TI *Bluetooth*® low energy

Training, October 2013

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Introduction

TI *Bluetooth* low energy benefits – CC2541

Cost Effective

✓ **Highly integrated solution**
- Single-chip and WNP solution
- Flash-based

✓ **Low cost HW design**
- 6x6mm QFN package
- 2 layers layout

✓ **Quick software development**
- SW examples for all adopted profiles
- iOS App source code

Flexibility

✓ **Mature solution**
- TI first to market (2010)
- >7000kits shipped
- Leading market share (IMS/ABI)

✓ **Flexible configuration**
- Central/Peripheral role switching
- Combo Roles
- Over-the-air SW update
- Boot Image Manager (BMI)

✓ **Support**
- www.ti.com/ble
- Most active BLE community (www.ti.com/ble-forum)
- All information publicly available

High Performance

✓ **Powerful**
- >1 year battery life with CR2032
- 97dB link budget

✓ **Ultra-low power**
- Very low-power sleep modes
- Short transition times between operating modes
- Ref.design with dc-dc (TPS62730)

TI *Bluetooth* low energy enabled Products

Kensington
Proximity tag

Nokia
Precious Tag

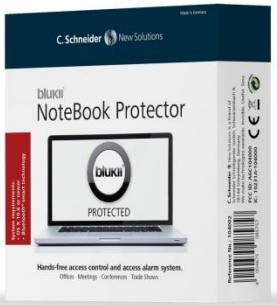
Lifesense
Blood Pressure Monitor

Ruwido/Swisscom
Remote Control

UnderArmor
Heart Rate Monitor

Kwikset
Smart door lock

Schneider
Notebook protector



TI *Bluetooth* low energy enabled Products

Smartbiotics
Smart LED Bulbs

Misfit Wearable's
Shine – Activity Monitor

KEEO
Smart Key

TI *Bluetooth* low energy enabled Products

Kinetek

LifeTrak

TetherCell

UniKey

Parrot

BACTrack

TI *Bluetooth* low energy enabled Products

Murata

Polar

ZOMM

Schneider

Bluetrek

Recon

Ace Sensor

TI *Bluetooth* low energy enabled Products

Blast Motion

IDT

Griffin

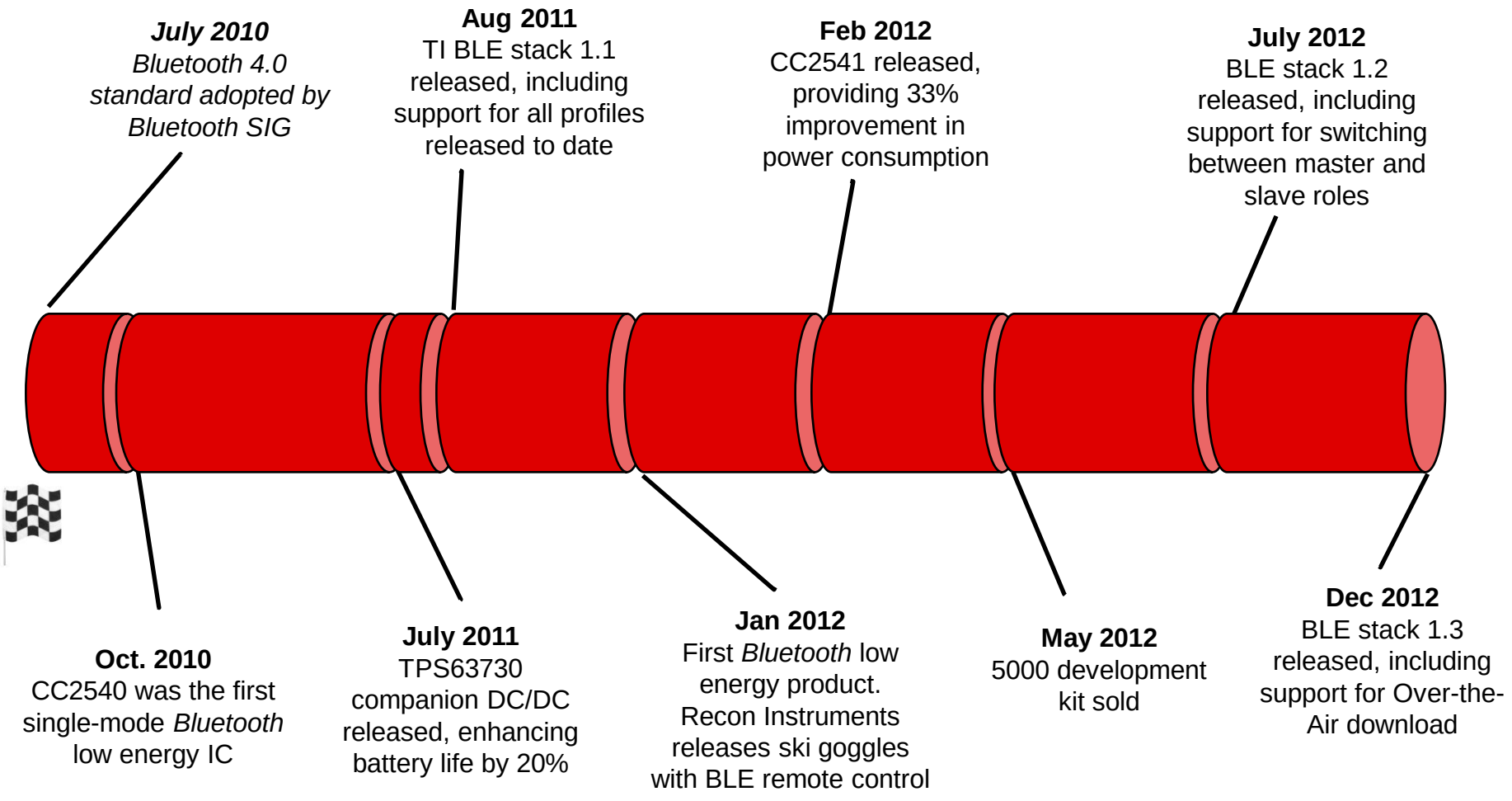
Citizen

MonBaby

SoundOfMotion

Tom Tom

TI track record



"As shown with its certifications, new profile offerings and updated Bluetooth low energy stack, we are pleased to see TI playing a critical role in delivering Bluetooth v4.0 with low energy capabilities to new places – from health monitoring to fitness equipment, alert notifications and more."
Mike Foley, Ph. D., Executive Director, Bluetooth SIG

Texas Instruments

TI Hardware

TI *Bluetooth* low energy Hardware

CC2540
Flash SoC
USB

CC2541
Flash SoC
I2C

CC2541S
Flash WNP

Two ways of using TI *Bluetooth* low energy

One-Chip Solution

CC2540
CC2541

BLE Stack + Application + Profiles

Two-Chip Solution
(Network Processor)

MCU — Serial — CC2540 CC2541 CC2541S

Application + Profiles | BLE Stack

TI *Bluetooth* low energy Hardware

CC2540
Flash SoC
USB

CC2541
Flash SoC
I2C

CC2541S
Flash WNP

Development Kits

CC2540DK-MINI
CC2541DK-MINI

The most easiest way of evaluating Bluetooth low energy

BOOST-CC2541S

BoosterPack for MSP430, Stellaris and C2000

CC2540DK
CC2541EMK

Advanced kit with several peripheral interfaces and features

CC2541DK-SENSOR

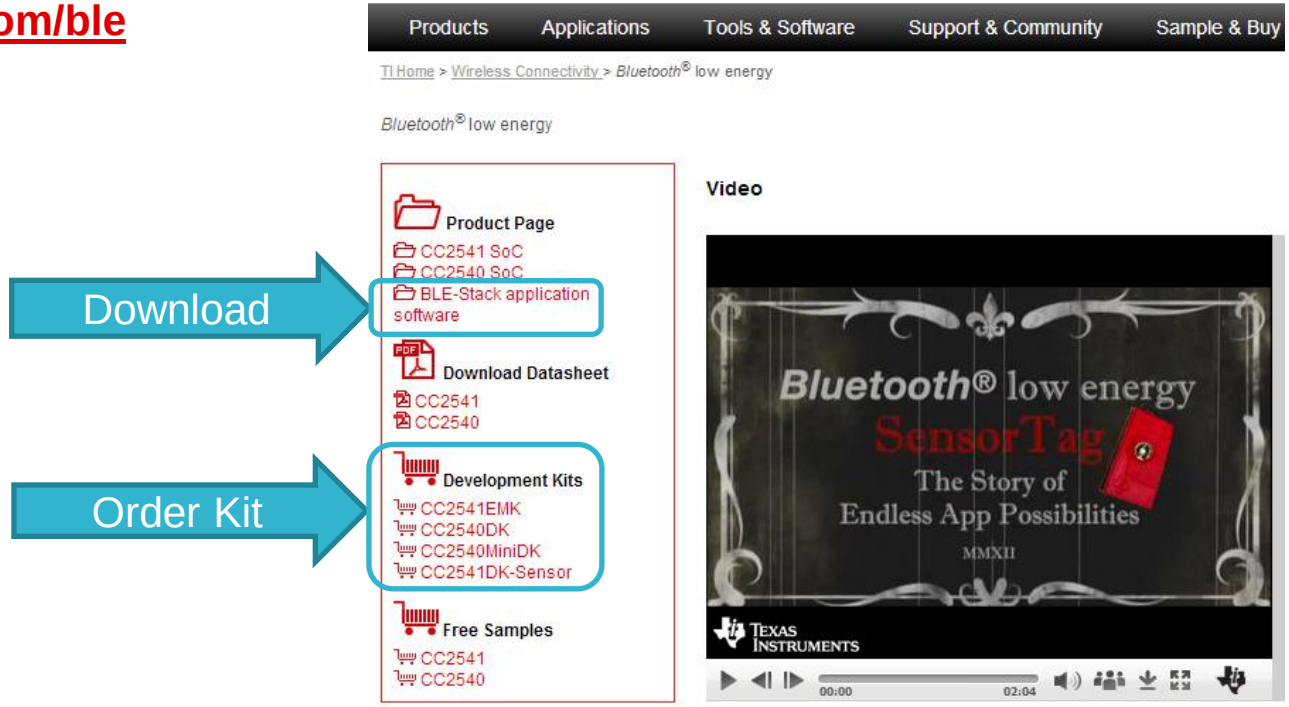
Targiting Smart Phone App developers. Provides sensor data from 6 sensors

CC2541DK-RC

Operates as a mouse, keyboard and consumer remote using HOGP

Order Kit and Download SDK

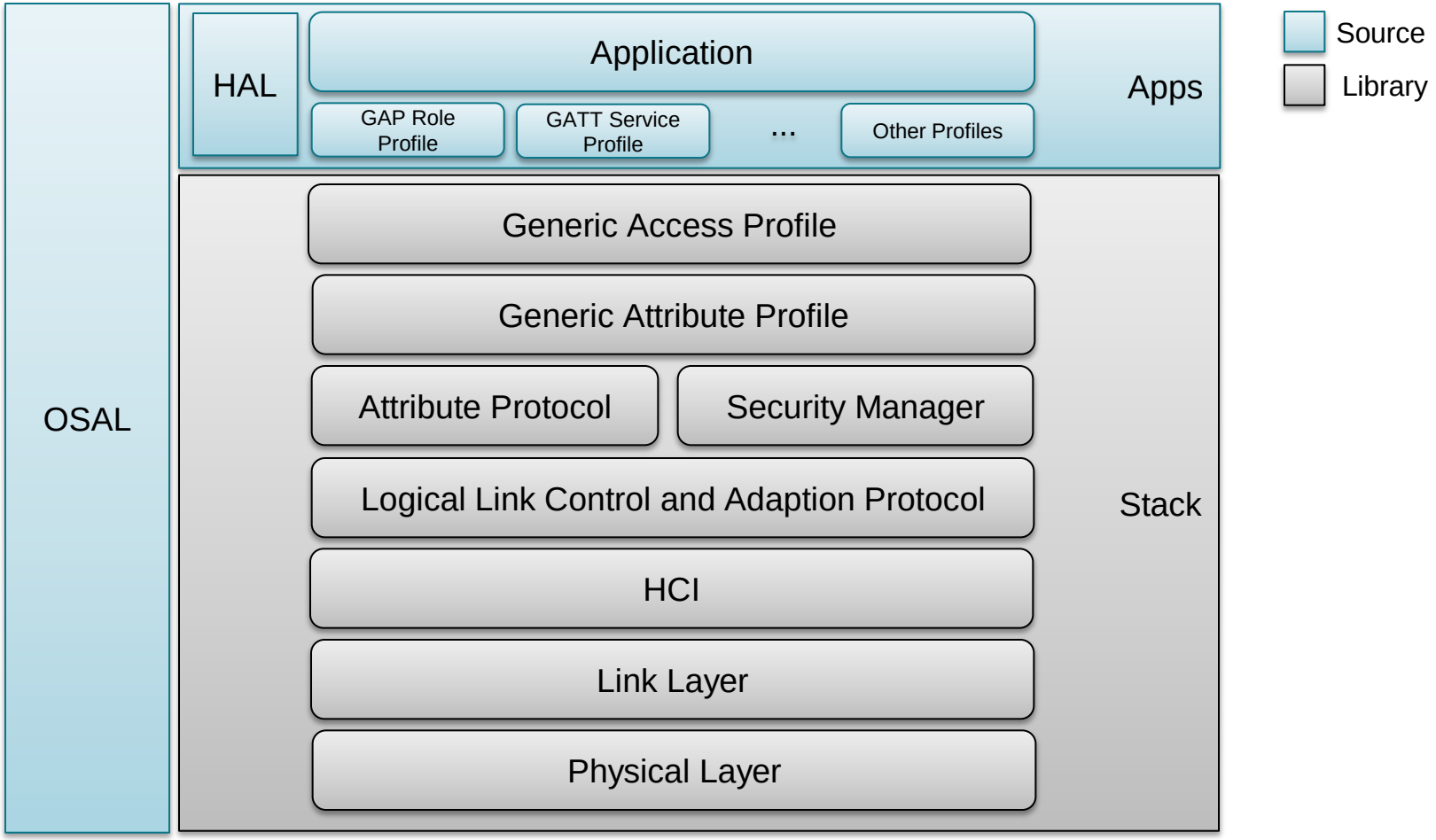
- **Visit [ti.com/ble](ti.com/ble)**



Order Kit → Download SW Stack → Evaluate and Learn *Bluetooth* low energy

Software Solution

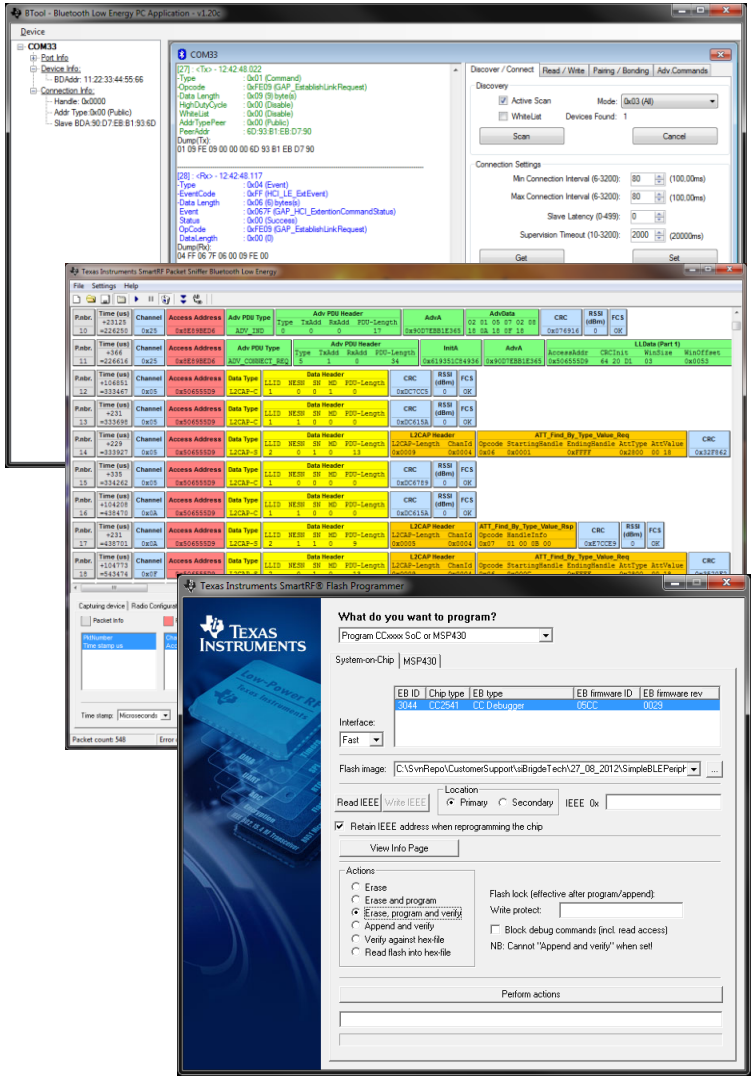
TI BLE Software Solution



OSAL = Operating System Abstraction Layer (Prioritized task handling loop)
HAL = Hardware Abstraction Layer (Drivers and API for LEDs, Buttons etc)
Full API to access all stack functionality in the stack (Library) from the Application and Profiles

TI *Bluetooth* low energy Tools

- BTool
  - Run and test *Bluetooth* low energy communication through a CC254x Network Processor
- Sniffer
  - Capture Bluetooth low energy communication live with full overview.
- Flash Programmer
  - Program CC254x devices
  - Read and write IEEE addresses



Documentation and Support

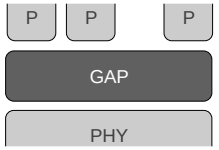
- Guides included in the BLE installer
  - TI BLE Software Developers Guide
  - TI BLE Sample Applications Guide
  - TI BLE Vendor Specific HCI Guide
  - TI BLE API Guide
- Online documentation
  - TI BLE Product Page (www.ti.com/ble)
  - TI BLE Wiki (www.ti.com/ble-wiki)
- Online Support
  - TI BLE E2E forum

Data Sheets
User Guides
Reference Designs
Application Notes

Application Examples
Walkthrough
Step by Step guides
FAQ

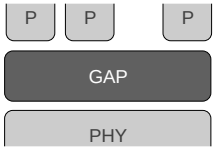
Bluetooth low energy Protocol Stack

GAP - Roles



- A *Bluetooth* low energy device can operate in four profile roles:
  - **Broadcaster**
    - An advertiser that is non-connectable
    - *Example: Temperature Sensor*
  - **Observer**
    - Scans for advertisements, but cannot initiate connections
    - *Example: Temperature Display*
  - **Peripheral**
    - An advertiser that is connectable
    - Operates as a **slave** in a connection
    - *Example: Watch*
  - **Central**
    - Scans for advertisements and initiates connections
    - Operates as a **master** in connections.
    - *Example: Smart Phone*

GAP – Multiple Roles



- The BLE specification multiple-role configurations:
  - Peripheral and Broadcaster
    - device operates as a slave in a single link layer connection
    - send out non-connectable advertisements
  - Peripheral and Observer:
    - device operates as a slave in a single link layer connection
    - Scan for advertisements without initiating a connection
  - Central and Broadcaster:
    - Device scans for advertisements and initiates connections as a master
    - Broadcast non-connectable advertisements

TI *Bluetooth* low energy Software Examples

- Profile Specific
  - Heart Rate
  - Glucose
  - HID Keyboard
  - Etc.
- ”General”
  - SimpleBLEPeripheral
  - SimpleBLECentral
  - SimpleBLEBroadcaster
  - SimpleBLEObserver

Bluetooth SIG adopted Profiles

Cycling Speed and Cadence	**- Certified**	(BLEv1.3.2, June ‘13)
Running Speed and Cadence	**- Certified**	(BLEv1.3.2, June ‘13)
Blood Glucose	**- Certified**	(BLEv1.2, February ‘12)
HID over GATT	**- Certified**	(BLEv1.2, February ‘12)
Proximity	**- Certified**	(BLEv1.1, July ‘11)
Find me	**- Certified**	(BLEv1.1, July ‘11)
Health thermometer	**- Certified**	(BLEv1.1, July ‘11)
Heart rate sensor	**- Certified**	(BLEv1.1, July ‘11)
Time	**- Certified**	(BLEv1.1, July ‘11)
Alert Notification	**- Certified**	(BLEv1.1, July ‘11)
Battery Status	**- Certified**	(BLEv1.1, July ‘11)

Proprietary Profile

- Uses GATT Architecture for easy implementation

- Proprietary Services uses 128bit UUID
  - Example in Sensor Tag project (www.ti.com/ble-stack)
  - Custom example available at wiki (www.ti.com/ble-wiki)
  - UUIDs can be generated online (www.uuidgenerator.com)

- Use adopted Services (www.bluetooth.org)
  - Faster implementation
  - Ensure interoperability

- TI base UUID
  - F000*XXXX*-0451-4000-B000-000000000000

Memory Footprint Examples (BLEv1.3)

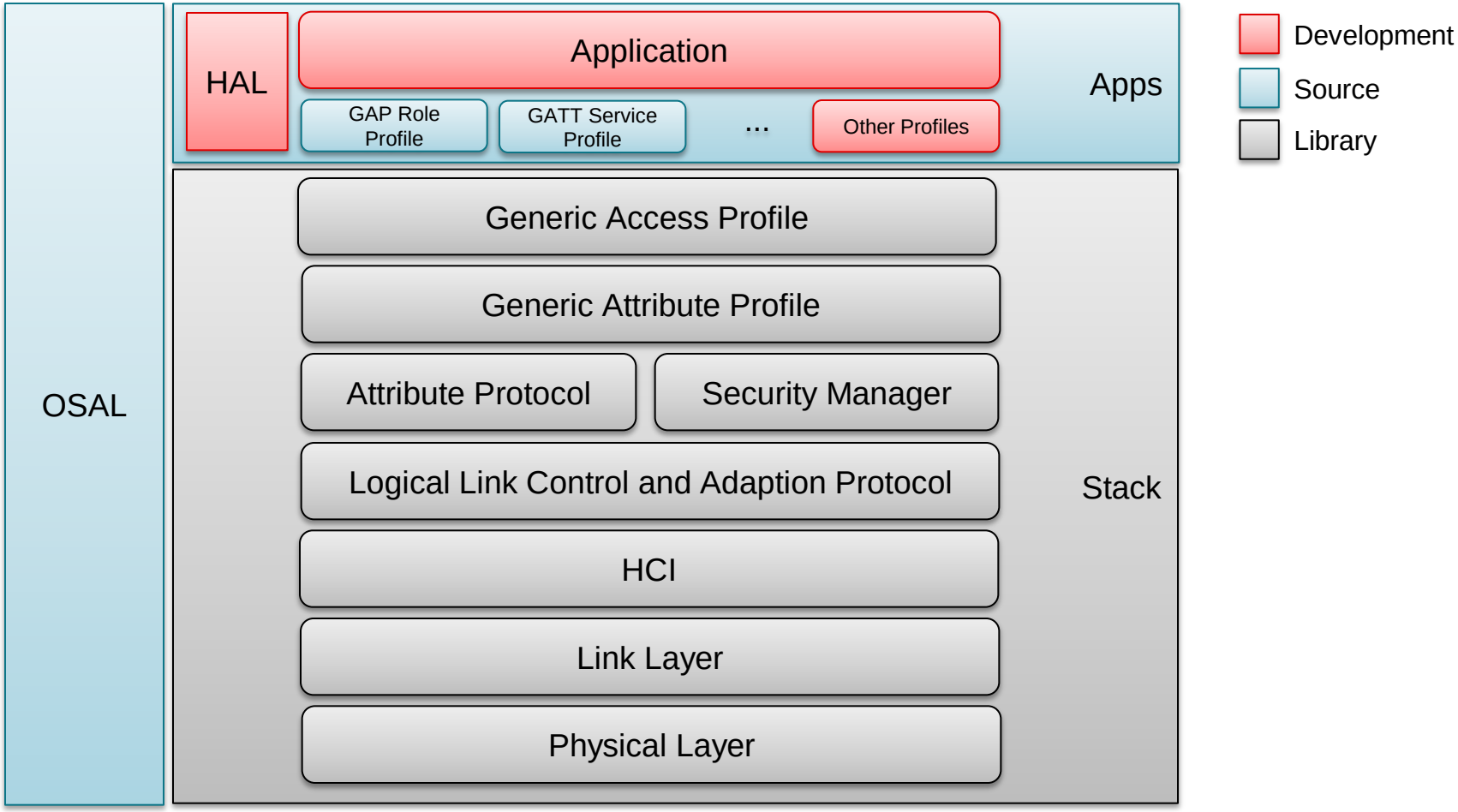
Project	Flash [KBytes]	RAM [KBytes]
SimpleBLEPeripheral	114	6.2
SimpleBLECentral	123	7.2
SimpleBLEObserver	43	3.3
SImpleBLEBroadcaster	39	3.3
KeyFobDemo	116	6.4
Heart Rate	112	6.1
HostTest (Network Processor)	151	7.5

Profiles	Flash [KBytes]	RAM [KBytes]
Device Information Service	1.068	0.176
Heart Rate Service	0.678	0.078
Battery Service	0.846	0.053
Proximity	0.984	0.094

Software Development Kit

- User Requirements
  - An intermediate level of knowledge of the C programming language
- Runs on embedded 8051 (MCU) with limited resources
  - Algorithms and application should be coded efficiently
  - C standard library should not be used
- Concepts of encapsulation and information hiding:
  - GetParameter and SetParameter functions etc.
  - Callbacks

Embedded Software



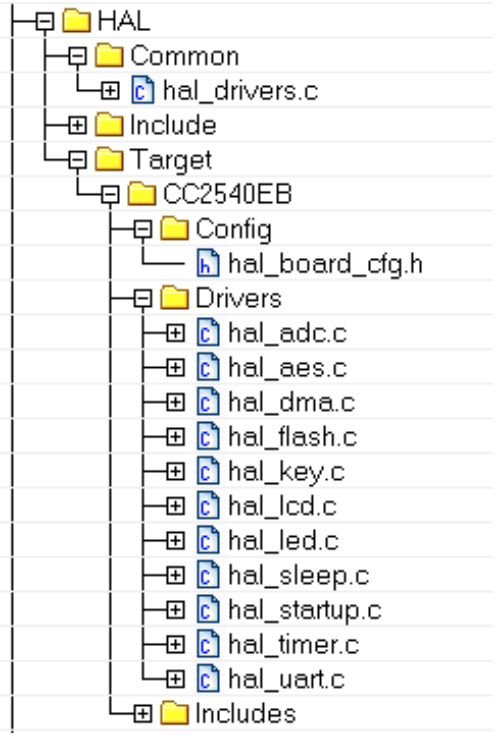
OSAL = Operating System Abstraction Layer (Prioritized task handling loop)
HAL = Hardware Abstraction Layer (Drivers and API for LEDs, Buttons etc)
Full API to access all stack functionality in the stack (Library) from the Application and Profiles

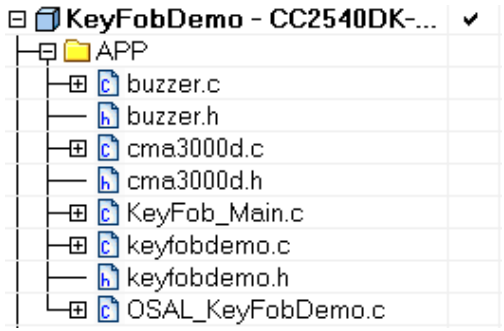
Developer's resources

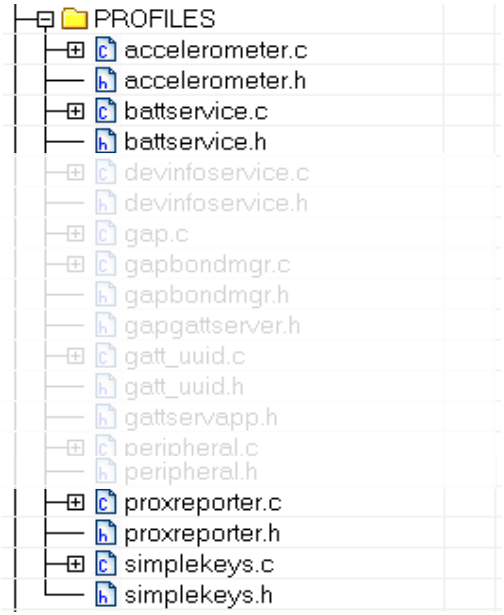
HAL

User Application

Other Profiles







- HAL
  - Some are very specific to our boards/ICs
- APP
  - User application
  - Specific drivers
- PROFILES
  - Adopted (Battery, Proximity)
  - Proprietary (Accelerometer, SimpleKeys)

Operating System Abstraction Layer (OSAL)

- The SW architecture is based around the Operating System Abstraction Layer (OSAL)
- The OSAL is a control loop that allows SW to setup execution of events
- Each subsystem of the software runs as an OSAL task, and has a unique task identifier (ID)
- Low task ID → Task has higher priority
- Typical Project has 12 OSAL tasks

ID	Task
0	Link Layer
1	HAL
2	HCI
3	OSAL Callback Timer
4	L2CAP
5	GAP
6	GATT
7	SM
8	GAP Role
9	GAP Bond Manager
10	GATT Server
11	Application

OSAL – Files and Key API's

- Key Files:
  - osal.c – API's for OSAL
  - osal.h – OSAL API declarations

- Key API's:

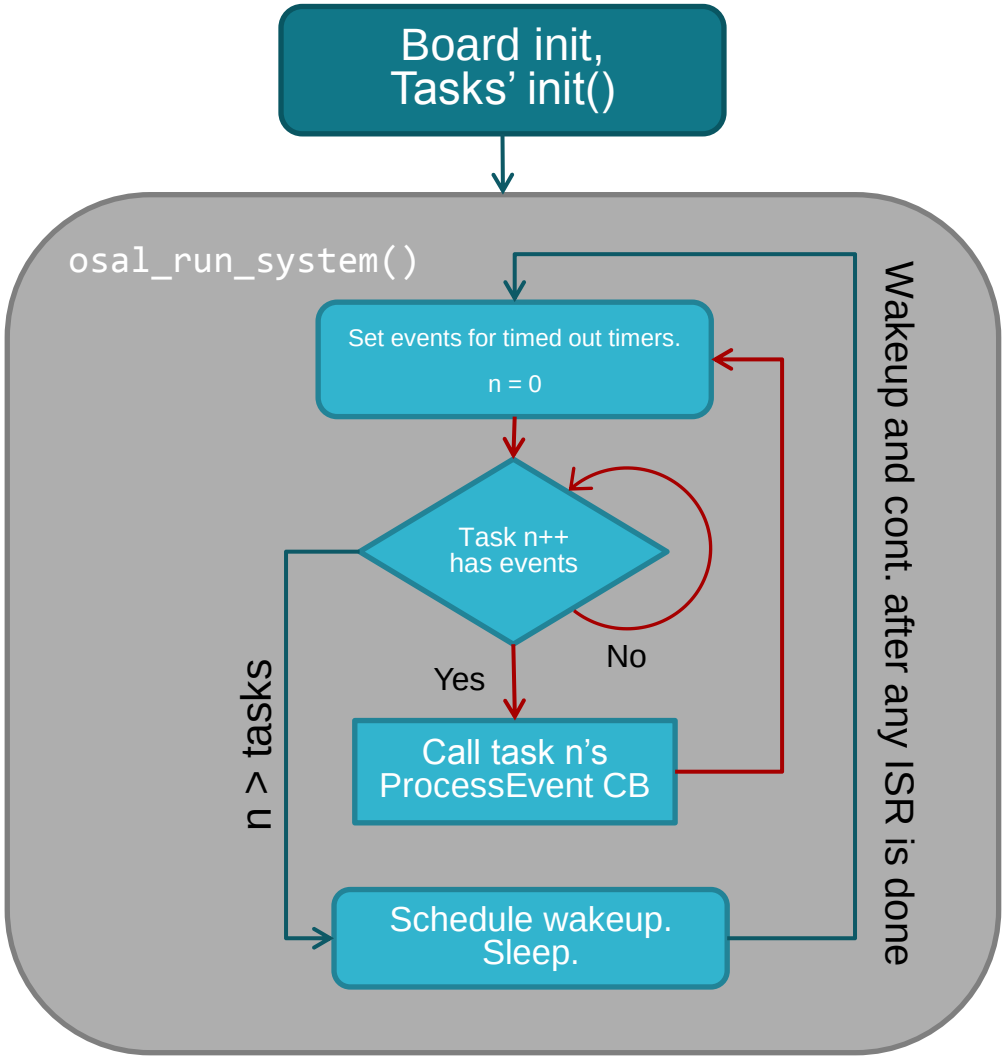
– osal_init_system	Initializes OSAL
– osal_start_system	Starts the OSAL main loop
– osal_set_event	Sets an OSAL event for a task
– osal_start_timerEx	Sets an OSAL event for a task at a scheduled moment in time
– osal_stop_timerEx	Cancels an existing OSAL event
– osal_msg_allocate	Dynamically allocates memory for an OSAL message
– osal_msg_send	Sends an OSAL message to a specific task
– osal_msg_deallocate	Deallocates an OSAL message (call this from receiving task)
– osal_mem_alloc	Dynamically allocates memory
– osal_mem_free	Free previously allocated memory

- Additional information on the OSAL can be found in the OSAL API guide:

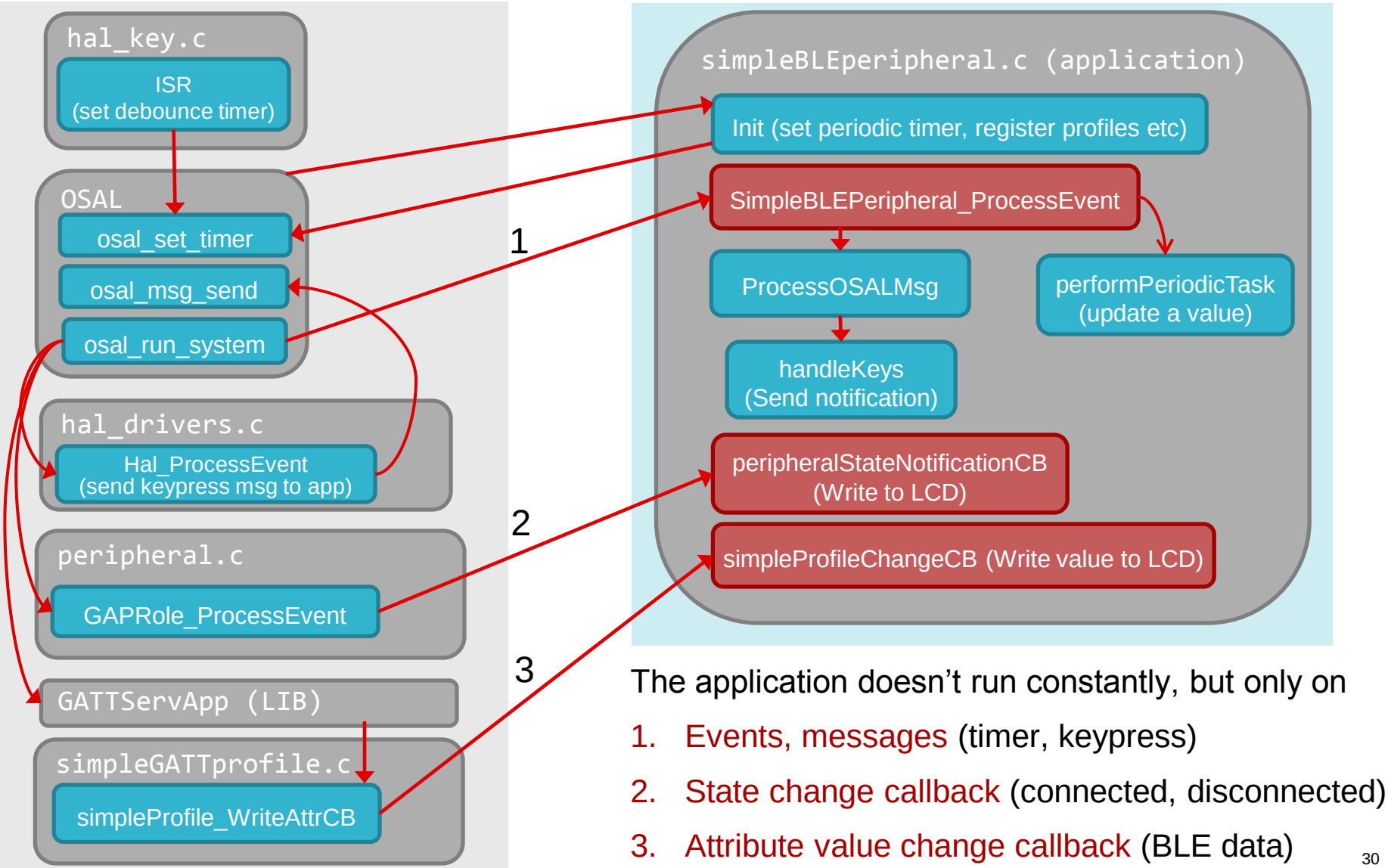
  C:\Texas Instruments\BLE-CC2540\Documents\osal**OSAL API.pdf**

Execution flow: OSAL's point of view

- OSAL is a prioritized work-queue
  - If two tasks have events, handle highest first
- The stack is event-driven
  - Act on the environment, then
  - Sleep until something happens
- Lower stack layers communicate via OSAL messages and events
  - Then call functions in the user application:
    - On attribute writes/reads
    - On connection loss/establishment



Execution flow: Application point of view



The application doesn't run constantly, but only on

1. Events, messages (timer, keypress)
2. State change callback (connected, disconnected)
3. Attribute value change callback (BLE data)

Hardware Abstraction Layer

- The Hardware Abstraction Layer (HAL) provides an application programming interface to hardware-related functions such as
  - ADC
  - UART
  - SPI
  - Flash
  - Timers
  - Sleep
  - Keys
  - LED
  - LCD

- Additional details on HAL functions can be found in the HAL API Guide:

  C:\Texas Instruments\BLE-CC2540\Documents\hal**HAL Driver API.pdf**

OAD Profile

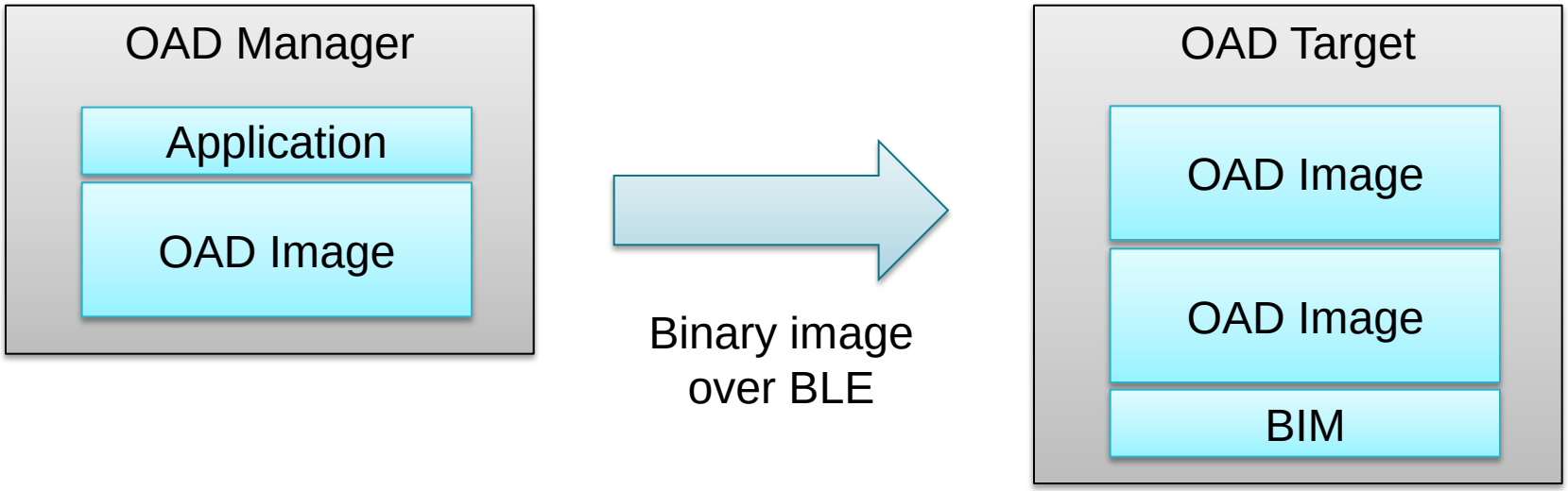
Over the Air Download

Introduction – OAD Profile

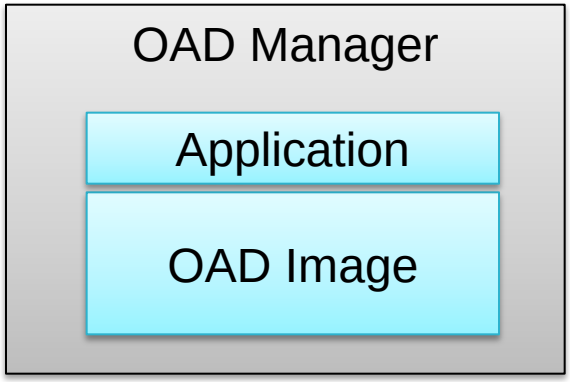
- What is OAD?
  - OAD is a feature that provides a solution for updating code in released products without the cost of physical access (i.e. programming header).
  - OAD is a client-server mechanism in which one device acts as the OAD image server (OAD manager) and the other device is the OAD image client (OAD target).

- What is a proprietary Profile?
  - Uses GATT Architecture for easy implementation
  - Proprietary Services uses 128bit UUID
    - Example in Sensor Tag project (www.ti.com/ble-stack)
    - Custom example available at wiki (www.ti.com/ble-wiki)
    - UUIDs can be generated online (www.uuidgenerator.com)
  - TI base UUID
    - F000*XXXX*-0451-4000-B000-000000000000

OAD System Overview



OAD Manager - Examples

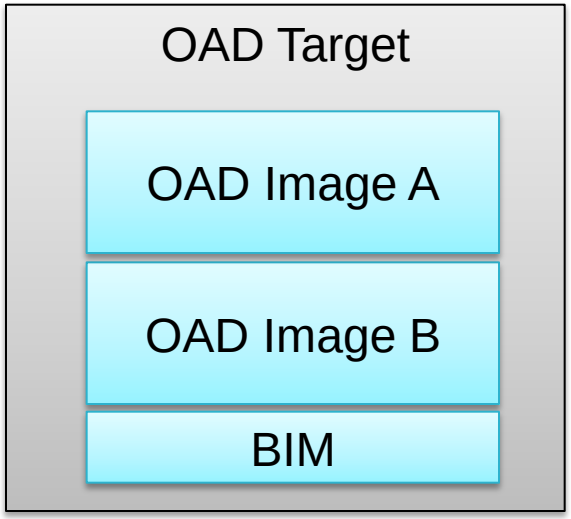


- Acts as a Central Client

- OADManager
  - Use SBL Tool towards a SmartRF05+EM that runs OADManager
- MultiTool
  - Runs on an iOS Device
- Device Monitor
  - Runs on PC and utilizes CC2540USB Dongle

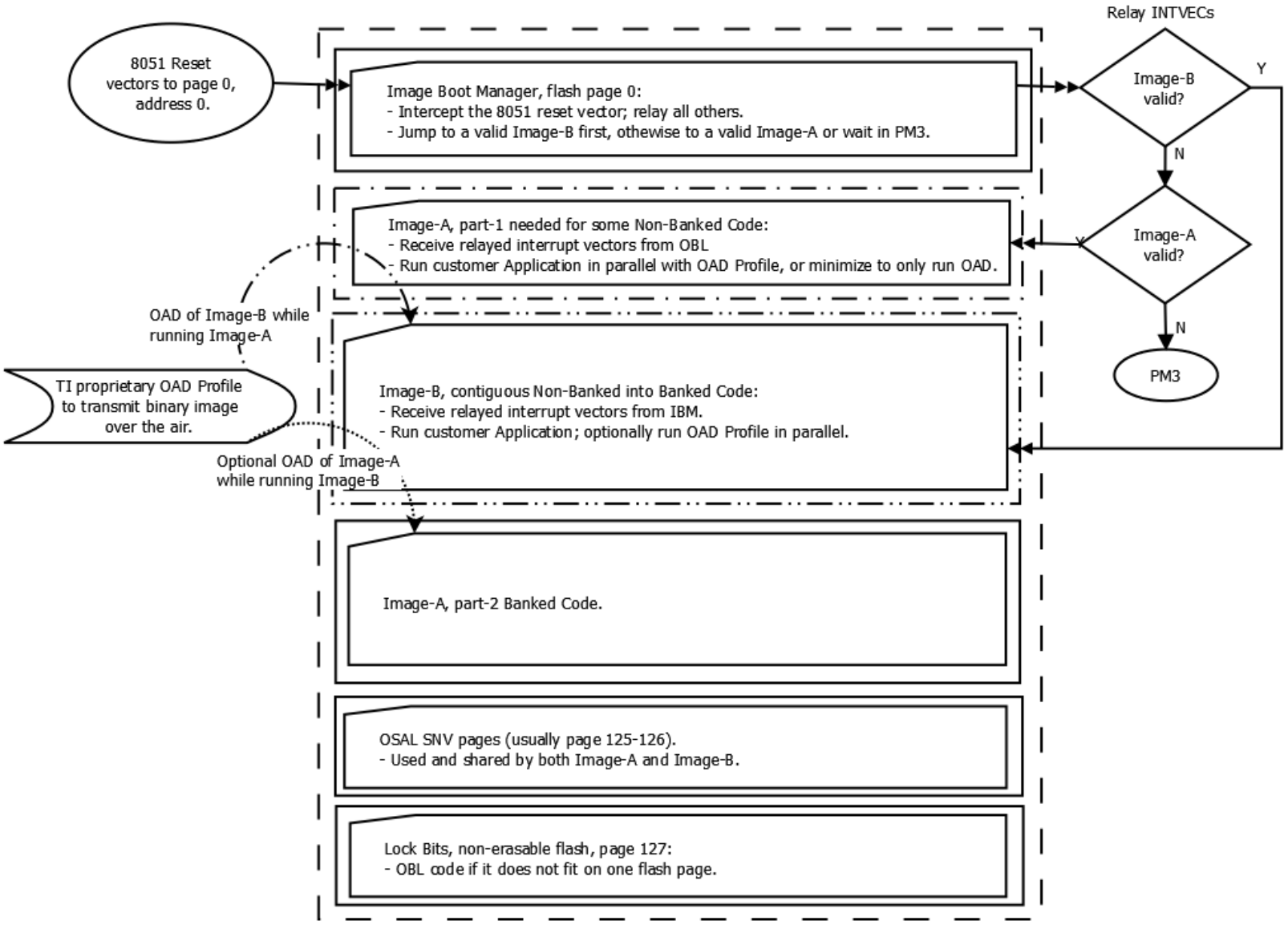
OAD Target - Examples

- Acts as a GATT Server



- OAD is a GATT Profile.
- Projects examples implementing OAD Target
  - SensorTag (CC2541)
    - A & B images
  - SimpleBLEPeripheral
    - A & B Images
    - Encrypted A & B Images

Memory Architecture



How to build OAD System

- Target Requirements
  - Target must be setup with BIM (Boot Image Manager)
    - *..\BLE-CC254x-1.3.1\Projects\ble\util\BIM\cc254x\BIM.eww*
  - Target must be setup with Image A with OAD Profile

- Choose a OAD Manager platform , ex. iPhone/iPad or Device Monitor

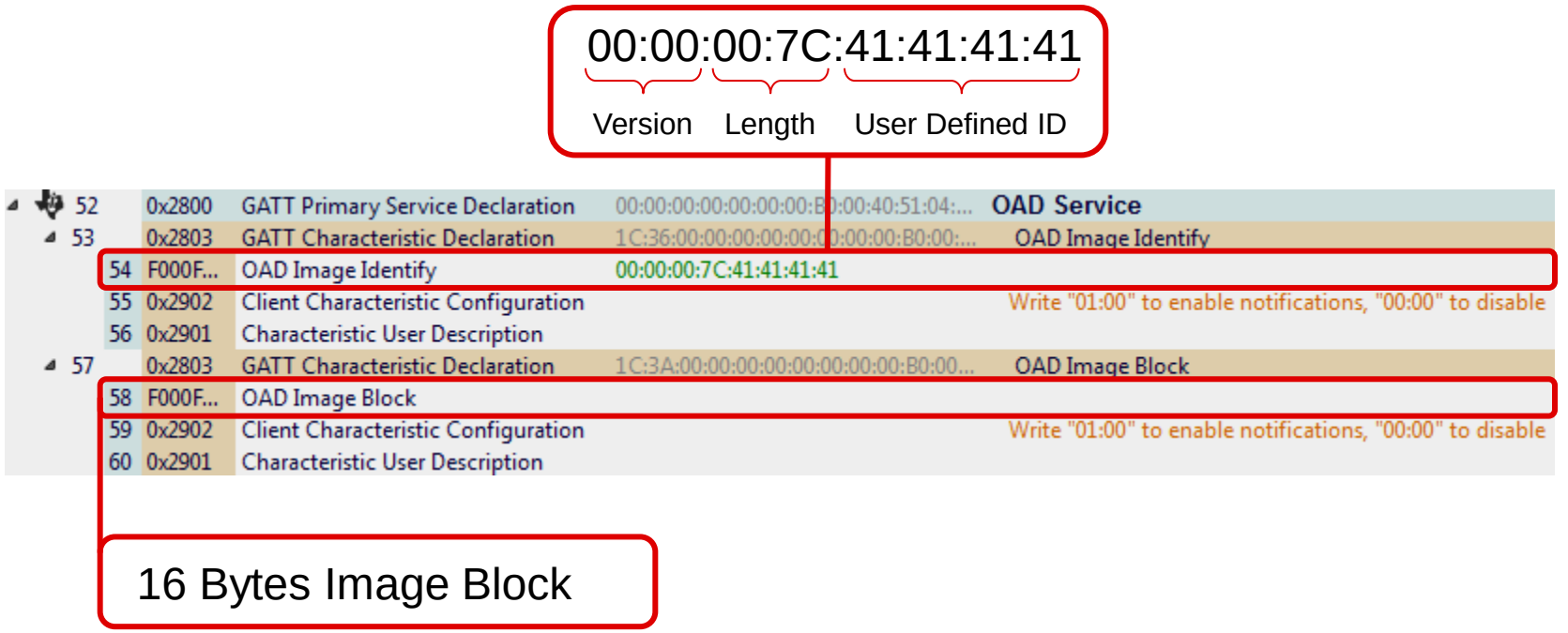
- Build an Image B with OAD Profile.

How to build add OAD Profile

- Target Setup
  - Create a new configuration
    - ex. CC2541-OAD-ImgA
  - Add PROFILE files
    - oad_target.c/h
    - oad.h
  - Add definitions:
    - FEATURE_OAD
    - OAD_KEEP_NV_PAGES
    - FEATURE_OAD_BIM
    - HAL_IMAGE_A
  - Include path to the OAD Profile
  - Add Build Actions
    - "$PROJ_DIR$\..\..\common\CC2540\cc254x_ubl_pp.bat“
    - "$PROJ_DIR$" "ProdUBL"
    - "$PROJ_DIR$\CC2541-OAD-ImgA\Exe*ProjectName*”
  - In Application
    - Add OAD_AddService()
    - Add includes for
      - “oad.h“
      - "oad_target.h"
  - Linker configuration file
    - $PROJ_DIR$\..\..\common\CC2541\cc254x_f256_imgA.xcl

OAD Target Profile

```
typedef struct {
uint16 crc1;    // CRC-shadow must be 0xFFFF.
uint16 ver;     // User-defined Image Version Number
uint16 len;     // Image length in 4-byte blocks
uint8  uid[4]; // User-defined Image Identification bytes.
uint8  res[4]; // Reserved space for future use.
} img_hdr_t;
```



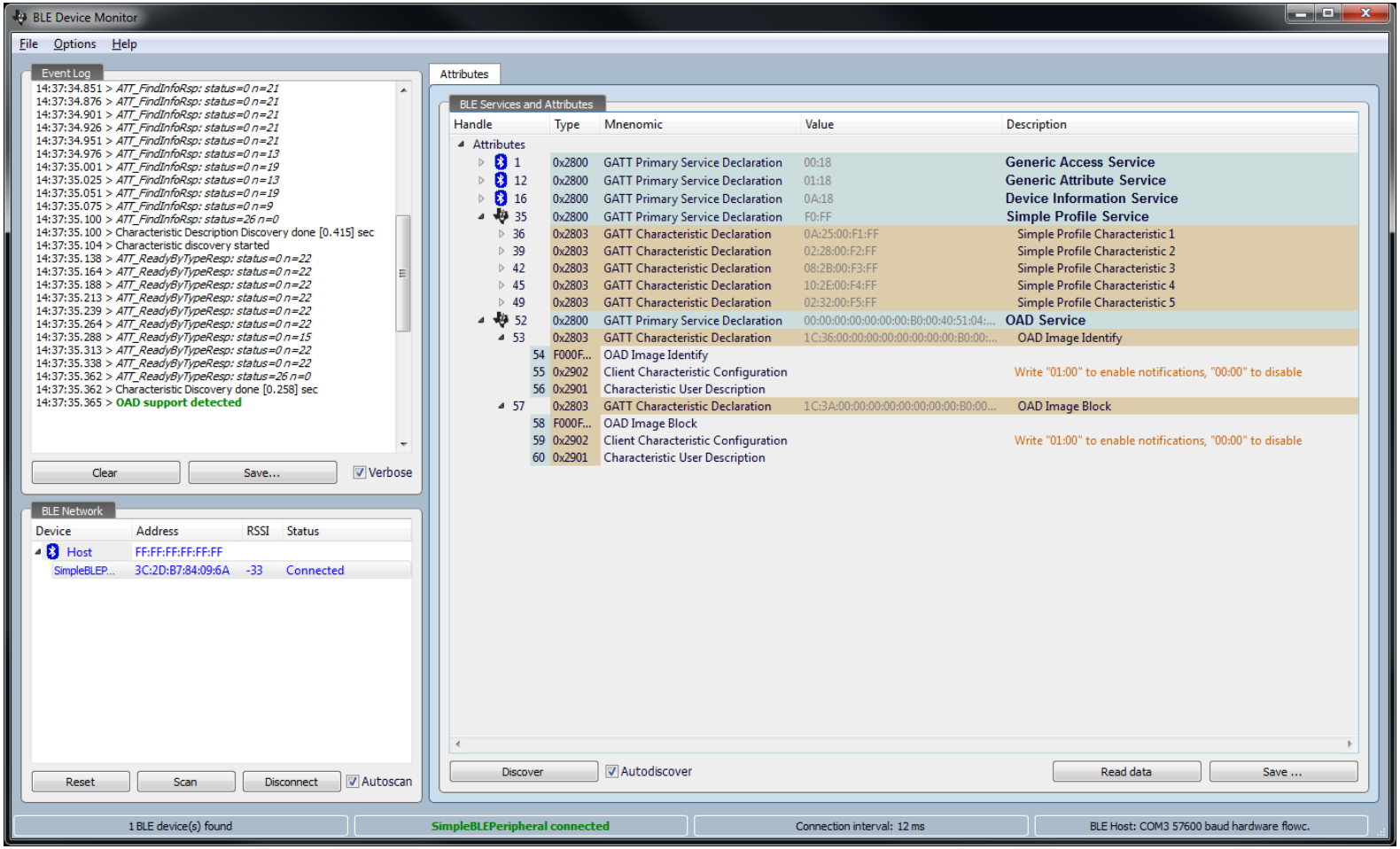
OAD Resources

- Developer's Guide for Over Air Download for CC254x
  - Found at www.ti.com/blewiki

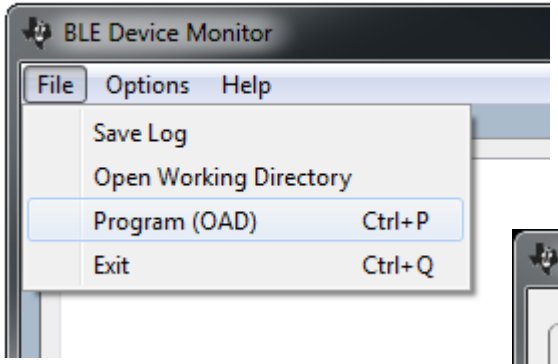
Device Monitor

Debugging and Features

Device Monitor - Demo

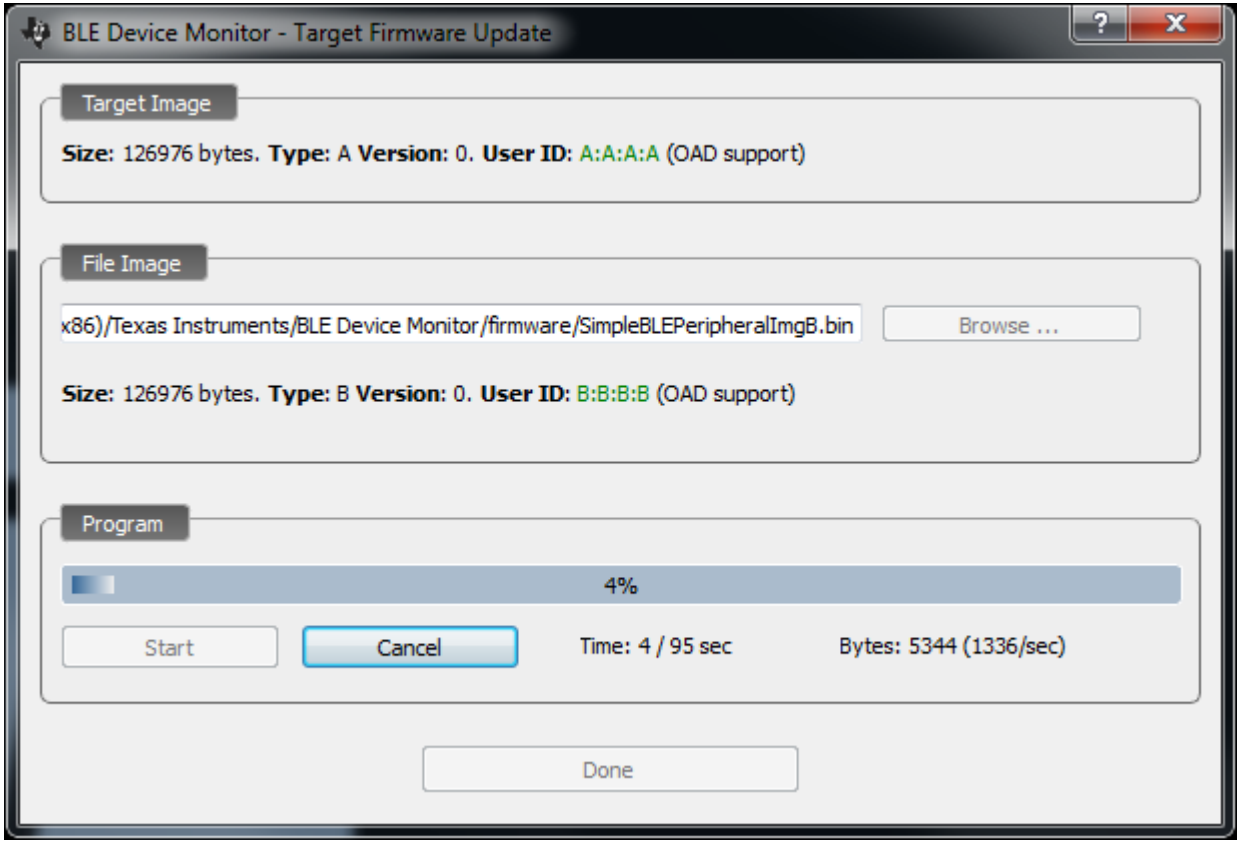


Device Monitor



Easy to download image

But it takes some time...



IAR Embedded Workbench

Debugging and Features

IAR Embedded Workbench IDE

- All software development on the CC2540/41 is done using IAR Embedded Workbench for 8051 Integrated Development Environment (IDE)

- IAR Embedded Workbench for 8051 includes:
  - C Compiler
  - Assembler
  - Library Builder
  - Support for Hardware Debugger

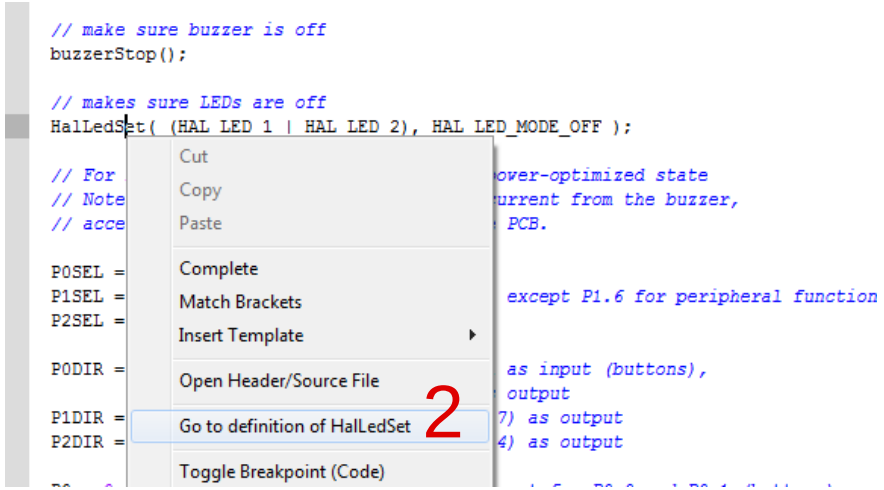
IAR Website: www.iar.com

Go to definition

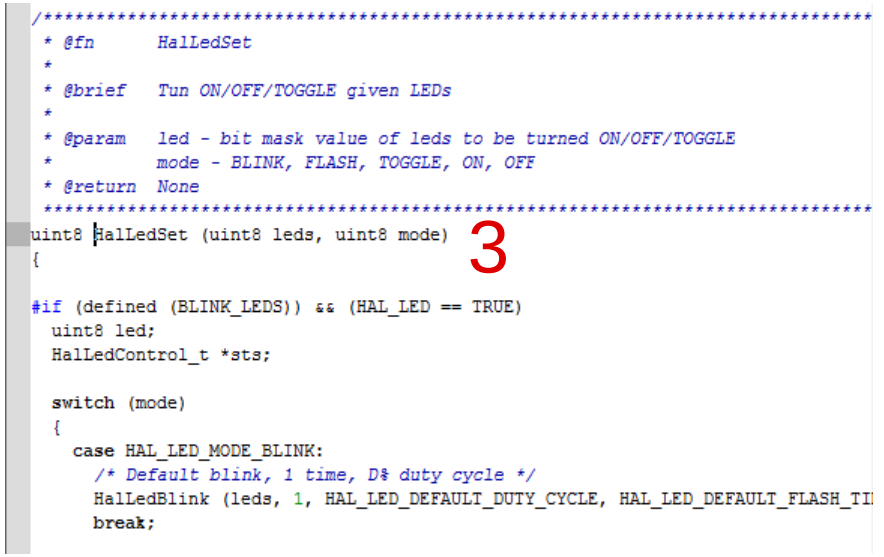
If you ever wonder what a function does, how and where a macro or variable is defined:

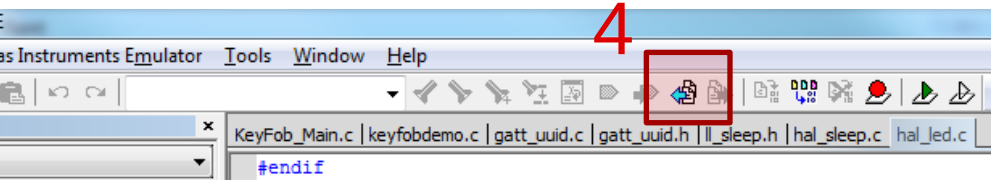
1. Right click on a symbol you want to follow
2. Press Go to definition of...
3. Enjoy saving time
4. Go back whence you came

APP/keyfobdemo.c



HAL/Target/CC2540EB/Drivers/hal_led.c

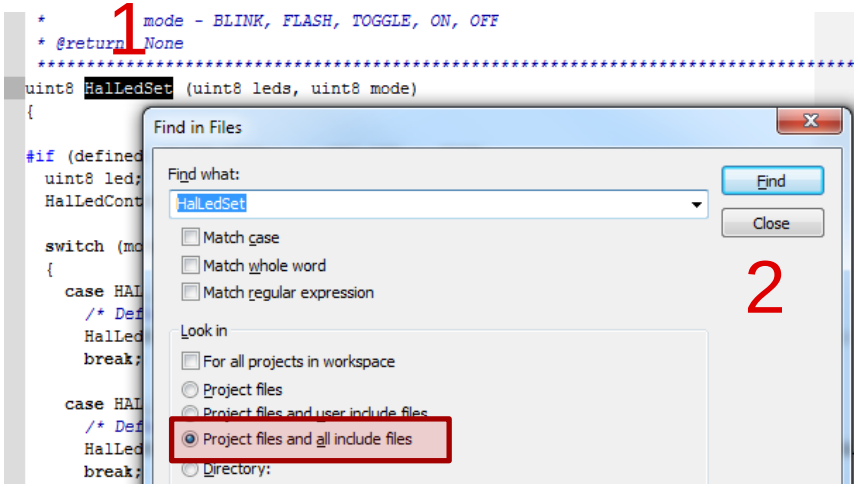


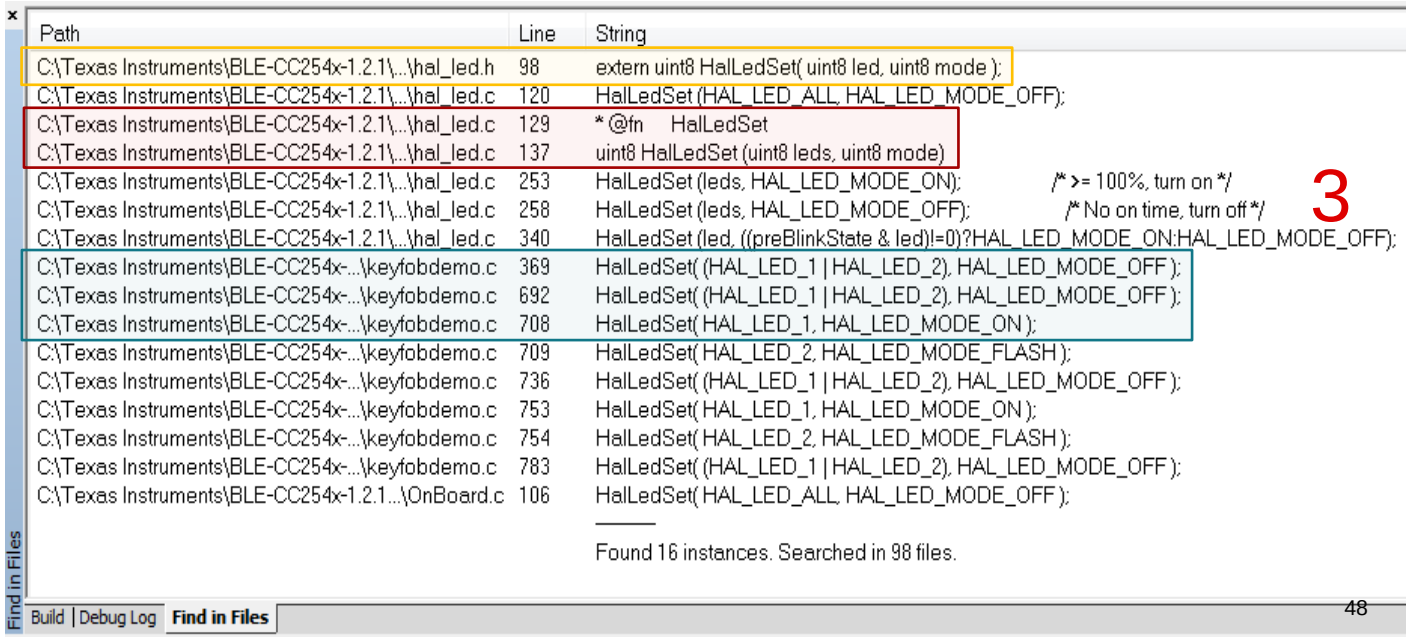


Find all in files..

To find where a certain variable is manipulated, where an OSAL Event is handled, or where a function is called:

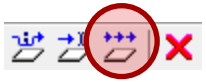
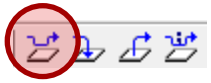
1. Double click on the symbol
2. Press CTRL+SHIFT+F
3. Double click to jump in the code





Declaration
Definition
Calls to function

Break the Code

1. Put the cursor on a line
2. Press F9. Code broken.
3. Download, *Ctrl+D* or 
4. Run, *F5* or 
5. Step Over, *F10* or 

simpleBLEPeripheral.c | SimpleBLEPeripheral_Main.c

1,2

```
716 static void performPeriodicTask( void )
717 {
718   uint8 valueToCopy;
719   uint8 stat;
720
721   // Call to retrieve the value of the third characteristic in the profile
722   stat = SimpleProfile_GetParameter( SIMPLEPROFILE_CHAR3, &valueToCopy);
723
724   if( stat == SUCCESS )
725   {
726     /*
727      * Call to set that value of the fourth characteristic in the profile.
728      * that if notifications of the fourth characteristic have been enabled
729      * a GATT client device, then a notification will be sent every time th
730      * function is called.
731      */
732     SimpleProfile_SetParameter( SIMPLEPROFILE_CHAR4, sizeof(uint8), &valueT
733   }
734 }
```

simpleBLEPeripheral.c | SimpleBLEPeripheral_Main.c

5

```
716 static void performPeriodicTask( void )
717 {
718   uint8 valueToCopy;
719   uint8 stat;
720
721   // Call to retrieve the value of the third characteristic in the profile
722   stat = SimpleProfile_GetParameter( SIMPLEPROFILE_CHAR3, &valueToCopy);
723
724   if( stat == SUCCESS )
725   {
726     /*
727      * Call to set that value of the fourth characteristic in the profile. Note
728      * that if notifications of the fourth characteristic have been enabled by
729      * a GATT client device, then a notification will be sent every time this
730      * function is called.
731      */
732     SimpleProfile_SetParameter( SIMPLEPROFILE_CHAR4, sizeof(uint8), &valueToCopy);
733   }
734 }
```

simpleBLEPeripheral.c | SimpleBLEPeripheral_Main.c

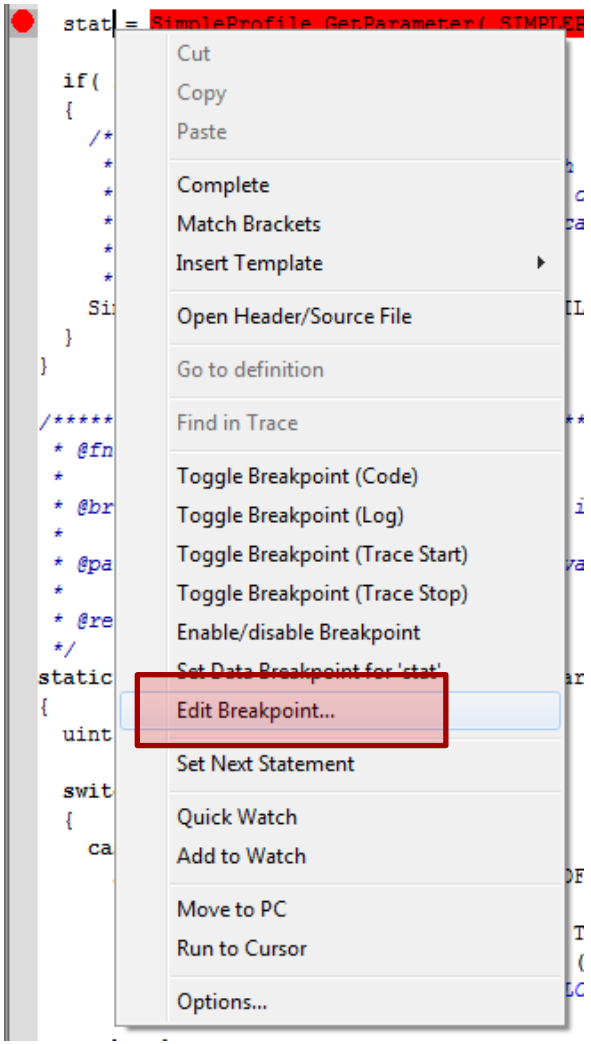
4

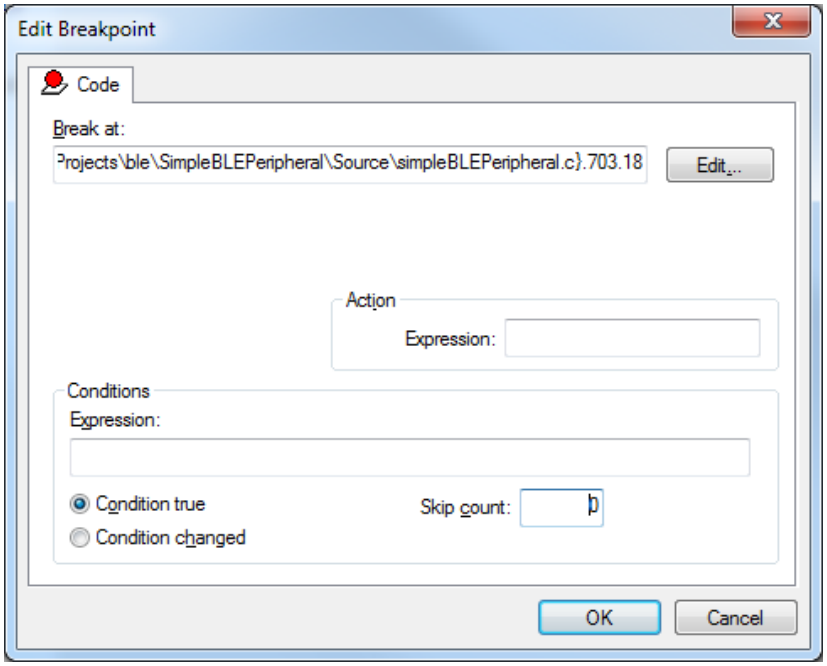
```
716 static void performPeriodicTask( void )
717 {
718   uint8 valueToCopy;
719   uint8 stat;
720
721   // Call to retrieve the value of the third characteristic in the profile
722   stat = SimpleProfile_GetParameter( SIMPLEPROFILE_CHAR3, &valueToCopy);
723
724   if( stat == SUCCESS )
725   {
726     /*
727      * Call to set that value of the fourth characteristic in the profile.
728      * that if notifications of the fourth characteristic have been enabled
729      * a GATT client device, then a notification will be sent every time th
730      * function is called.
731      */
732     SimpleProfile_SetParameter( SIMPLEPROFILE_CHAR4, sizeof(uint8), &valueT
733   }
734 }
```

Note that breaking the code during a connection will terminate the connection

Hairline fracture

- Right click on a breakpoint
- Choose Edit Breakpoint...
- Don’t break the code until it’s helpful
  - Skip a number of breaks
  - Break on a condition

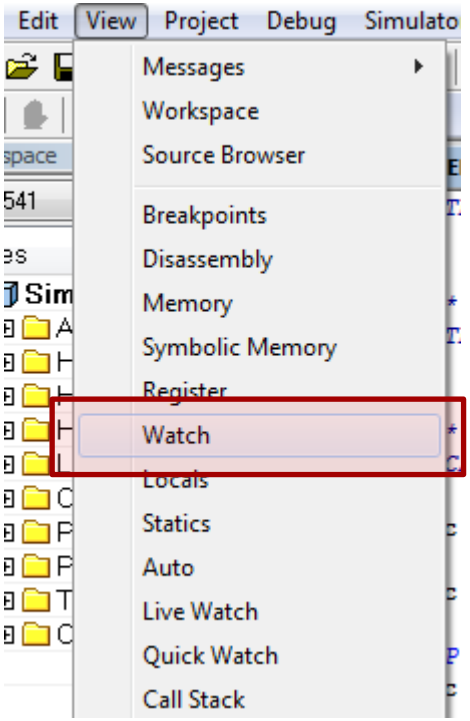




Watch the data

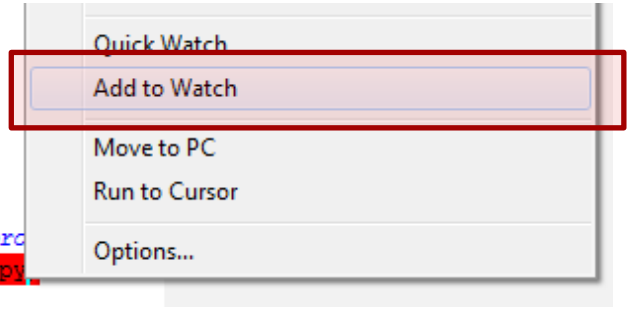
- View the watch window
- Add a variable to the watch list (right click)

- Next step
  - Run until breakpoint
  - Hit F10 to step over the statement
  - Check new value of variable in watch window



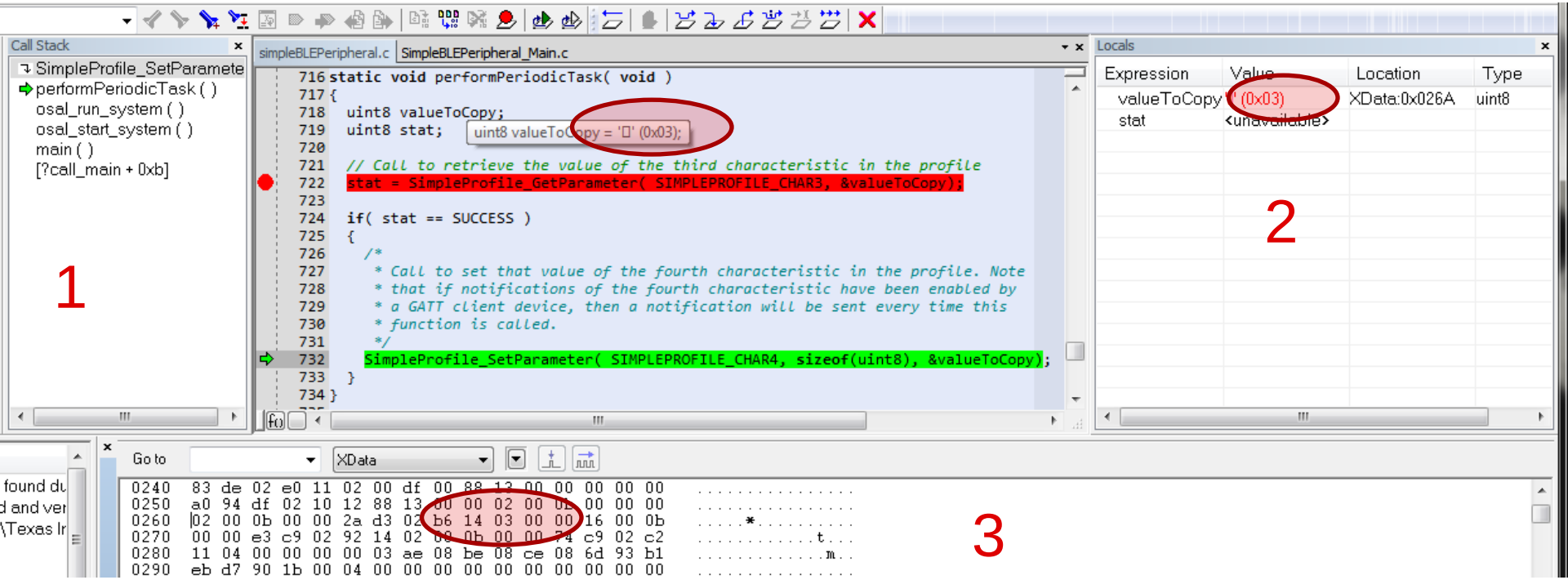

```
 * @return  none
 */
static void performPeriodicTask( void )
{
  uint8 valueToCopy;
  uint8 stat;

  // Call to retrieve the value of the third characteristic in the pro
  stat = SimpleProfile_GetParameter( SIMPLEPROFILE_CHAR3, &valueToCopy
```



How did I get here?

- Monitor
  1. Function Call Sequence: View -> Call Stack
  2. Local Variables: View -> Locals
  3. Memory: View -> Memory



Watch Out

- Avoid compiling with optimization when debugging is on the Menu
  - Variables are often ”Unavailable” with optimization on
    - Add `volatile` to the declaration, i.e. `volatile uint8 variable;`
    - If that doesn’t work, move the declaration outside the function.
  - Single stepping (F11) will sometimes behave oddly or break IAR.
    - Assembly code is moved around and changed with optimization, so if debugging features are unavailable, try turning optimizations off.

Qualification and Certification

Introduction

TI BLE Subsystems

TI BLE Subsystem	Controller	Host	Profile
QDID	**B016552**	**B017183**	**B020954**
Include	HCI Link Layer RF PHY	GAP GATT ATT SMP L2CAP HCI	Health Thermometer Profile/Service Device Information Service Find Me Profile Immediate Alert Service Link Loss Service Proximity Profile Tx Power Service Heart Rate Profile/Service Time Profile Phone Alert Status Profile Alert Notification Profile Blood Pressure Profile/Service Battery Service HID Service Scan Parameters Service HID over GATT Profile Scan Parameters Profile. Running Speed and Cadence Profile/Service Cycling Speed and Cadence Profile/Service

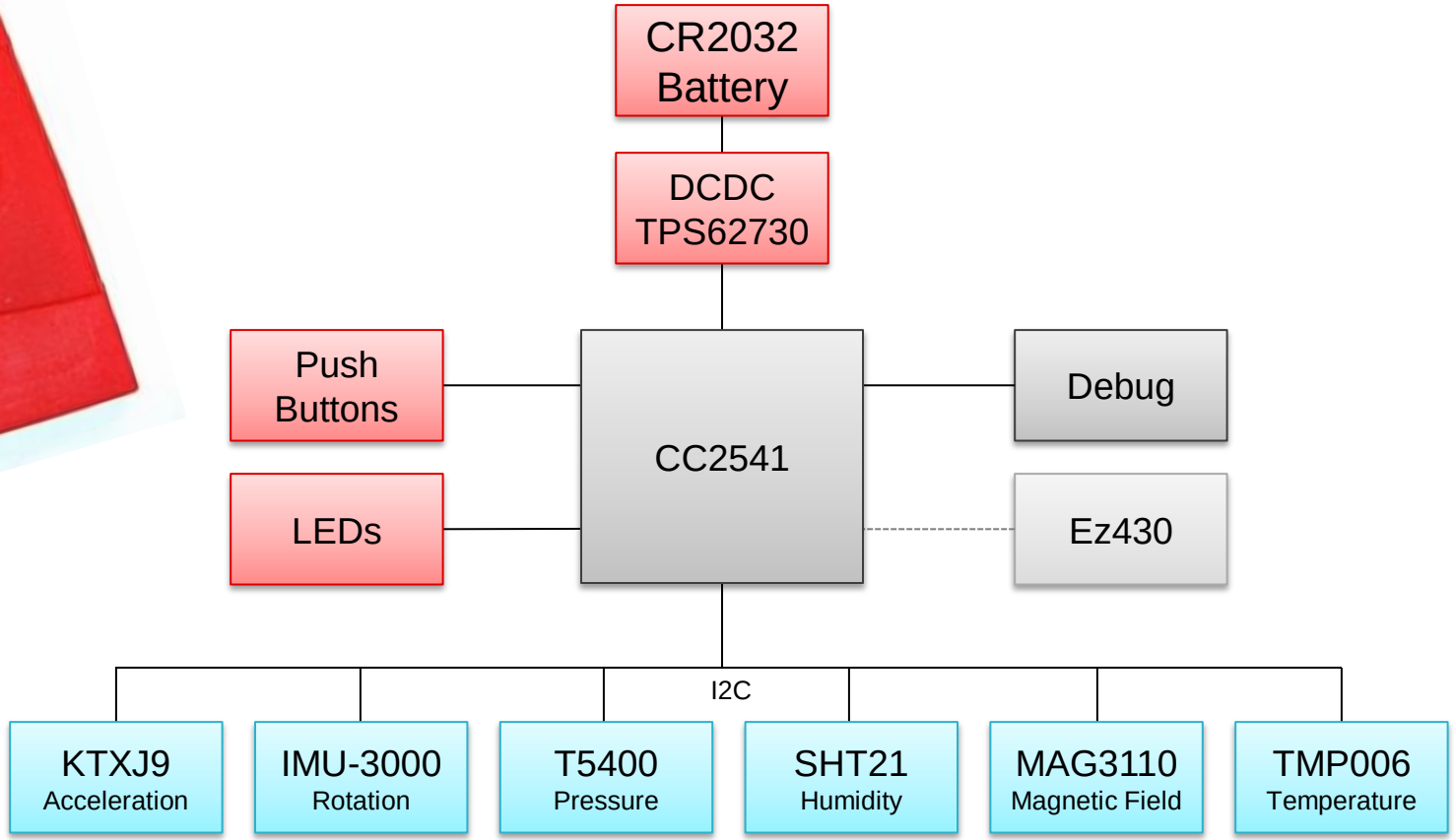
SensorTag

Evaluation

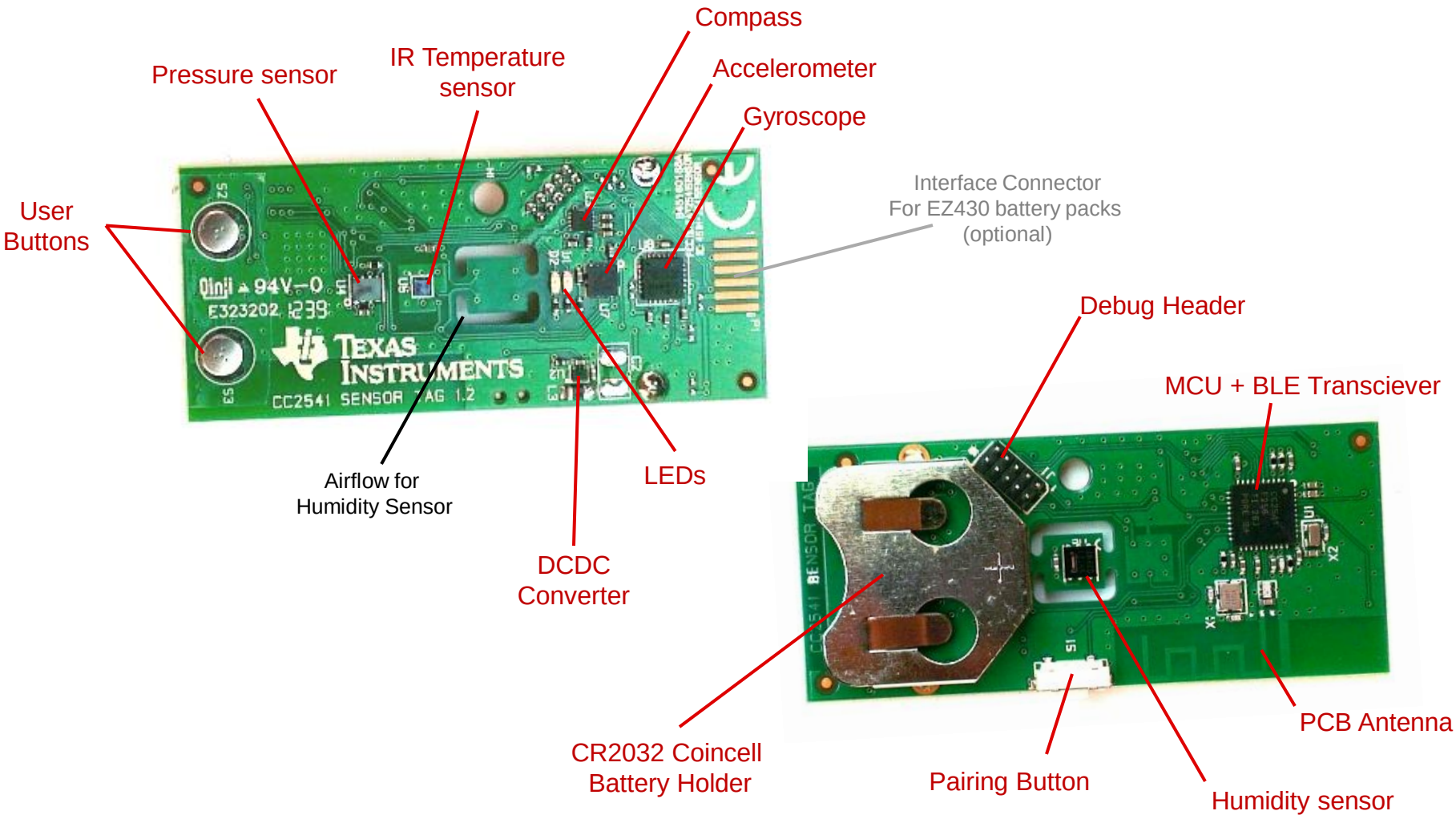
Bluetooth low energy SensorTag

- Includes *Bluetooth* low energy
  - CC2541
- 6 sensors
  - Temperature
  - Humidity
  - Pressure
  - Accelerometer
  - Gyroscope
  - Magnetometer
- Single cell coin cell battery (CR2032)
- FCC, IC and ETSI certified solution

Bluetooth low energy SensorTag

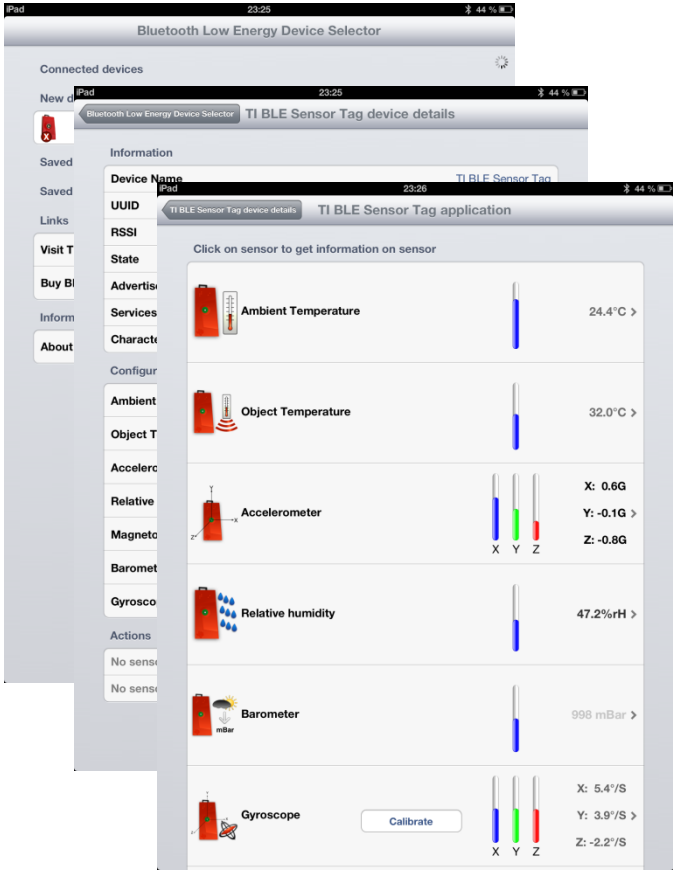


Bluetooth low energy SensorTag



Bluetooth low energy SensorTag

- Targeting Smart Phone App Developers
- Limitless App Possibilities
  - Health and fitness, medical, educational tools, toys, remote controls, mobile phone accessories, proximity and indoor locationing.
- The CC2541 SensorTag kit shortens the design time for Bluetooth low energy app development from months to hours
  - No embedded software design knowledge required.
  - The SensorTag includes all SW needed for App development
  - TI has a SensorTag App on the App Store providing developers with easy access to the tools they need.



Hands-On: SensorTag

Pre-requisites

- BLE Device Monitor (http://www.ti.com/lit/zip/swrc258)
- Packet Sniffer (http://www.ti.com/tool/packet-sniffer)

Kit Contents

- SensorTag
- 1x CR2032 Battery
- Documentation

The RF boards in this kit are FCC and IC certified and tested/complies with ETSI/R&TTE over temperature from 0 to +35°C[1]. The RF board have integrated PCB antenna.

Assembly of the SensorTag

Insert the battery in the battery connector and place the printed circuit board in the black plastic cover with the battery facing down.

Note that when inserting the battery for the first time, the PCB contact point surface has a thin layer of solder residue that may prevent contact with the battery. Remove and insert the battery a few times to power the SensorTag.

Push the side button to check if the battery is correctly inserted. When the button is pushed the LED marked D1 should start to blink.

Add the transparent plastic cover to close the inner hard plastic pieces.

Complete the assembly of the SensorTag by adding the red plastic cover.

System Overview

Bluetooth
low energy

Configuration

Sensor Data

Peripheral Device

- Slave
- Server (has data)

BLE Sniffer

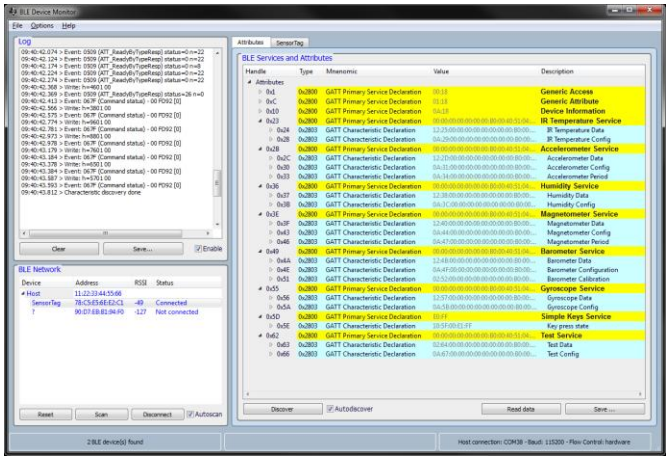
Central Device

- Master
- Client (wants data)

BLE Device Monitor

- Windows Application
- The BLE Device Monitor allows you to
  - Discover
  - Read
  - Alter attributes

  on any *Bluetooth* low energy device



- More information about the BLE Device Monitor at:

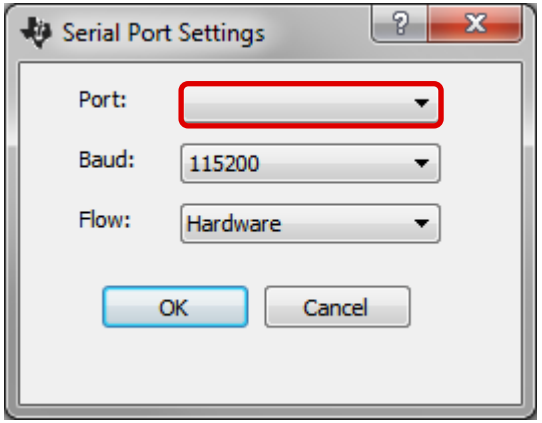
  www.ti.com/SensorTag

Setup BLE Device Monitor

- Download: http://www.ti.com/litv/zip/swrc258a

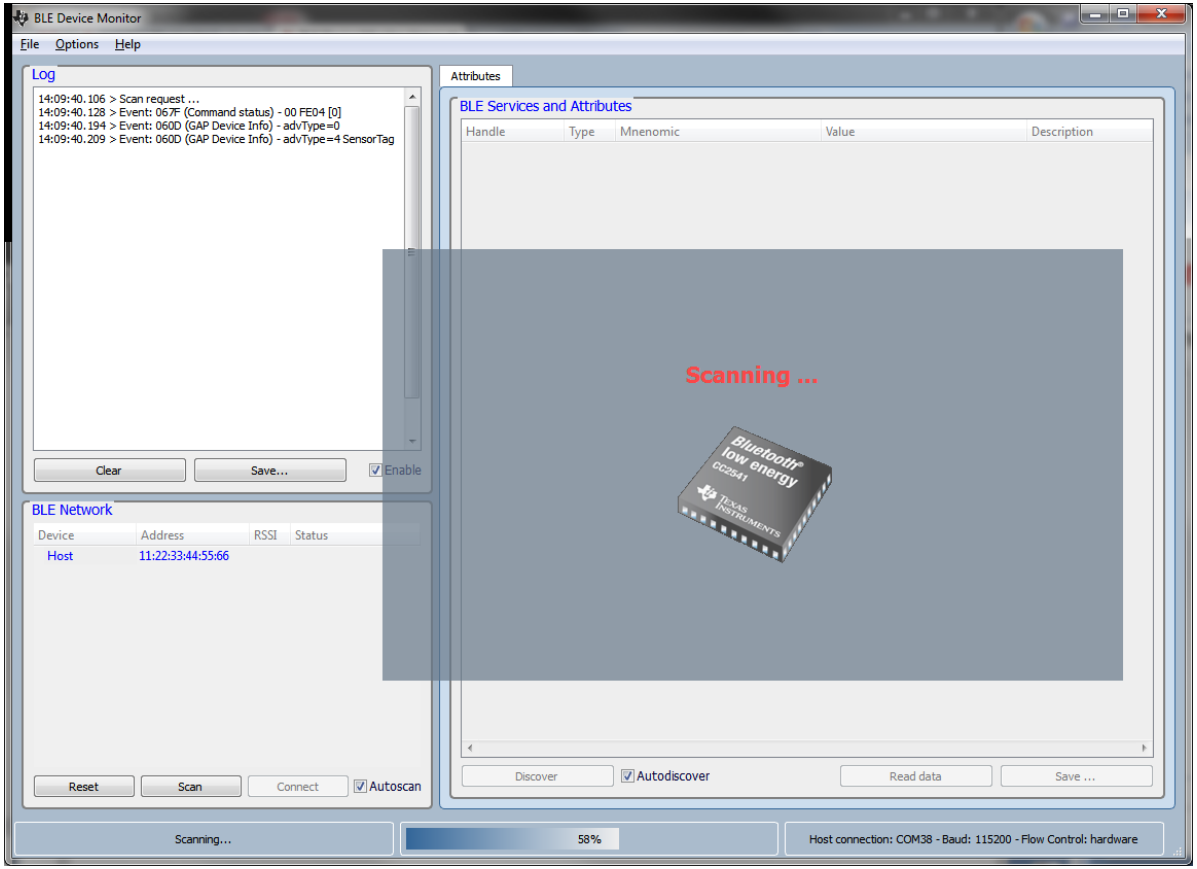
- Connect CC2540 USB dongle,
  - Program the Dongle with CC2540_USBdongle_HostTestRelease_All.hex
    (C:\Program Files\Texas Instruments\BLE Device Monitor\firmware)
  - Install USB CDC Driver, usb_cdc_driver_cc2540.inf
    (C:\Program Files\Texas Instruments\BLE Device Monitor)

- Start BLE Device Manager
  - In Options, select Port



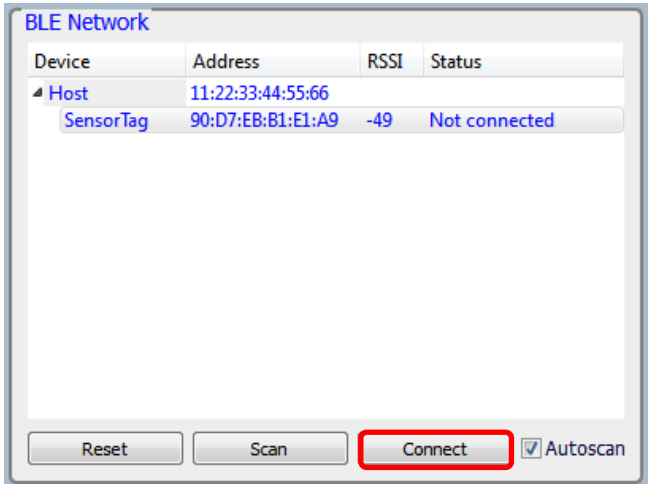
Discover the SensorTag

- Press Side Button to start Advertise



Connect to the SensorTag

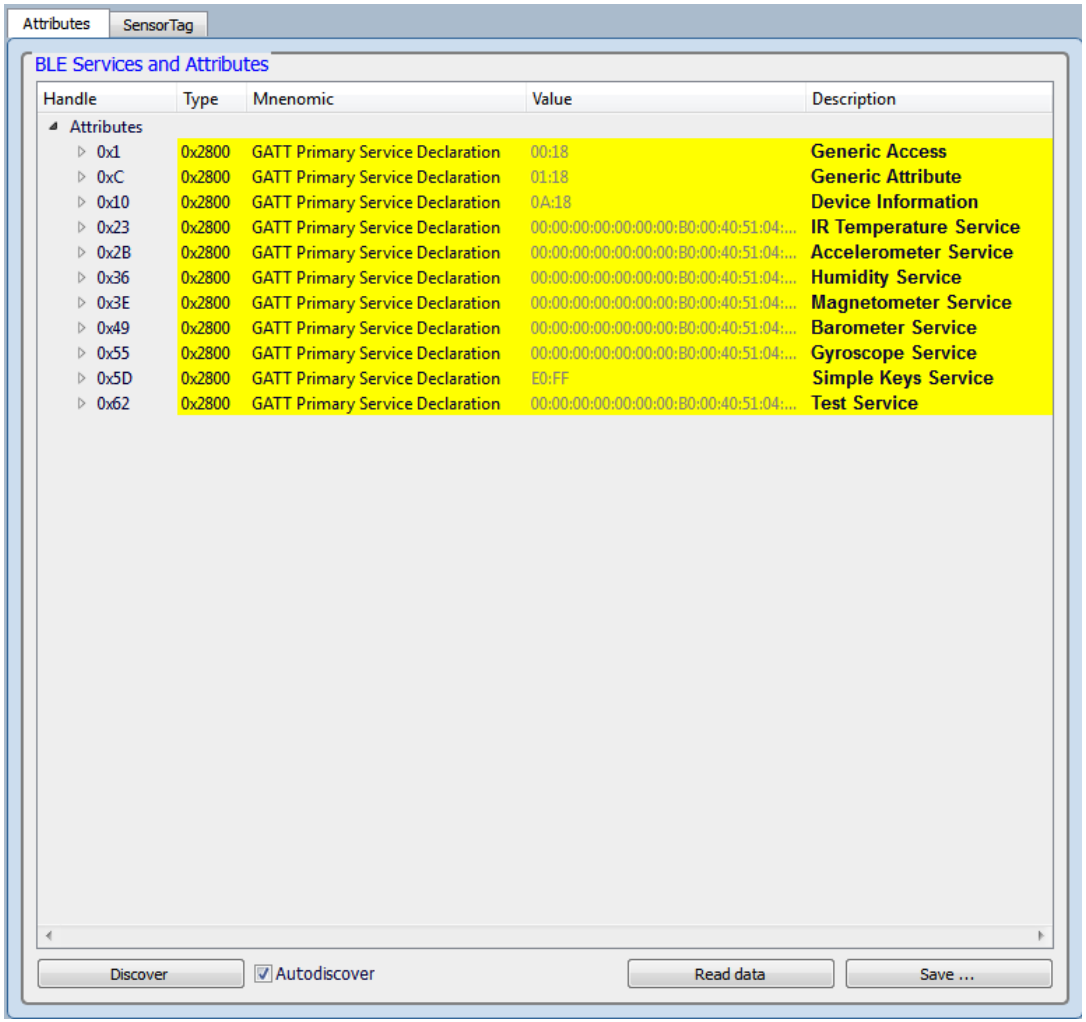
- Select the SensorTag and click on “Connect”

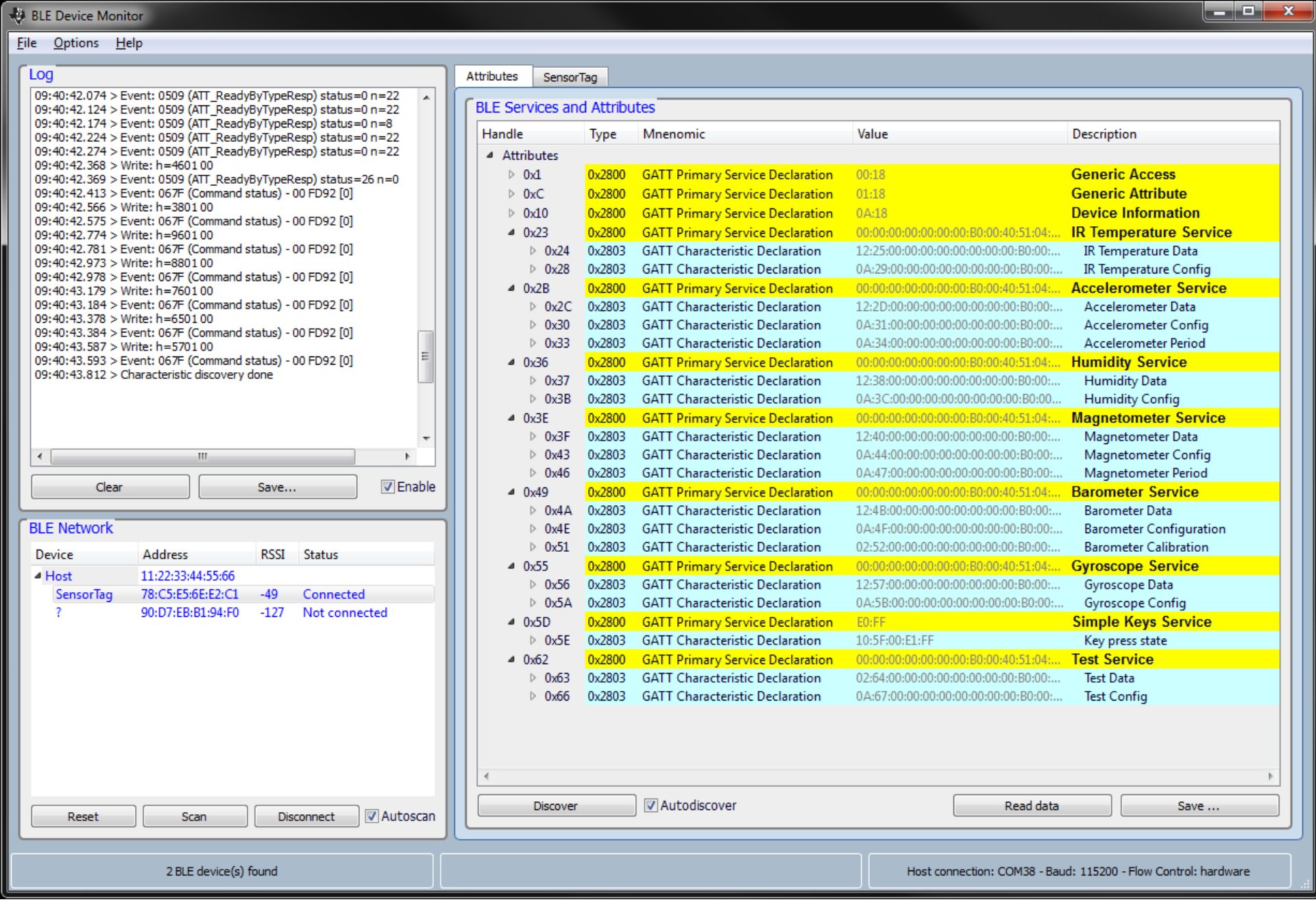


- Status will change from **Not Connected** to **Connected** and all *Bluetooth* low energy Services and Attributes are shown.

Using Attributes Tab

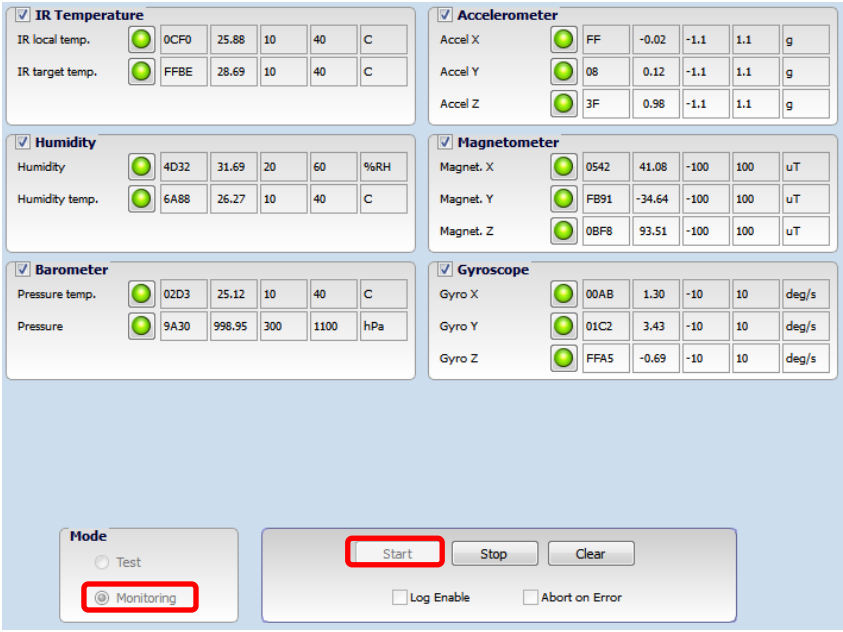
- The Attribute tab will list all the GATT Primary Services that is available for the *Bluetooth* low energy device.
- Click on the + to display the corresponding characteristics to the Service.





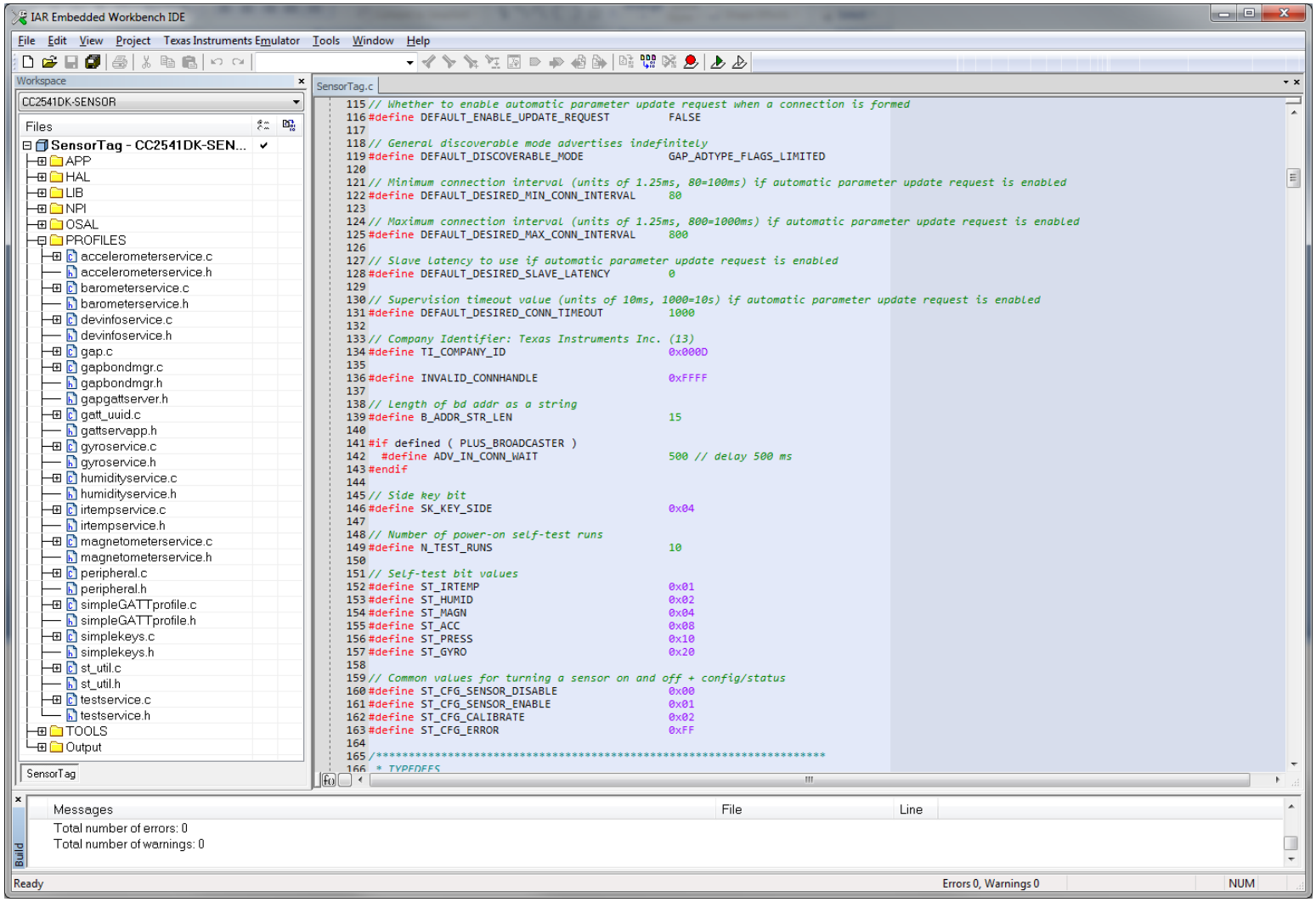
Using SensorTag Tab

- **Monitor mode** provides numerical readings of the sensors
  1. Select Monitoring
  2. Select the sensors
  3. Click on “Start”



- **Test Mode** is a production test functionality of the SensorTag which will enable you to test all the Sensors and peripherals that are available on the SensorTag. The result will be stored in time stamped log file.

SensorTag Source Code



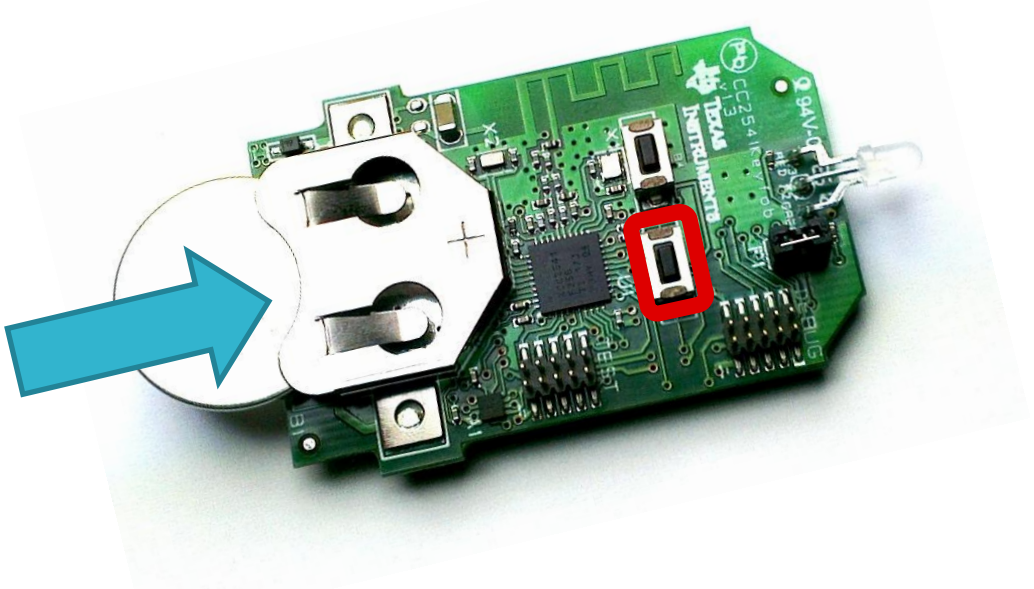
Evaluation of CC2541DK-MINI

CC2541DK-MINI Unboxing

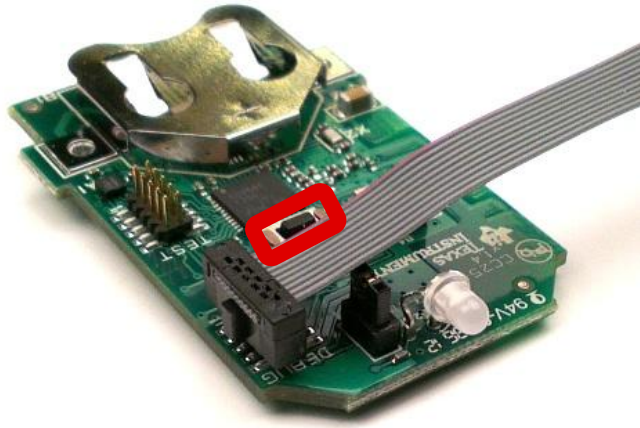
Both CC2541 Keyfob and CC2540USB Dongle are pre-programmed

Power up the Keyfob

- There are two ways of powering the CC2541 Keyfob
  - Using a CR2032 Coin Cell Battery
  - Using CC Debugger (Note that the header must be mounted on P1)



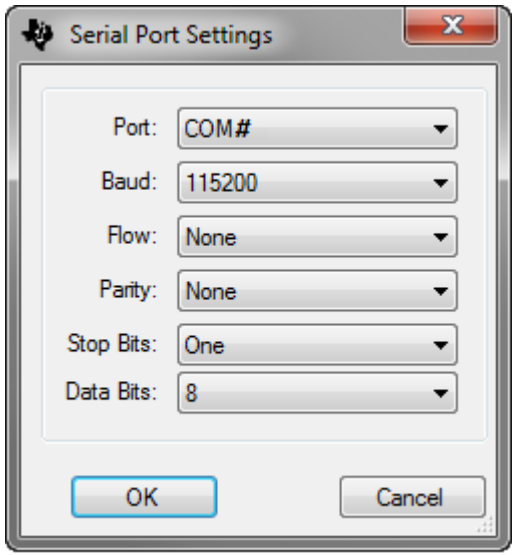
OR

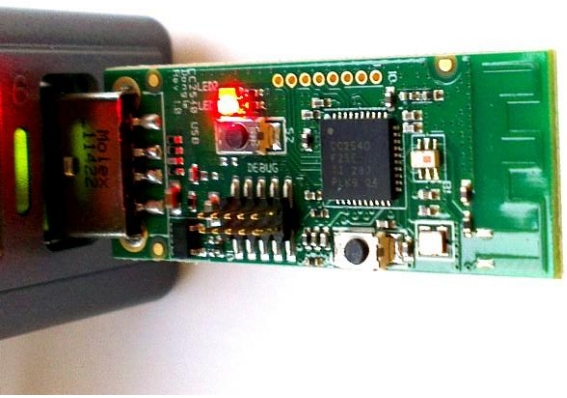


  - Device LED should lit green for 1 second
  - Press Right button to start advertisement – Device LED should blink red during the advertisment mode.

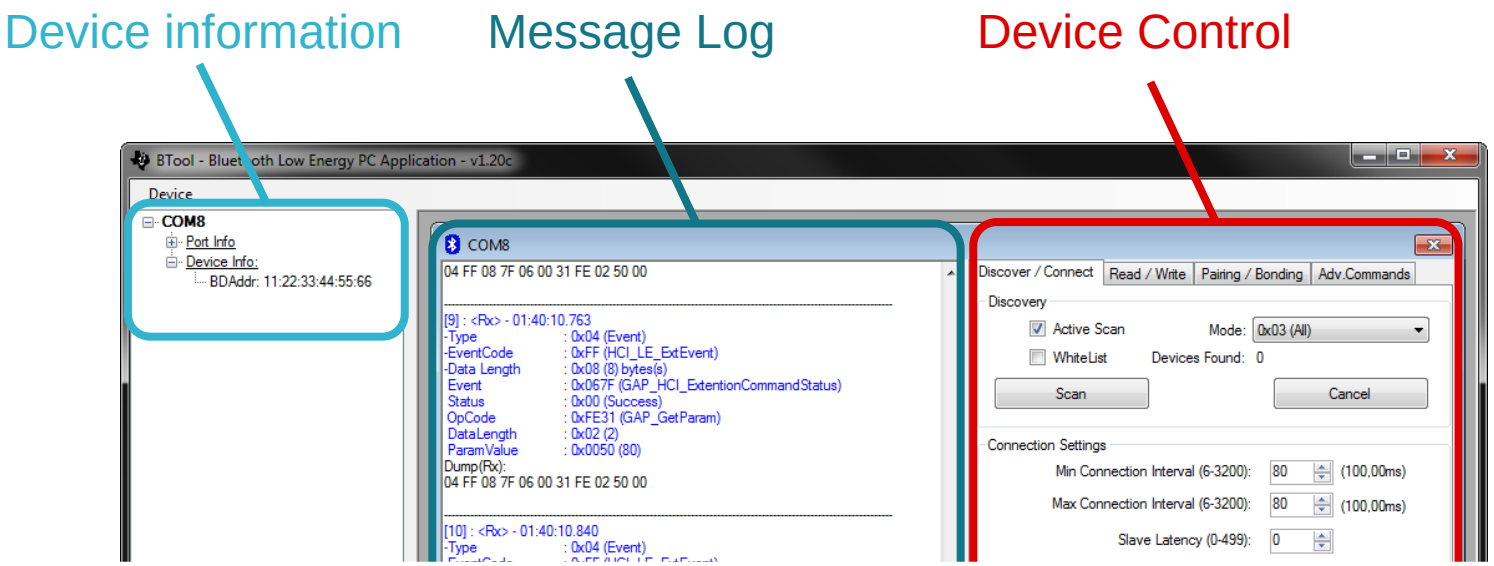
Setup PC environment

1. Insert CC2540 USB Dongle
2. Install driver, located at ..\BLE-CC254x-1.3\Accessories\Drivers
3. Start BTool
    1. Choose Port (dependent on your machine)
    2. Press OK

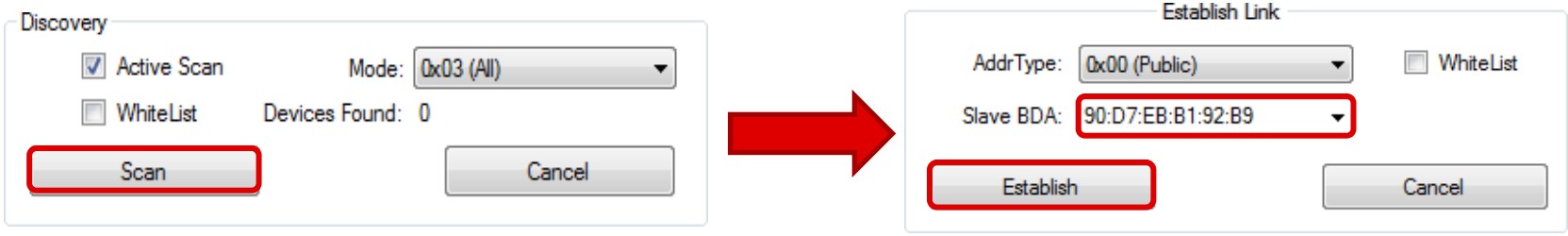




Evaluate CC2541DK-MINI

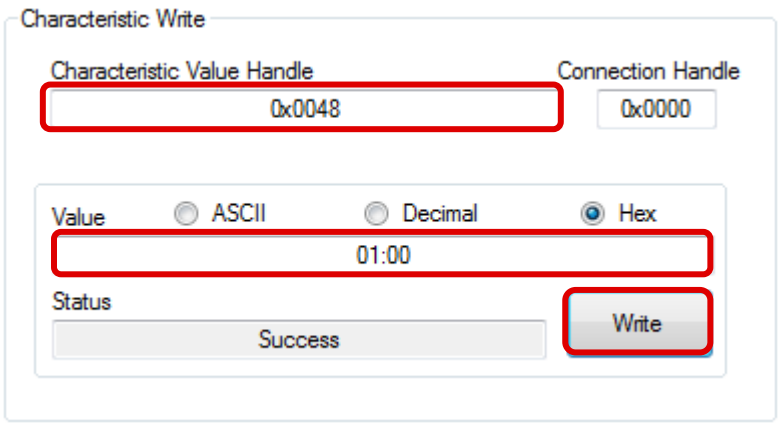


- Connect to CC2541 Keyfob

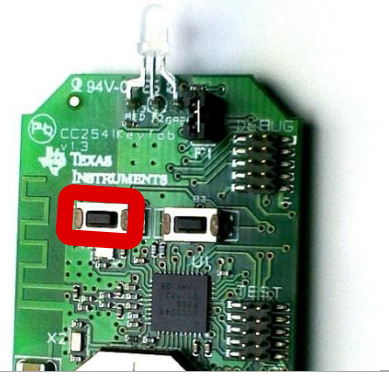


Interact with the Keyfob - Buttons

- Button Notifications
  - In Btool: Enable notifications by writing 01:00 to handle 0x0048



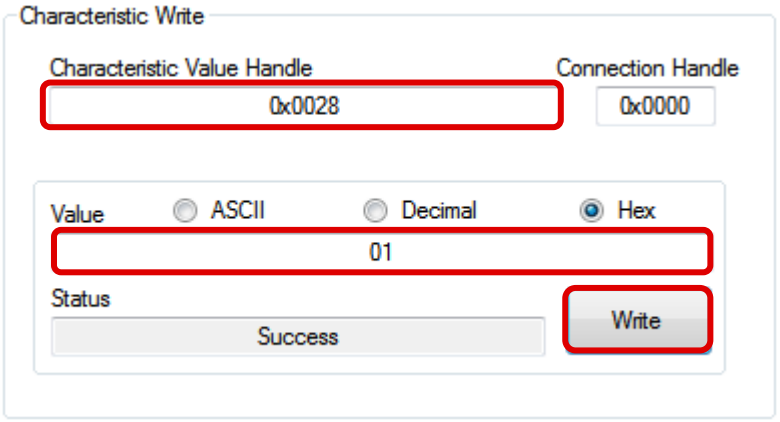
  - On Keyfob: Press buttons to send notification



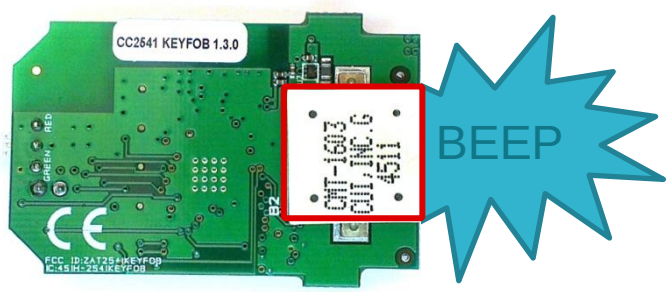
```
[42] : <Rx> - 11:02:26.367
-Type                : 0x04 (Event)
-EventCode           : 0xFF (HCI_LE_ExtEvent)
-Data Length         : 0x09 (9) bytes(s)
 Event               : 0x051B (ATT_HandleValueNotification)
 Status              : 0x00 (Success)
 ConnHandle          : 0x0000 (0)
 PduLen              : 0x03 (3)
 Handle              : 0x0047 (71)
 Value               : 01
Dump(Rx):
04 FF 09 1B 05 00 00 00 03 47 00 01
```

Interact with the Keyfob - Alert

- Immediate Alert
  - In Btool: Trigger a buzzer alert by writing 01:00 to handle 0x0028

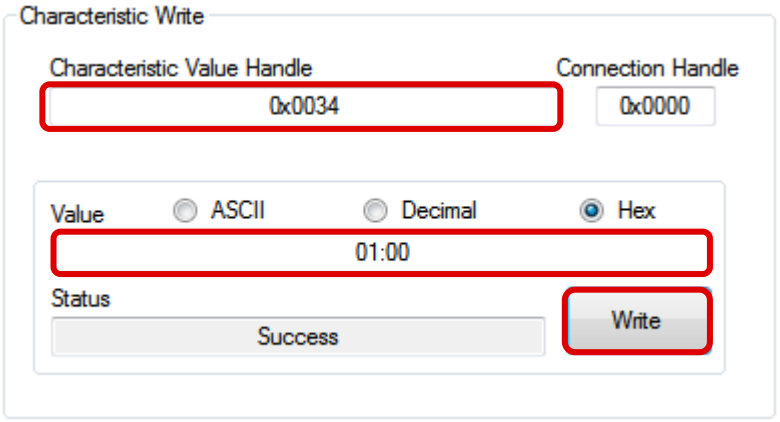


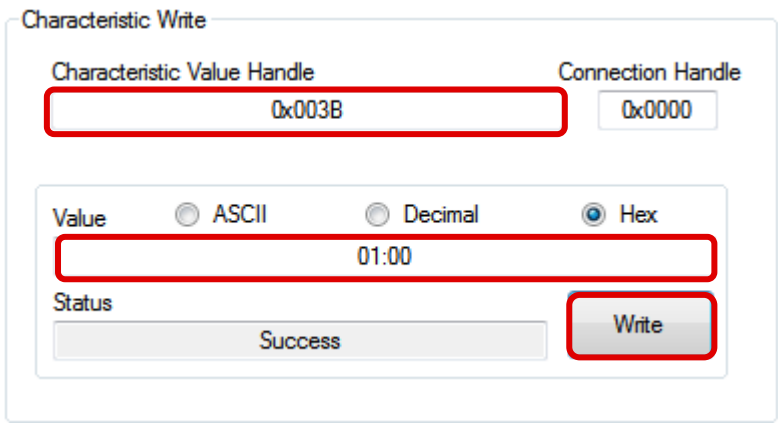
01 for Low Alert
02 for High Alert
00 to Turn Off



Interact with the Keyfob - Accelerometer

- Accelerometer
  - In Btool: Enable accelerometer by writing 01:00 to handle 0x0034
  - In Btool: Enable x-axis notifications by writing 01:00 to handle 0x003B





  - Move the Keyfob

```
[160] : <Rx> - 03:33:36.833
-Type              : 0x04 (Event)
-EventCode         : 0xFF (HCI_LE_ExtEvent)
-Data Length       : 0x09 (9) bytes(s)
 Event             : 0x051B (ATT_HandleValueNotification)
 Status            : 0x00 (Success)
 ConnHandle        : 0x0000 (0)
 PduLen            : 0x03 (3)
 Handle            : 0x003A (58)
 Value             : E6
Dump(Rx):
04 FF 09 1B 05 00 00 00 03 3A 00 E6
```

Human Interface Device over Generic Attribute Profile

HID over GATT Profile

HOGP

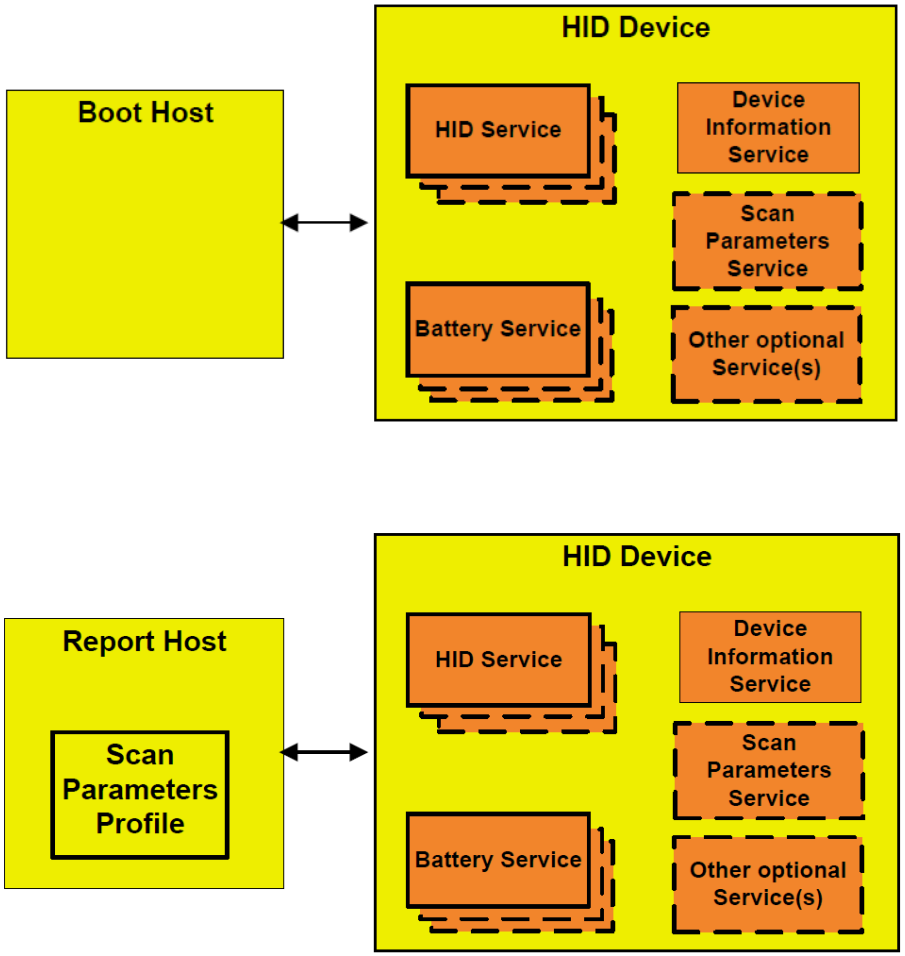
BLE HID: Introduction

- ”HID Over GATT” Profile specification was approved by the BT SIG in December 2011
- Specification is publicly available at bluetooth.org
- Microsoft has already announced native support for LE HID in Windows 8

HID over GATT Profile

- Host and Device behave according to HoG Profile
- Data is exchanged using characteristics in the HID Service
- HID Service is a wrapper for usual USB HID reports.

Profile in yellow,
Services in orange



Attribute table: HOGP req. services

Legend, properties
- Notification
- Read
- Write
- WriteNoRsp

Battery service

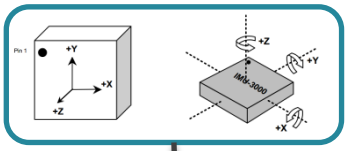
Scan Param. Service

HID Service

Handle	Uuid	Uuid Description	Value	
0x0023	0x2800	GATT Primary Service Declaration	0F:18	
0x0024	0x2803	GATT Characteristic Declaration	12:25:00:19:2A	
0x0025	0x2A19	Battery Level	00	
0x0026	0x2902	Client Characteristic Configuration	9E:00	
0x0027	0x2908	Report Reference	04:01	
0x0028	0x2800	GATT Primary Service Declaration	13:18	
0x0029	0x2803	GATT Characteristic Declaration	04:2A:00:4F:2A	
0x002A	0x2A4F	Scan Interval Window		Info about Host scanning behaviour
0x002B	0x2803	GATT Characteristic Declaration	10:2C:00:31:2A	
0x002C	0x2A31	Scan Refresh		
0x002D	0x2902	Client Characteristic Configuration	9E:00	Request from RC about Host scan info
0x002E	0x2800	GATT Primary Service Declaration	12:18	
0x002F	0x2802	GATT Include Declaration	23:00:27:00:0F:18	
0x0030	0x2803	GATT Characteristic Declaration	02:31:00:4A:2A	
0x0031	0x2A4A	HID Information		HID version, country code, remote wake
0x0032	0x2803	GATT Characteristic Declaration	04:33:00:4C:2A	
0x0033	0x2A4C	HID Control Point		Host is suspending/waking
0x0034	0x2803	GATT Characteristic Declaration	06:35:00:4E:2A	
0x0035	0x2A4E	Protocol Mode		Boot mode or Report mode
0x0036	0x2803	GATT Characteristic Declaration	02:37:00:4B:2A	
0x0037	0x2A4B	Report Map	05:01:09:02:A1:01:85:01:09:01:A1:00:05:09:19:01:29:03:15:00:25:01	USB HID Report Descriptor
0x0038	0x2907	External Report Reference	19:2A	
0x0039	0x2803	GATT Characteristic Declaration	12:3A:00:4D:2A	
0x003A	0x2A4D	Report		HID Mouse IN
0x003B	0x2902	Client Characteristic Configuration	9E:00	
0x003C	0x2908	Report Reference	01:01	
0x003D	0x2803	GATT Characteristic Declaration	12:3E:00:4D:2A	
0x003E	0x2A4D	Report		HID Keyboard IN
0x003F	0x2902	Client Characteristic Configuration	9E:00	
0x0040	0x2908	Report Reference	02:01	
0x0041	0x2803	GATT Characteristic Declaration	12:42:00:4D:2A	
0x0042	0x2A4D	Report		HID Consumer Control IN
0x0043	0x2902	Client Characteristic Configuration	9E:00	
0x0044	0x2908	Report Reference	03:01	
0x0045	0x2803	GATT Characteristic Declaration	0E:46:00:4D:2A	
0x0046	0x2A4D	Report		HID LED OUT
0x0047	0x2908	Report Reference	00:02	
0x0048	0x2803	GATT Characteristic Declaration	12:49:00:22:2A	
0x0049	0x2A22	Boot Keyboard Input Report		Boot Keyboard IN
0x004A	0x2902	Client Characteristic Configuration	9E:00	
0x004B	0x2803	GATT Characteristic Declaration	0E:4C:00:32:2A	
0x004C	0x2A32	Boot Keyboard Output Report		Boot Keyboard OUT
0x004D	0x2803	GATT Characteristic Declaration	12:4E:00:33:2A	
0x004E	0x2A33	Boot Mouse Input Report		Boot Mouse IN
0x004F	0x2902	Client Characteristic Configuration	9E:00	
0x0050	0x2803	GATT Characteristic Declaration	0A:51:00:4D:2A	
0x0051	0x2A4D	Report		Feature report
0x0052	0x2908	Report Reference	00:03	

IN = To host
OUT = To device

Typical dataflow



Scan keys on ISR
hal_key.c / OSAL.c / hal_drivers.c

Keyscan result, row & col

Application callback
hidAdvRemote.c : KeyCback

Command, Usage page

Build HID report
hidAdvRemote.c :hid[Key|CC]SendReport

HID Kbd/CC Input report

Periodic sensor poll*
hal_motion.c

Raw I²C sensor data

MOVEA library
AIR_MOTION_LIB_3G3A-Banked.r51

X + Y "Mickeys"

Application callback
hidAdvRemote.c : MotionSensorCback

X + Y "Mickeys"

Build HID report
hidAdvRemote.c : hidMouseSendReport

HID Mouse Input report

Queue report
hidDev.c : HidDev_Report

HID Mouse/Kbd/CC Input report

Send report
hidDev.c : hidDevSendReport

GATT Notification

BLE Stack

OTA to Central device acting as HOGP Host

* Application turns off polling when idle, then restarts on Acc ISR if applicable

What does a report contain

0x0039	0x2803	GATT Characteristic Declaration	12:3A:00:4D:2A
0x003A	0x2A4D	Report	

- Mouse, 4 bytes data
  - Buttons
  - MickeysX
  - MickeysY
  - Wheel

0x0041	0x2803	GATT Characteristic Declaration	12:42:00:4D:2A
0x0042	0x2A4D	Report	

- Consumer Control, 2 bytes
  - Bitmap of command

0x003D	0x2803	GATT Characteristic Declaration	12:3E:00:4D:2A
0x003E	0x2A4D	Report	

- Keyboard, 8 bytes
  - Modifier
  - Reserved
  - Keycode 1..6

- Significance determined by which characteristic report sent via.

```
static void hidMouseSendReport( uint8 mouseStates, int8 mickeysX, int8 mickeysY )
{
  uint8 buf[HID_MOUSE_IN_RPT_LEN];

  // No need to include Report Id
  buf[0] = mouseStates;          // Buttons
  buf[1] = mickeysX;             // X
  buf[2] = mickeysY;             // Y
  buf[3] = 0;                    // Wheel

  HidDev_Report( HID_RPT_ID_MOUSE_IN, HID_REPORT_TYPE_INPUT,
                 HID_MOUSE_IN_RPT_LEN, buf );
}
```

```
static void hidCCSendReport( uint8 cmd, bool keyPressed, uint8 keyRepeated )
{
  // Only send the report if something meaningful to report
  if ( keyRepeated == 0 )
  {
    uint8 buf[HID_CC_IN_RPT_LEN] = { 0, 0 };

    // No need to include Report Id
    if ( keyPressed )
    {
      hidCCBuildReport( buf, cmd );
    }

    HidDev_Report( HID_RPT_ID_CC_IN, HID_REPORT_TYPE_INPUT,
                   HID_CC_IN_RPT_LEN, buf );
  }
}
```

```
static void hidKeyboardSendReport( uint8 modifiers, uint8 keycode )
{
  static uint8 prevKeycode = HAL_KEY_CODE_NOKEY;
  static uint8 prevModifiers = HID_KEYBOARD_RESERVED;

  // Only send the report if something meaningful to report
  if ( ( prevKeycode != keycode ) || ( prevModifiers != modifiers ) )
  {
    uint8 buf[HID_KEYBOARD_IN_RPT_LEN];

    // No need to include Report Id
    buf[0] = modifiers;          // Modifier keys
    buf[1] = 0;                  // Reserved
    buf[2] = keycode;            // Keycode 1
    buf[3] = 0;                  // Keycode 2
    buf[4] = 0;                  // Keycode 3
    buf[5] = 0;                  // Keycode 4
    buf[6] = 0;                  // Keycode 5
    buf[7] = 0;                  // Keycode 6

    HidDev_Report( HID_RPT_ID_KEY_IN, HID_REPORT_TYPE_INPUT,
                   HID_KEYBOARD_IN_RPT_LEN, buf );
```

iOS BLE App Development

Introduction

Developing for iOS

- Development happens in Xcode
- Xcode runs on OSX [Mountain] Lion

- Xcode and simulator is free
  - BLE requires physical iOS device

- Physical device download requires Apple Developer Account
  - Costs 99$ per year at `developer.apple.com/programs/ios`

1. Develop

Develop your application with the iOS SDK and a wealth of technical resources in the iOS Dev Center.
Learn more ▸

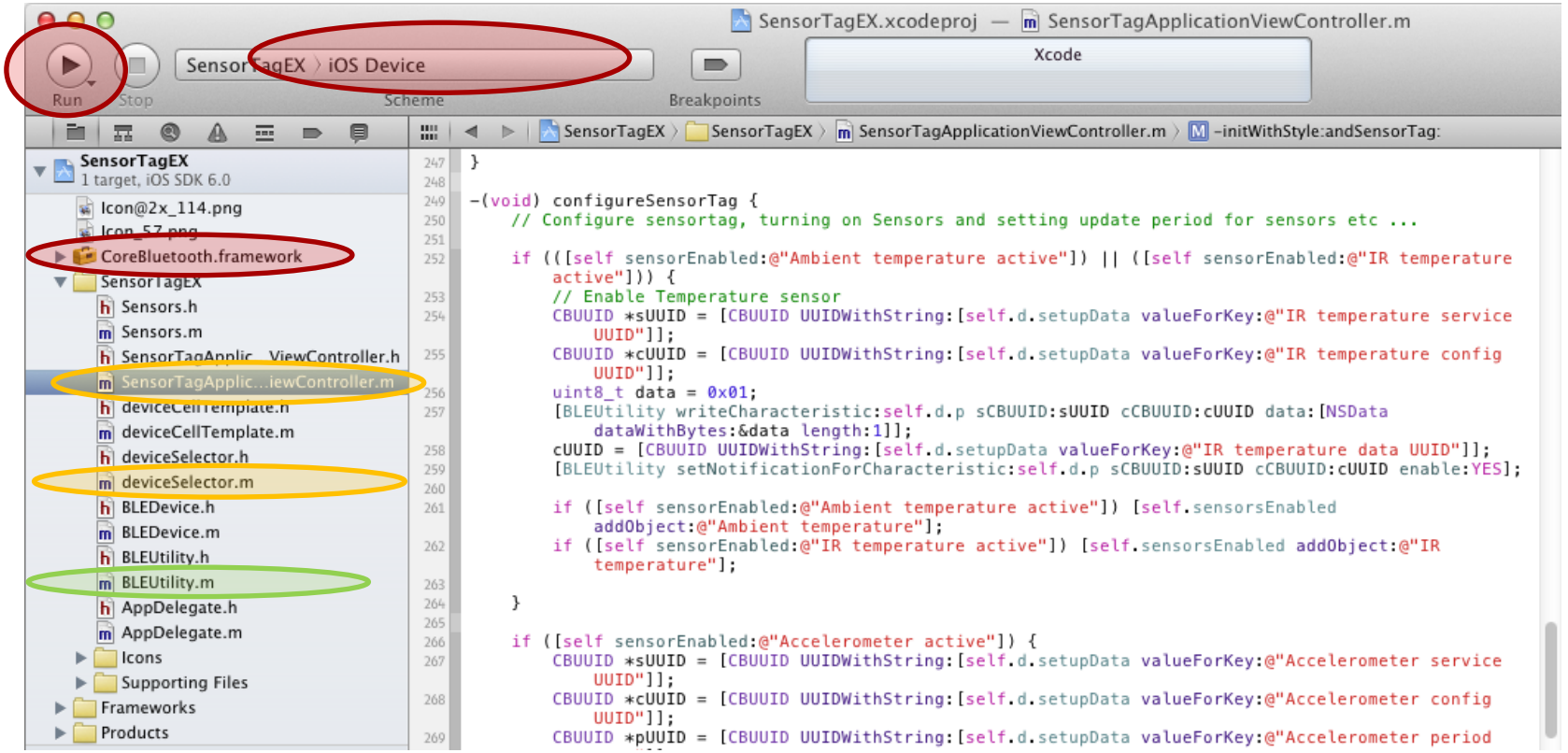
2. Test

Test and debug your code on iPad, iPhone and iPod touch to finalize your applications.
Learn more ▸

3. Distribute

Distribute your apps on the App Store and reach millions of iPad, iPhone, and iPod touch users.
Learn more ▸

Using Xcode



iOS apps are separated* into Model, View and Controller (MVC).

In our example, CoreBluetooth callbacks are in the ViewControllers, and some CoreBt functions are wrapped for convenience in BLEUtility

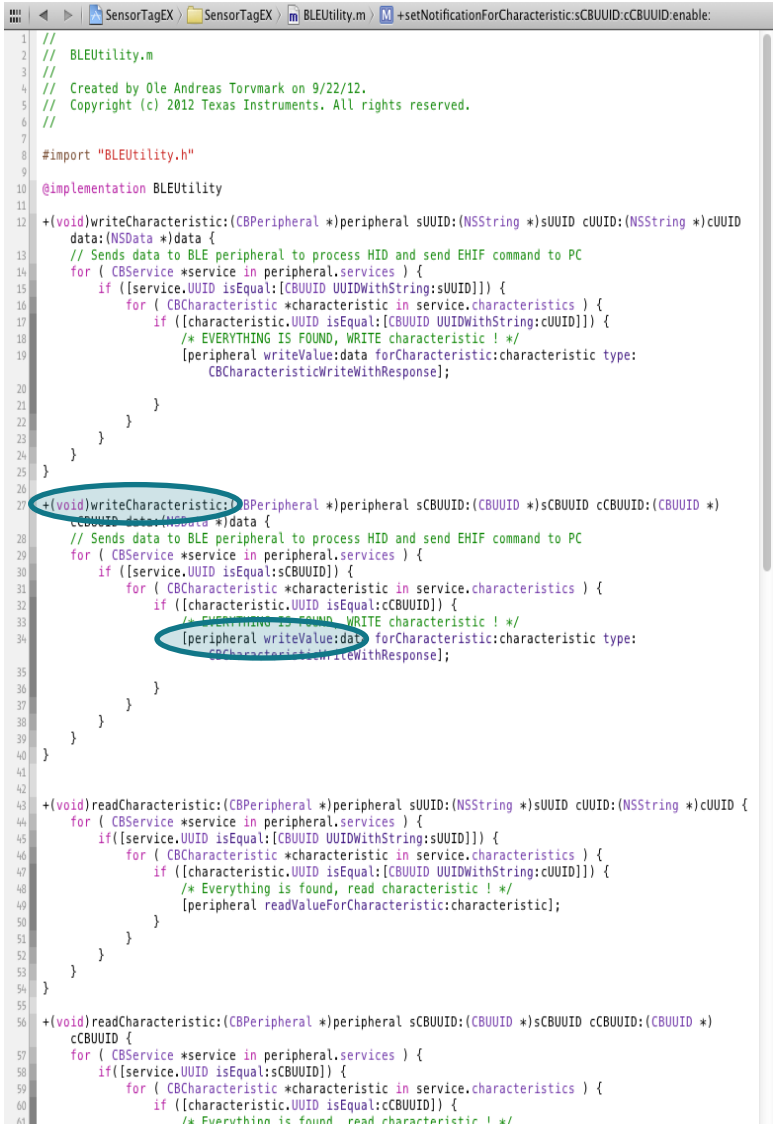
*ideally

Adding a device to Xcode

- Open Organizer (under Window)
- Click on device
- Click add to Portal
- Play button works

The iOS Source Code

- The communication is asynchronous between app and iOS's CoreBluetooth
- We issue commands to CBCentralManager and CBPeripheral
  - `[BLEUtility writeCharacteristic ...]` ➔
  - `[peripheral writeValue:data ... ];`
- Then act as *delegate* for CBCentralManager
  - `centralManagerDidUpdateState`
  - `didDiscoverPeripheral`
  - `didConnectPeripheral`
- And for CBPeripheral
  - `didDiscoverServices`
  - `didUpdateValueForCharacteristic`
  - `didWriteValueForCharacteristic`
- *Delegates* implement callbacks according to a *protocol*. A design pattern used in iOS.



The iOS BLE Limitations

- Uses Private resolvable address instead of fixed IEEE address
  - Cannot use whitelist towards iOS devices
  - Cannot use directed advertisements towards iOS devices

- Connection parameter limitations
  - Connection parameters must be updated by slave device(!)
  - Interval must be higher than 20ms; combined with latency, less than 2s
  - Supervisor timeout <= 6s
  - Slave latency >= 4

- BLE data hidden from the user:
  - IEEE address of peripheral
  - Characteristic handles
  - Descriptors
  - Connection parameters

References

- Getting started with iOS development
  - Setting up account and development environment (Xcode)
  - Developing, installing and testing an app
  - Distributing on the appstore (pretty complicated)
  - https://developer.apple.com/programs/ios/gettingstarted/

- Objective-C and iOS
  - If you are familiar with C:
    - http://en.wikipedia.org/wiki/Objective-C (very helpful)
  - Your first iOS app
    - http://developer.apple.com/library/ios/#documentation/iphone/conceptual/iphone101/Articles/00_Introduction.html
  - BLE Blog by Ole Andreas Torvmark (TI Contractor in Oslo)
    - http://ble.stalliance.no/

- Sensortag example project
  - http://www.ti.com/sensortag-wiki

Frequently Asked Questions

FAQ / known issues

- Using IAR v.8.20, compile/linker error
  - Answer: We recommend 8.10.4 or 8.11.4.bacause version 8.20 generates an extra (unnecessary) instruction. Workaround: In hal_sleep.c, remove *PCON = halSleepPconValue;* in halSetSleepMode replacing it with the line *asm("MOV 0x87,halSleepPconValue");*

- Porting projects from BLEv1.2.1 to BLEv1.3
  - Answer: See porting guide at wiki

Thank You

- TI *Bluetooth* low energy Solutions

  http://www.ti.com/ble

- TI *Bluetooth* low energy Wiki

  http://www.ti.com/ble-wiki

- TI BLE-Stack

  http://www.ti.com/ble-stack

- TI *Bluetooth* low energy E2E Forum

  http://www.ti.com/ble-forum

- TI *Bluetooth* low energy SensorTag

  http://www.ti.com/sensortag