA (UUID: **0xAA41**)	GATT_PERMIT_READ	
0x4B	75	**0xAA41**	BAROMETER_DATA_UUID	00:00:00:00 (4 bytes)	GATT_PERMIT_READ	TempLSB:TempMSB:PressureLSB:PressureMSB
0x4C	76	0x2902	GATT_CLIENT_CHAR_CFG_UUID	00:00 (2 bytes)	GATT_PERMIT_READ | GATT_PERMIT_WRITE	
0x4D	77	0x2901	GATT_CHAR_USER_DESC_UUID	"Barometer Data" (15 bytes)	GATT_PERMIT_READ	
0x4E	78	0x2803	GATT_CHARACTER_UUID	0A (properties: read/write) 53 00 (handle: 0x0053) 42 AA (UUID: **0xAA42**)	GATT_PERMIT_READ	
0x4F	79	**0xAA42**	BAROMETER_CONF_UUID	1 (1 byte)	GATT_PERMIT_READ | GATT_PERMIT_WRITE	Write "01" to start Sensor and Measurements, "00" to put to sleep, "02" to read calibration values from sensor
0x50	80	0x2901	GATT_CHAR_USER_DESC_UUID	"Barometer Conf." (16 bytes)	GATT_PERMIT_READ	
0x51	81	0x2803	GATT_CHARACTER_UUID	02 (properties: read only) 4F 00 (handle: 0x004F) 43 AA (UUID: **0xAA43**)	GATT_PERMIT_READ	
0x52	82	**0xAA43**	BAROMETER_CALI_UUID	00:00:...:00:00 (16 bytes)	GATT_PERMIT_READ	When write 02 to Barometer Conf. has been issued, the calibration values is found here
0x53	83	0x2902	GATT_CLIENT_CHAR_CFG_UUID	00:00 (2 bytes)	GATT_PERMIT_READ | GATT_PERMIT_WRITE	
0x54	84	0x2901	GATT_CHAR_USER_DESC_UUID	"Barometer Cali." (16 bytes)	GATT_PERMIT_READ	
0x55	85	0x2800	GATT_PRIMARY_SERVICE_UUID	**0xAA50** (GYROSCOPE_SERV_UUID)	GATT_PERMIT_READ	Start of Sensor Profile Gyroscope Service
0x56	86	0x2803	GATT_CHARACTER_UUID	12 (properties: read/notify) 57 00 (handle: 0x0057) 51 AA (UUID: **0xAA51**)	GATT_PERMIT_READ	
0x57	87	**0xAA51**	GYROSCOPE_DATA_UUID	00:00:00:00:00:00 (6 bytes)	GATT_PERMIT_READ	XLSB:XMSB:YLSB:YMSB: ZLSB:ZMSB
0x58	88	0x2902	GATT_CLIENT_CHAR_CFG_UUID	00:00 (2 bytes)	GATT_PERMIT_READ | GATT_PERMIT_WRITE	
0x59	89	0x2901	GATT_CHAR_USER_DESC_UUID	"Gyro. Data" (11 bytes)	GATT_PERMIT_READ	
0x5A	90	0x2803	GATT_CHARACTER_UUID	0A (properties: read/write) 5B 00 (handle: 0x005B) 52 AA (UUID: **0xAA52**)	GATT_PERMIT_READ	
0x5B	91	**0xAA52**	GYROSCOPE_CONF_UUID	1 (1 byte)	GATT_PERMIT_READ | GATT_PERMIT_WRITE	Write 0 to turn off gyroscope, 1 to enable X axis only, 2 to enable Y axis only, 3 = X and Y, 4 = Z only, 5 = X and Z, 6 = Y and Z, 7 = X, Y and Z
0x5C	92	0x2901	GATT_CHAR_USER_DESC_UUID	"Gyro. Conf." (13 bytes)	GATT_PERMIT_READ	
0x5D	93	0x2800	GATT_SERVICE_UUID	0xFFE0 (SK_KEYPRESSED_UUID)	GATT_PERMIT_READ	Start of Simple Keys Service
0x5E	94	0x2803	GATT_CHARACTER_UUID	10 (notify permission) 34 00 (handle 0x0034) E1 FF (UUID 0xFFE1)	GATT_PERMIT_READ	Keys state characteristic declaration
0x5F	95	0xFFE1	SK_KEYPRESSED_UUID	0	(none)	Keys state characteristic value (bit mask of left / right key presses). Side key as bit 2 in test mode only.
0x60	96	0x2902	GATT_CLIENT_CHAR_CFG_UUID	0x0000	GATT_PERMIT_READ | GATT_PERMIT_WRITE	
0x61	97	0x2901	GATT_CHAR_USER_DESC_UUID	"Key Press State"	GATT_PERMIT_READ	Keys state characteristic user description
0x62	98	0x2800	GATT_SERVICE_UUID	**0xAA60** (TEST_SERVICE_UUID)	GATT_PERMIT_READ	Start of TestService
0x63	99	0x2803	GATT_CHARACTER_UUID	02 (read permission) 64 00 (handle 0x0064) 61 AA (UUID: **0xAA61**)	GATT_PERMIT_READ	Test Data characteristic declaration
0x64	100	**0xAA61**	TEST_DATA_UUID	1 byte	GATT_PERMIT_READ	Test Data: 1 bit set of each test passed
0x65	101	0x2901	GATT_CHAR_USER_DESC_UUID	"Test Data" (10 bytes)	GATT_PERMIT_READ	
0x66	102	0x2803	GATT_CHARACTER_UUID	0A (read/write permission) 68 00 (handle 0x0068) 62 AA (UUID: **0xAA62**)	GATT_PERMIT_READ	Test Config characteristic declaration
0x67	103	**0xAA62**	TEST_CONFIG_UUID	1 byte	GATT_PERMIT_READ	Test Config: bit 7 - enable test mode, bit 1 - set LED2, bit 0 - set LED 1
0x68	104	0x2901	GATT_CHAR_USER_DESC_UUID	"Test Config" (12 bytes)	GATT_PERMIT_READ	

3.3.1 Reading a Characteristic Value by UUID

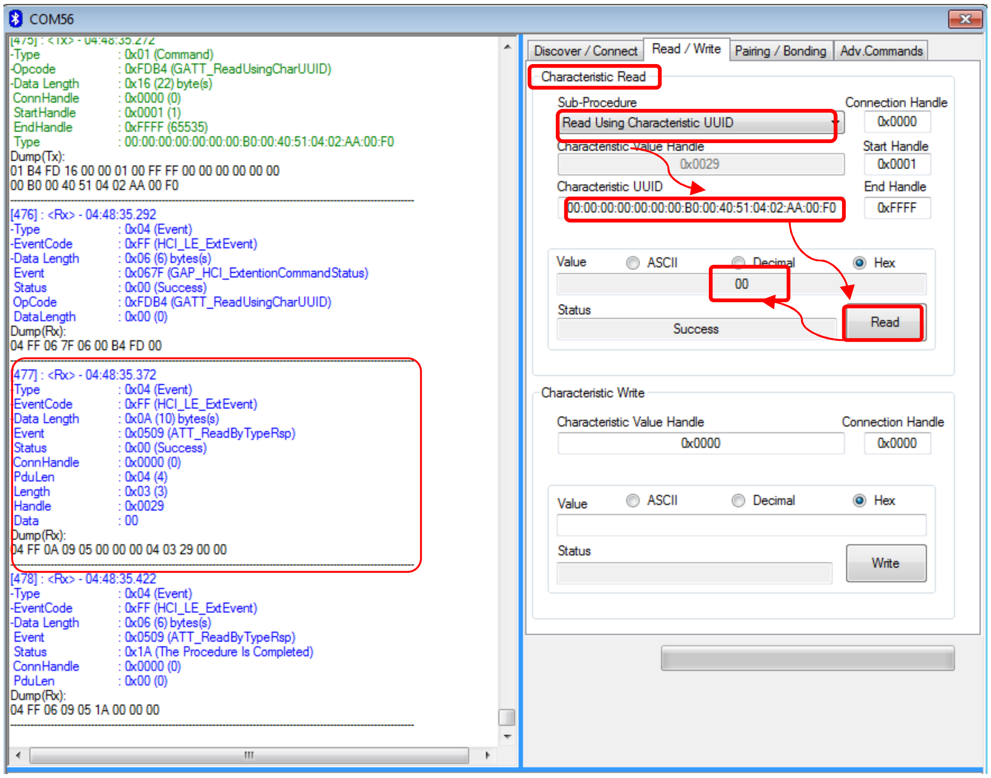
A characteristic value is essentially where the data payload is stored, which could be, for example, temperature data or battery level. It is the stored data in a server that a client wants to access. A characteristic is a discrete value that has, at minimum, the following three properties associated with it:

1. A handle (address)
2. A type (UUID)
3. A set of permissions

Let's consider the IR Temperature service: handles 0x23 to 0x2A as seen above. This service has two characteristics: IR temperature data and IR temperature config. We must first enable the IR sensor by writing to the IR temperature config characteristic. We can then read the temperature by reading from the IR temperature data characteristic. First, let's read the IR temperature config characteristic to ensure that isn't already enabled (it won't be). The simplest way to read its value is to use the "Read Characteristic by UUID" sub-procedure. To do this, you will first need to click the "Read / Write" tab in BTool. Select the option "Read Using Characteristic UUID" under the "Sub-Procedure" option in the "Characteristic Read" section at the top of the screen. Enter the UUID we are looking for. The UUID from the table above is 0xAA02. However, this is a 128-bit UUID so we must add the TI Base UUID. The effective UUID we are looking for is F000**AA02**-0451-4000-B000-000000000000. Also, we must enter this LSB to MSB in BTool with each byte separated by a colon. So enter 00:00:00:00:00:00:00:B0:00:40:51:04:**02:AA**:00:F0 in the "Characteristic UUID" box, and click the "Read" button as shown below.

An attribute protocol *Read by Type Request* packet gets sent over the air from the central device to the peripheral device, and an attribute protocol *Read by Type Response* packet gets sent back from the peripheral device to the central device. The value "00" is displayed in the "Value" box, and "Success" is displayed in the "Status" box. The "00" indicates that the temperature sensor is not enabled. In addition, the message window will display information on the *Read by Type Response* packet that was received by the central device. The message includes not only the characteristic's data value, but also the handle of the characteristic value (0x0029 in this case).

****Note that, as you read attributes from the peripheral, the attribute table in the bottom pane begins to fill up. You can actually fill this entire table up initially by choosing ATT_FindInfoReq in the Adv. Commands tab. You can then read and write to many characteristics by clicking on their respective column in the table. However, it is recommended to go through these manual steps first to gain understanding.



COM56

```
[475] : <Tx> - 04:48:35.272
-Type           : 0x01 (Command)
-Opcode         : 0xFDB4 (GATT_ReadUsingCharUUID)
-Data Length    : 0x16 (22) byte(s)
 ConnHandle     : 0x0000 (0)
 StartHandle    : 0x0001 (1)
 EndHandle      : 0xFFFF (65535)
 Type           : 00:00:00:00:00:00:00:B0:00:40:51:04:02:AA:00:F0
Dump(Tx):
01 B4 FD 16 00 00 01 00 FF FF 00 00 00 00 00 00
00 B0 00 40 51 04 02 AA 00 F0
--------------------------------------------------------------
[476] : <Rx> - 04:48:35.292
-Type           : 0x04 (Event)
-EventCode      : 0xFF (HCI_LE_ExtEvent)
-Data Length    : 0x06 (6) bytes(s)
 Event          : 0x067F (GAP_HCI_ExtentionCommandStatus)
 Status         : 0x00 (Success)
 OpCode         : 0xFDB4 (GATT_ReadUsingCharUUID)
 DataLength     : 0x00 (0)
Dump(Rx):
04 FF 06 7F 06 00 B4 FD 00
--------------------------------------------------------------
[477] : <Rx> - 04:48:35.372
-Type           : 0x04 (Event)
-EventCode      : 0xFF (HCI_LE_ExtEvent)
-Data Length    : 0x0A (10) bytes(s)
 Event          : 0x0509 (ATT_ReadByTypeRsp)
 Status         : 0x00 (Success)
 ConnHandle     : 0x0000 (0)
 PduLen         : 0x04 (4)
 Length         : 0x03 (3)
 Handle         : 0x0029
 Data           : 00
Dump(Rx):
04 FF 0A 09 05 00 00 00 04 03 29 00 00
--------------------------------------------------------------
[478] : <Rx> - 04:48:35.422
-Type           : 0x04 (Event)
-EventCode      : 0xFF (HCI_LE_ExtEvent)
-Data Length    : 0x06 (6) bytes(s)
 Event          : 0x0509 (ATT_ReadByTypeRsp)
 Status         : 0x1A (The Procedure Is Completed)
 ConnHandle     : 0x0000 (0)
 PduLen         : 0x00 (0)
Dump(Rx):
04 FF 06 09 05 1A 00 00 00
--------------------------------------------------------------
```

Characteristic Read

Sub-Procedure: Read Using Characteristic UUID

Connection Handle: 0x0000

Characteristic Value Handle: 0x0029

Start Handle: 0x0001

Characteristic UUID: 00:00:00:00:00:00:00:B0:00:40:51:04:02:AA:00:F0

End Handle: 0xFFFF

Value ○ ASCII ○ Decimal ● Hex: 00

Status: Success

Characteristic Write

Characteristic Value Handle: 0x0000

Connection Handle: 0x0000

Value ○ ASCII ○ Decimal ● Hex

Status