

RA4W1 Group

Bluetooth Low Energy Profile Developer's Guide

Introduction

This document guides you on how to configure and generate Bluetooth® Low Energy (LE) profiles for the following target device.

Target Device

- RA4W1 Group

Related Documents

- Bluetooth Core Specification (<https://www.bluetooth.com>)
- RA4W1 Group User's Manual: Hardware (R01UH0883)
- EK-RA4W1 Quick Start Guide (R20QS0015)
- e²studio Getting Started Guide (R20UT4204)
- RA4W1 Group BLE Sample Application (R01AN5402)
- RA Flexible Software Package Documentation

The Bluetooth® word mark and logos are registered trademarks owned by Bluetooth SIG, Inc. and any use of such marks by Renesas Electronics Corporation is under license. Other trademarks and registered trademarks are the property of their respective owners.

Contents

1. Overview	3
1.1 Structure of profile	3
1.2 Flow of profile development	4
2. Development environment	5
2.1 QE for BLE	5
2.2 Building development environment	7
2.2.1 Install QE for BLE	7
2.3 Create project for developing Bluetooth LE Application	7
3. Profile Configuration in QE for BLE	8
3.1 Overview of profile configuration	8
3.2 Configuration of Profile	10
3.2.1 Profile	11
3.2.2 Service	12
3.2.3 Characteristic	15
3.2.4 Descriptor	18
3.3 Configuration of peripheral	21
3.3.1 Advertising Data	21
3.3.2 Scan Response Data	23
3.3.3 Advertising Parameter	23
3.4 Configuration of central	24
3.4.1 Scan Parameter	25
3.4.2 Scan filter data	26
3.4.3 Connection Parameter	26
3.5 Setting to connect between two evaluation boards	27
4. Implementation of program	28
4.1 Implementation of custom service	28
4.1.1 Implementing encode/decode function	28
4.1.2 Implementing callback	32
4.1.3 Definition of service API	36
4.2 Implementation of app_main.c	38
4.2.1 Implementing callback	38
4.2.1.1 Service events	39
4.3 Notice	42
4.3.1 Implementation of multiple services	42
4.3.2 Implementation of same service	42
4.3.3 Implementation of secondary service	44
4.3.4 Implementation of discovery operation about included service	48
5. Running created project	50
Revision History	51

1. Overview

1.1 Structure of profile

In a Bluetooth LE Communication, Generic Attribute Protocol (GATT) is primarily used. GATT defines client and server roles, and profile communication is performed between client and server. The server has the profile data in GATT database and the client accesses the profile data by Bluetooth LE communication.

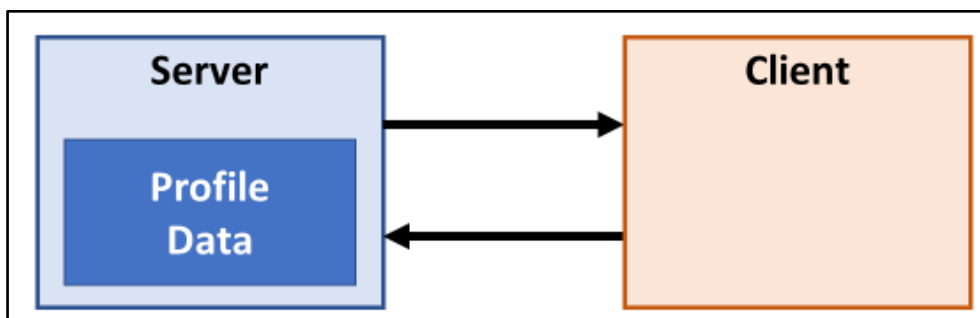


Figure 1.1 Overview of profile communication

Figure 1.2 shows Structure of profile in Bluetooth LE software.

In this Bluetooth LE software, user application and profiles run on the BLE Protocol Stack. Profile consist of three types of program:

- Framework for using Bluetooth LE features and profiles from user application.
- GATT database that defines the data structure of the services used in the profile.
- API program for accessing profile data.

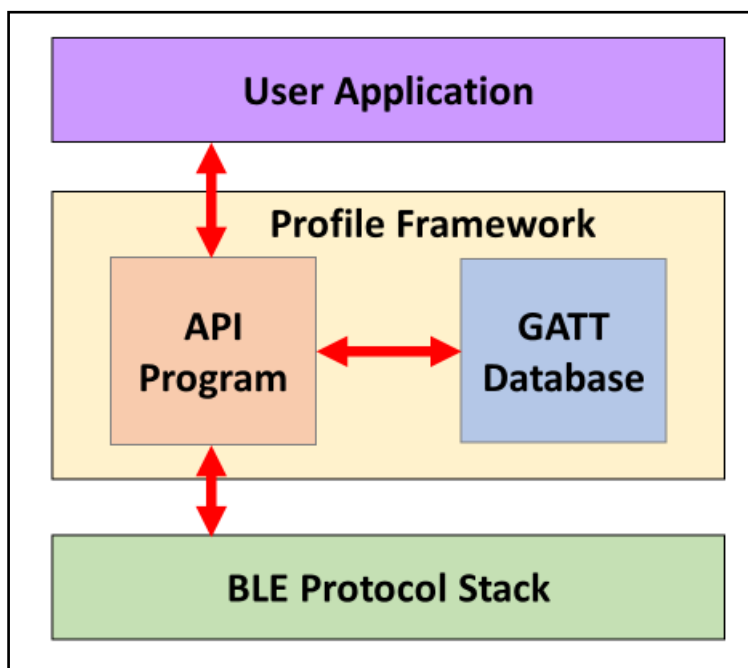


Figure 1.2 Structure of profile

Bluetooth LE software defines the data structure of the profile as a GATT database and provides the data accessing method as an API program for the service. The user application uses the API program for service to access the profile data to perform Bluetooth LE profile communication.

Bluetooth SIG Inc. defines specification of several services. In this document, those services are referred as SIG adopted services. On the other hand, if you want to achieve functionality that is not supported by SIG adopted service, you must define your own service. In this document, these are referred as custom service.

1.2 Flow of profile development

Figure 1.3 shows flow of profile development.

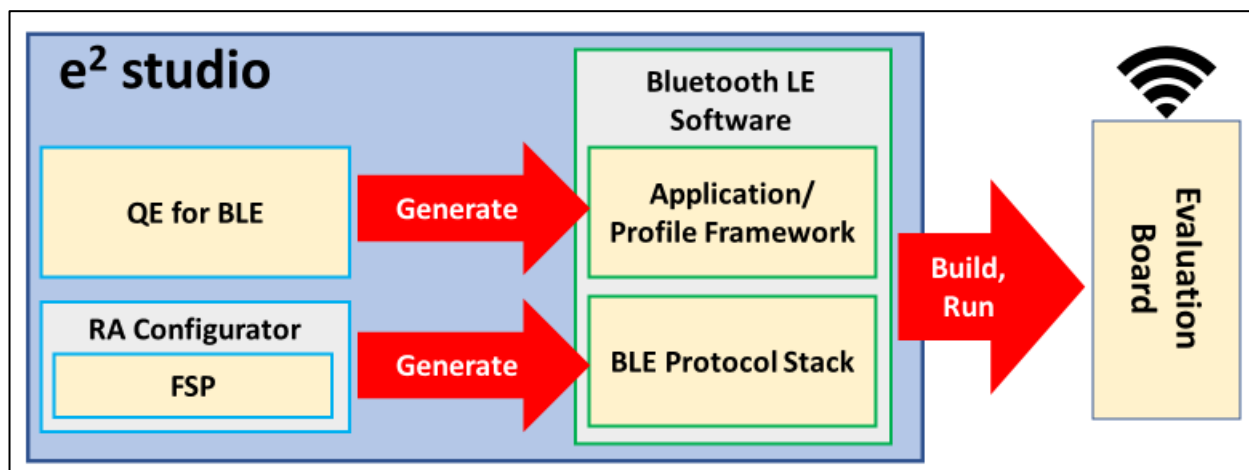


Figure 1.3 Flow of profile development

The steps for developing Bluetooth LE profiles are as follows:

1) Create project by using RA configurator

BLE Protocol Stack is provided as FSP. To use BLE Protocol Stack, you need to create a project and generate contents by RA Configurator properly.

2) Profile configuration in QE for BLE

Configure Bluetooth LE profiles by setting GUI provided from QE for BLE. Check See chapter [3 Profile Configuration in QE for BLE] for more information. QE for BLE generates code files in accordance with the configuration you set. Code files of API Program, GATT database, and Application Framework are generated on your project.

3) Implementation of application

You can implement application by customizing the code files generated by QE for BLE. For more information on how to implement user application, see chapter [4 Implementation of program].

4) Build and run user application

After building the project, you can run the application on RA family evaluation board which supports Bluetooth LE.

2. Development environment

2.1 QE for BLE

QE for BLE provides you of GUI to configure settings for BLE Connection and Profiles. In addition, QE for BLE generates program (code files) listed in the Table 2.1 in accordance with user settings.

Table 2.1 Programs generated by QE for BLE

file name	description
app_main.c	Application/Profile framework Skeleton program that is the basis of application/profile development.
gatt_db.c gatt_db.h	GATT database program Data structure of service which is checked on [server] in QE for BLE is defined.
r_ble_[abbreviation][s or c].c r_ble_[abbreviation][s or c].h	Profile API program Skeleton API program for accessing profile data categorized by service. Each file name is determined based on the [abbreviation], [server], and [client] set to service in QE for BLE. [abbreviation][s] is the server program, [abbreviation][c] is the client program. For Services supported by QE for BLE, complete API program will be generated from QE for BLE. Please refer Table 2.2 for supported services. Example) [abbreviation]=[sig], [server] : r_ble_sigs.c, r_ble_sigs.h [abbreviation]=[cus], [client] : r_ble_cusc.c, r_ble_cusc.h

All program generated by QE for BLE is output in [Project Name]/qe_gen/ble/.

Skeleton Programs are basis for profile and application development. How to implement application to skeleton program is described in chapter 4.

QE for BLE is also capable of generating Profile API Program to communicate with SIG adopted services. Table 2.2 shows SIG adopted services which QE for BLE supports. Specification of each SIG adopted Service is published by the Bluetooth SIG. For more information, visit the website of Bluetooth SIG: <https://www.bluetooth.com>.

Table 2.2 SIG Adopted Services supported by QE for BLE

Service name	abbreviation	version	service name	abbreviation	version
Alert Notification Service	AN	1.0	Automation IO Service	AIO	1.0
Battery Service	BA	1.0	Blood Pressure Service	BL	1.0
Body Composition Service	BC	1.0	Bond Management Service	BM	1.0
Continuous Glucose Monitoring Service	CGM	1.0.1	Current Time Service	CT	1.1
Cycling Power Service	CP	1.1	Cycling Speed and Cadence Service	CSC	1.0
Device Information Service	DI	1.1	Environmental Sensing Service	ES	1.0
Fitness Machine Service	FTM	1.0	Glucose Service	GL	1.0
Health Thermometer Service	HT	1.0	Heart Rate Service	HR	1.0
Human Interface Device Service	HID	1.0	Immediate Alert Service	IA	1.0
Insulin Delivery Service	ID	1.0	Link Loss Service	LL	1.0.1
Location and Navigation Service	LN	1.0	Next DST Change Service	NDC	1.0
Object Transfer Service	OT	1.0	Phone Alert Status Service	PAS	1.0
Pulse Oximeter Service	PLX	1.0	Reconnection Configuration Service	RC	1.0
Reference Time Update Service	RTU	1.0	Running Speed and Cadence Service	RSC	1.0
Scan Parameters Service	SCP	1.0	Tx Power Service	TP	1.0
User Data Service	UD	1.0	Weight Scale Service	WS	1.0
GATT Service			GAP Service		

Note: Object Transfer Service is not authenticated. Please contact us when considering this service to be used in your product.

2.2 Building development environment

2.2.1 Install QE for BLE

QE for BLE can be downloaded from the web page below.

<https://www.renesas.com/qe-ble>

Install method is as follows:

1. Activate e2 studio.
2. Click [Help], and then click the [Install New Software...] menu to open the [Install] dialog box.
3. Click the [Add (A)...] button to open the [Add Repository] dialog box.
4. Click the [Archive (A)...] button, select the installation file (zip file) in the opened file selection dialog box, and then click the [Open (O)] button.
5. Click the [OK] button in the [Add Repository] dialog box.
6. Expand the [Renesas QE] item shown in the [Install] dialog box, select all check boxes such as [Renesas QE for BLE[RA]], and then click the [Next (N)>] button.
7. Confirm that the installation target is correct, and then click the [Next(N)>] button.
8. After reviewing the license, select the [I agree to the terms of use (A)] radio button and then click the [End (F)] button.
9. When the selection dialog box for trusted certificates appears, check the displayed certificate, and then click the [OK] button to continue installation.
10. Restart e2 studio according to the instructions on the screen.
11. Start this product from the [Renesas Views] – [Renesas QE] menu of e2 studio.

For instructions on how to use this product, see the QE items in the [Help] menu of e2 studio.

2.3 Create project by RA configurator

Before using QE for BLE, you must create a project on e² studio. For more information on how to create a project for developing Bluetooth LE application, refer to chapter 4 "Create project" in the (R01AN5402) "RA4W1 Group BLE Sample Application" document.

3. Profile Configuration in QE for BLE

This chapter guides how to operate QE for BLE which is the tool to configure Bluetooth LE Profiles. To connect and communicate with peer device properly, you have to configure Bluetooth LE Profiles properly.

3.1 Overview of profile configuration

Procedures from the QE for BLE to generating code files are shown below:

1. Launch QE for BLE by selecting [Renesas view]→[Renesas QE]→[R_BLE Custom Profile RA (QE)] in menu of the e²studio.

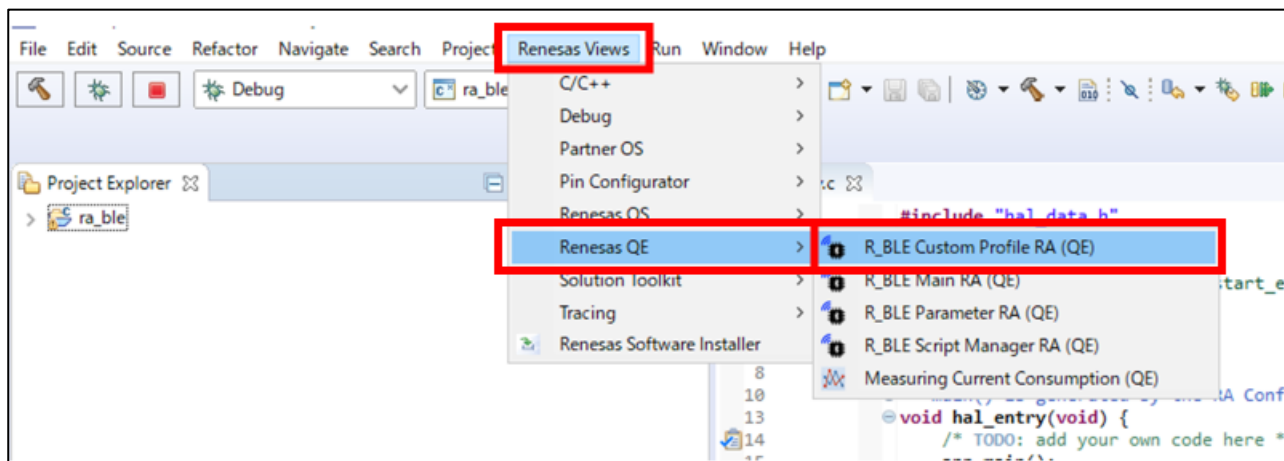


Figure 3.1 Select from [Renesas Views]

2. At the upper right of QE for BLE, specify the project name that you will configure.

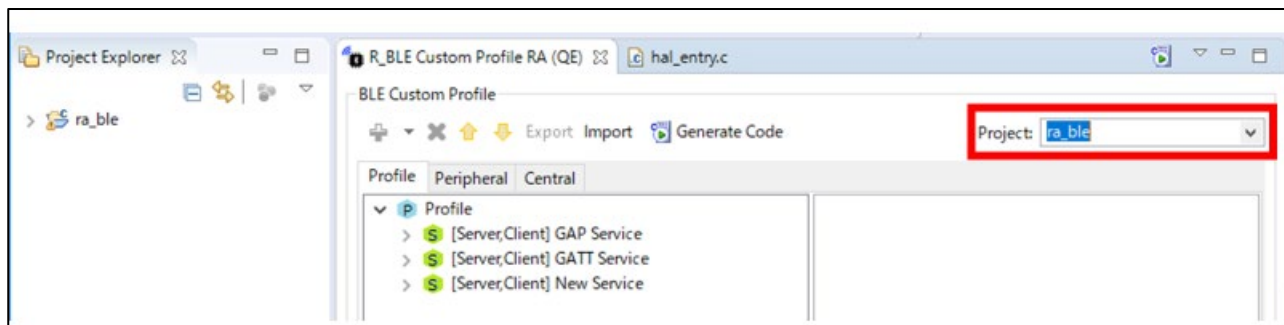


Figure 3.2 Select project to generate code

3. User need to choose GAP role of user application to configure QE for BLE.

Peripheral role will act as slave device in Bluetooth communication. This role will perform advertising operation.

Central role will act as master device in Bluetooth communication. This role will perform scan operation. Also, if advertising event is found in scan operation, it sends Connection request.

4. Configure settings in three tabs of QE for BLE: Profile, Peripheral, and Central tab.

- Profile tab: set Profiles including Services, Characteristics, and their Descriptors. You can also select GAP role in this tab. See Section 3.2.
- Peripheral tab: set Advertising information for working as a peripheral device. see Section 3.3.
- Central tab: set Scan and Connection information for working as a central device. see Section 3.4.

5. After you configure these setting, generate code files by clicking the Generate Code button.

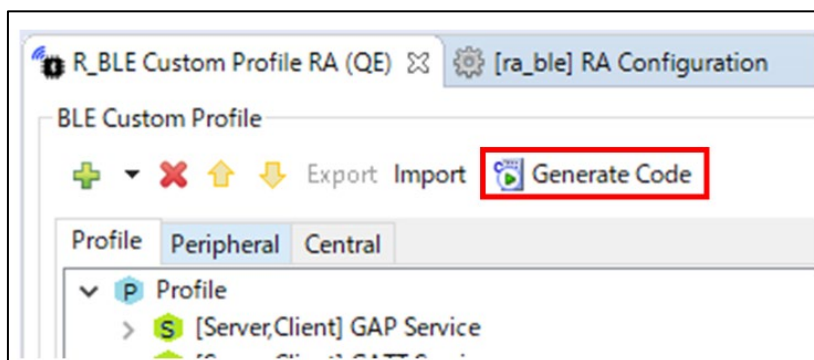


Figure 3.3 Generate code button

3.2 Configuration of Profile

You can configure profile in [Profile] tab. Figure 3.4 shows configuration screen of QE for BLE.

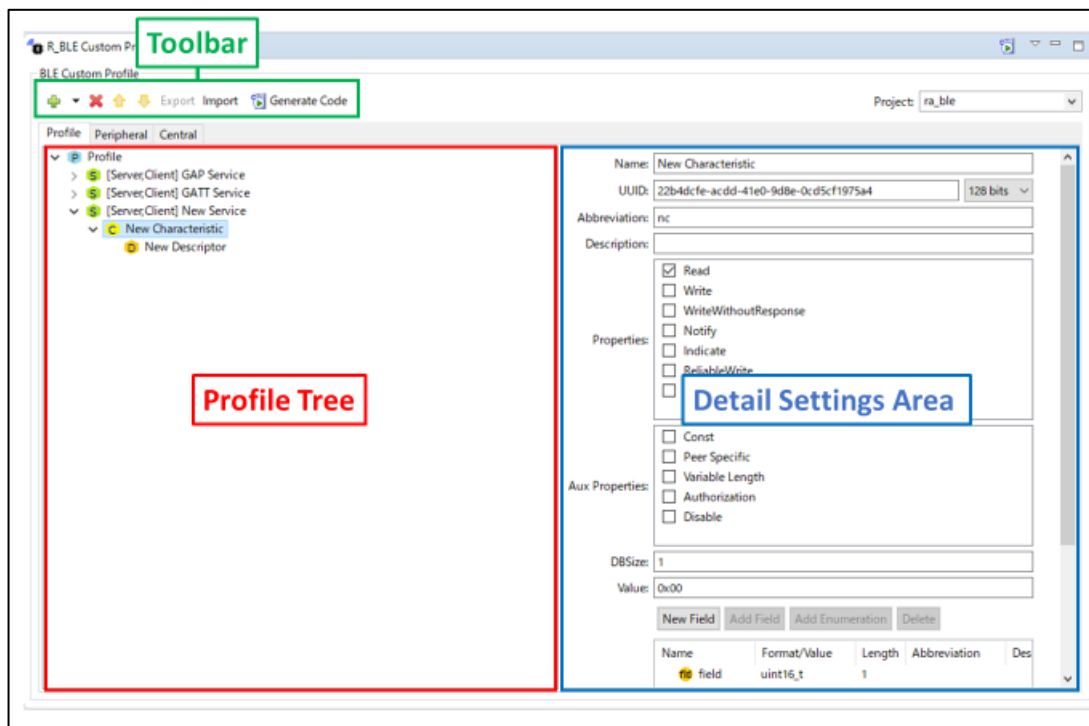


Figure 3.4 QE for BLE configuration screen

You can check the configuration of the profile that you are currently designing from [Profile Tree].

When you select each content of [Profile Tree], the settings are displayed for each type of contents selected in [Detail Setting Area]. You can configure the functionality of contents added to [Profile Tree] by editing the items displayed in [Detail Setting Area].

[Toolbar] is used when you want to add or delete contents from [Profile Tree]. The icons on [Toolbar] and their behavior are as follows:

- : Adds an contents to [Profile Tree]. The contents added depends on the contents selected in [Profile Tree]
- : Deletes selected contents in [Profile Tree].
- : Moves selected contents in [Profile Tree]. Use this to rearrange contents in [Profile Tree].
- : Outputs the configured service as JSON file.
- : Loads service defined JSON file and adds it to the profile.
- : Generate code from QE for BLE.

3.2.1 Profile

When you select profile [P] in [Profile Tree], profile configuration screen (Figure 3.5) will be shown in [Detail Settings Screen].

You can select GAP role on profile configuration screen. Use the radio button to choose whether to set profile to [Central] or [Peripheral]. Application framework is generated depending on this item. If you select [Peripheral], program which can operate advertising is generated. If you select [Central], program which can operate scan and send connection request is generated.

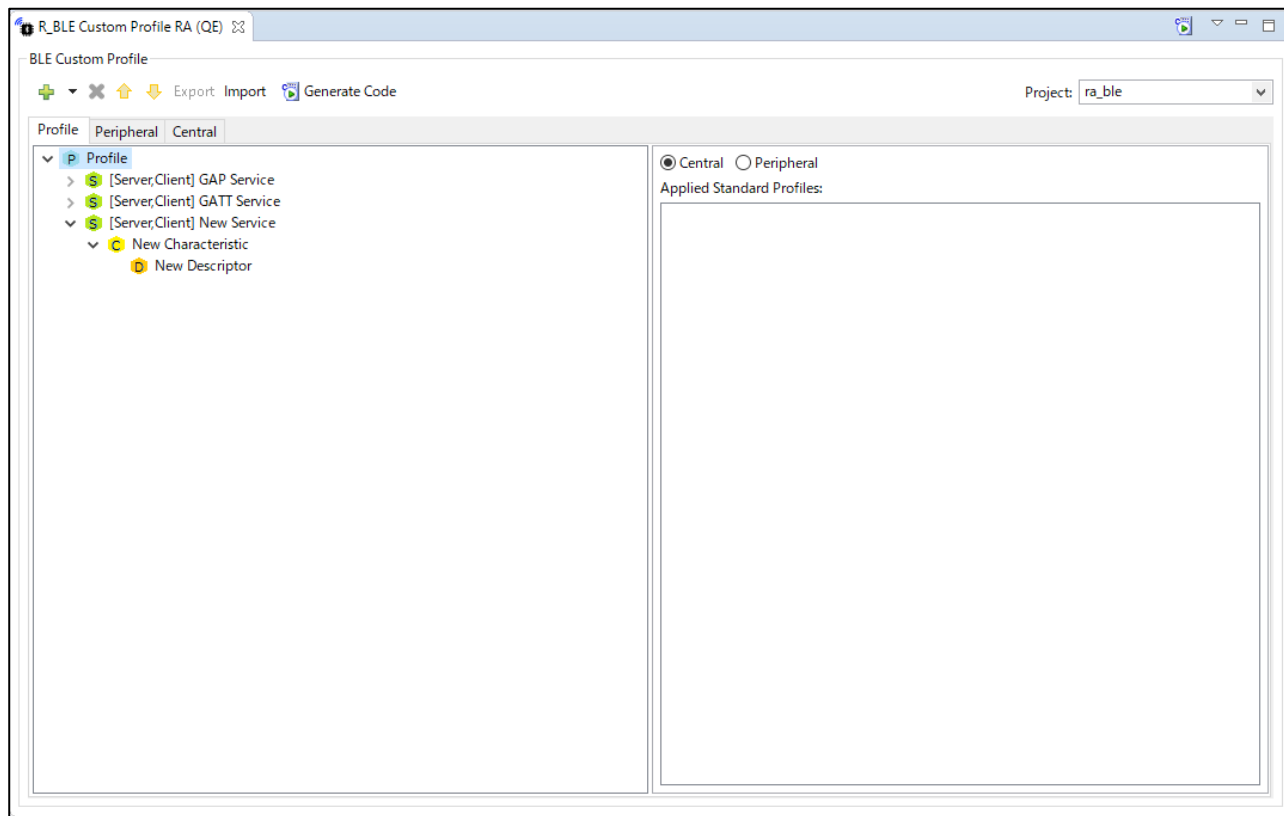


Figure 3.5 Profile configuration screen

You can add services by clicking  button with the profile selected in [Profile Tree] (Figure 3.6).

Select [New service] to add custom service or [Add service] to add a SIG adopted service. If you select [Add profile], you can select the profile that are defined in Bluetooth Specification. When you select the Bluetooth defined profile, all services consisting that profile are added to the configuring profile. Also name of selected profile will be added to [Applied Standard Profile]. In [Applied Standard Service], profile name will also be listed for services added independently.

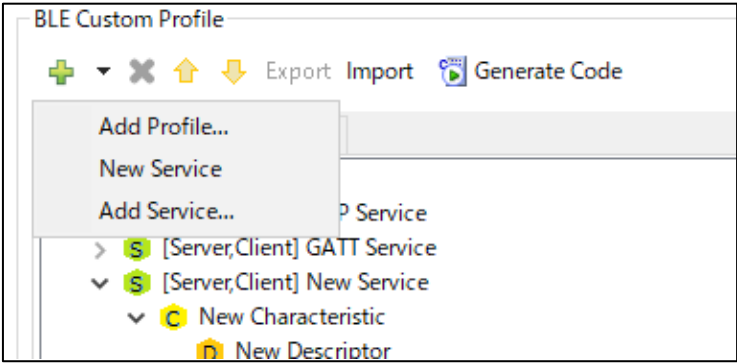


Figure 3.6 Adding service

3.2.2 Service

When you select service  in [Profile Tree], service configuration screen(Figure 3.7) will be shown in [Detail Settings Screen]. Table 3.1 describes each item on the configuration screen.
Note: The GAP service and GATT service are mandatory services. Do not delete these services.

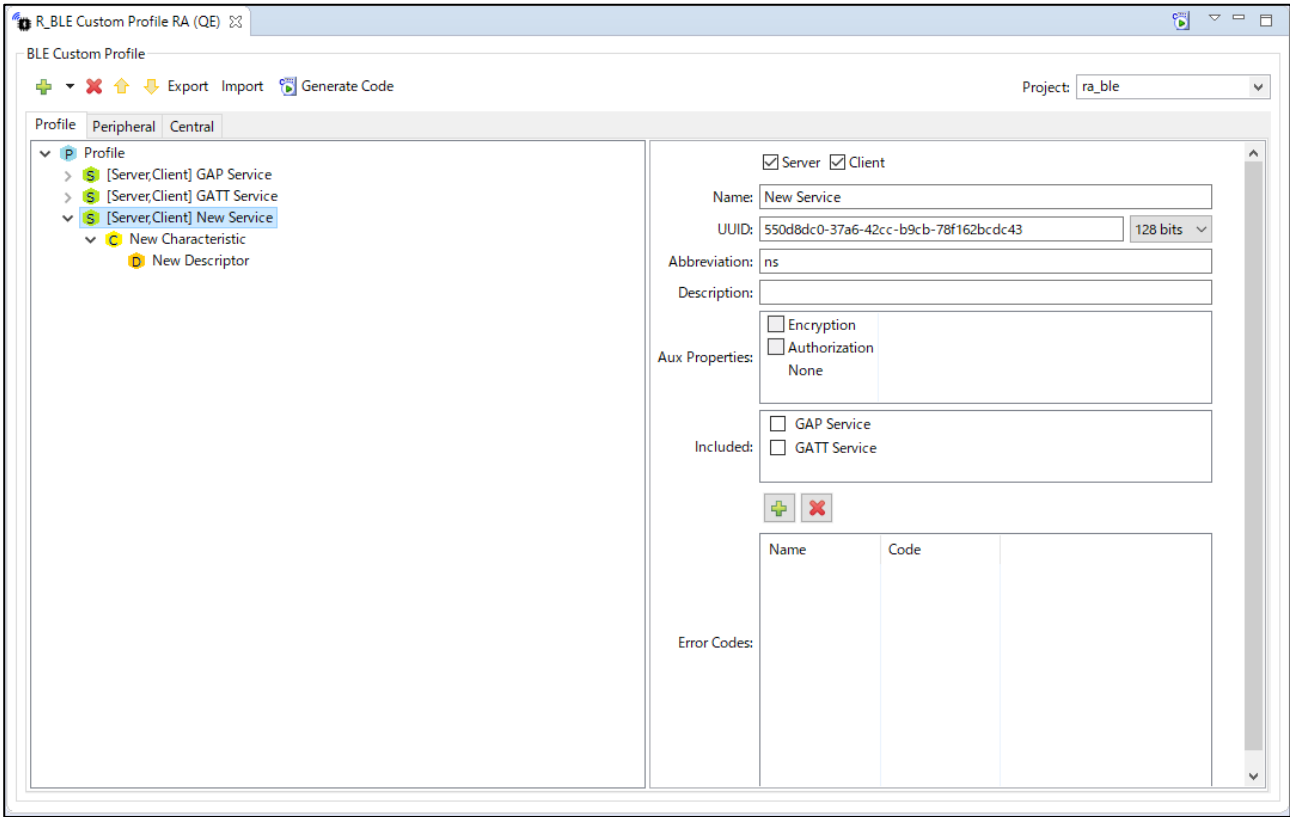


Figure 3.7 Service configuration screen

Table 3.1 Service configuration

Item	Description	
Server	Set check on this item to generate service program as server. Checking this item also adds characteristic and descriptors to GATT database.	
Client	Set check on this item to generate service program as client. Checking this item also adds discovery operation to application framework.	
Name	Name of service. Example) Custom service	
UUID	UUID of service. Select 128bit if service is custom service. Initial value is entered randomly. Please modify if needed. Example) 16bit : 0xe237 128bit : 96FE7990-2C76-89AB-DC49-AB7F123DEF9C	
Abbreviation	Abbreviation of service. This value is used in file name, function name and variable name. Beware not to conflict with other services. Example) cs	
Description	Description of service. Explain usage if needed. This description will be used as comments in generated program. Example) This service used for sending sensor data.	
Aux properties	AUX properties of service. Items below can be configured.	
	Encryption	Enable encryption.
	Authorization	Enable authorization. Use function R_BLE_GAP_AuthorizeDev() to authorize.
	Select appropriate security requirement stage from the following item	
	None	There are no requirements about security for accessing service.
	Unauthentication	Requires pairing for accessing service.
	Authentication	Requires pairing with MITM for accessing service.
	Secure Connection	Requires pairing on secure connection for accessing service.
Included	Sets Included service. Select the service to be included from the list.	
Error Codes	Adds error code of service. Error code added can be used by function R_BLE_GATTS_SendErrRsp().	
	Name	Name of error code. Example) Value not Supported
	Code	Value of error code. Select from value list.

Figure 3.8 shows the service configuration screen for SIG adopted service. In this state, only [server], [client], and [Included] items can be configured. You can edit all items by clicking the [Customize] button. Please use it in case creating a custom service based on SIG adopted service.

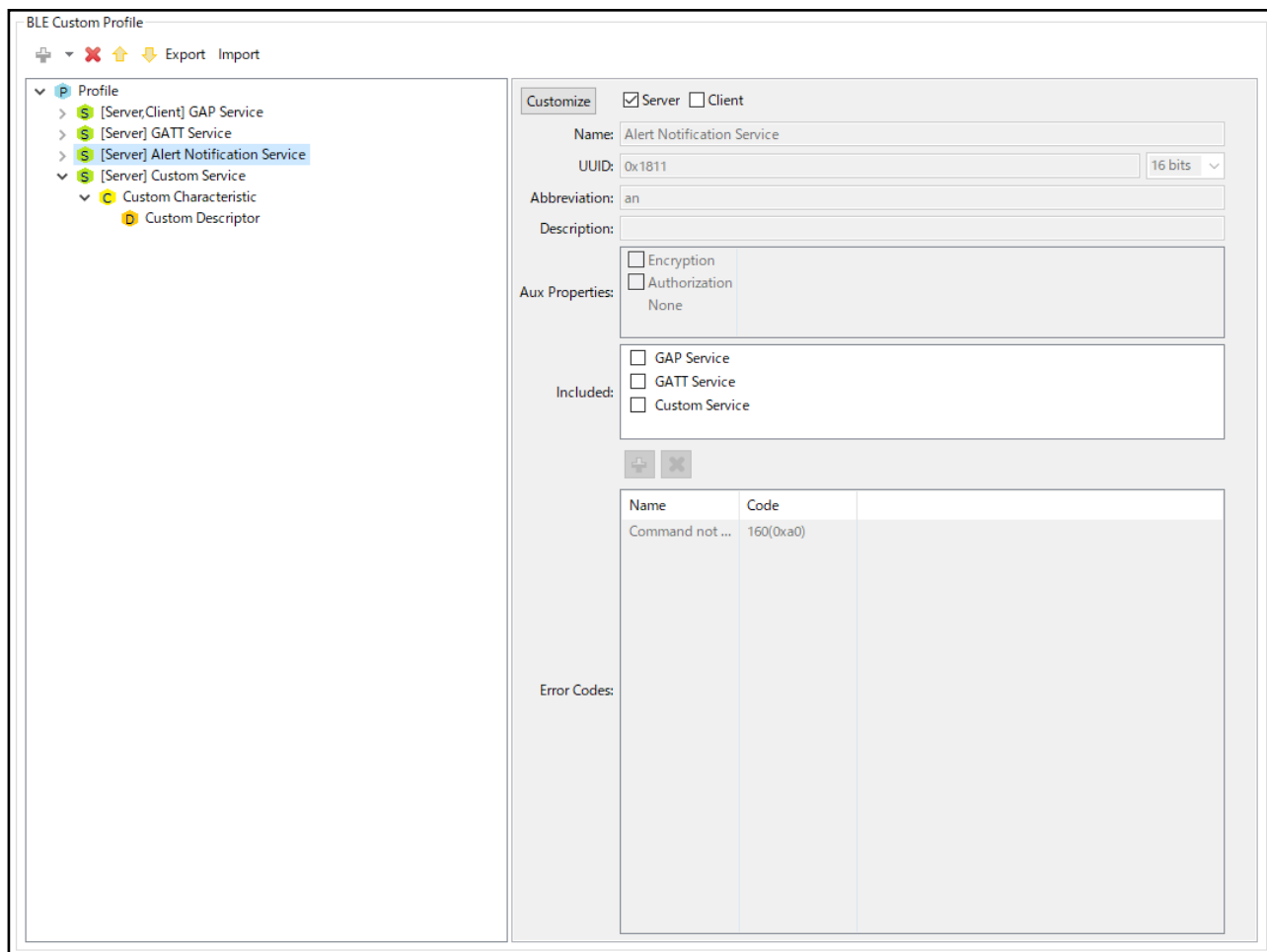


Figure 3.8 SIG adopted service configuration screen

You can add a characteristic by clicking [+] button with the service selected. Select [New Characteristic] to add a custom characteristic or [Add Characteristic] to add SIG adopted characteristic.

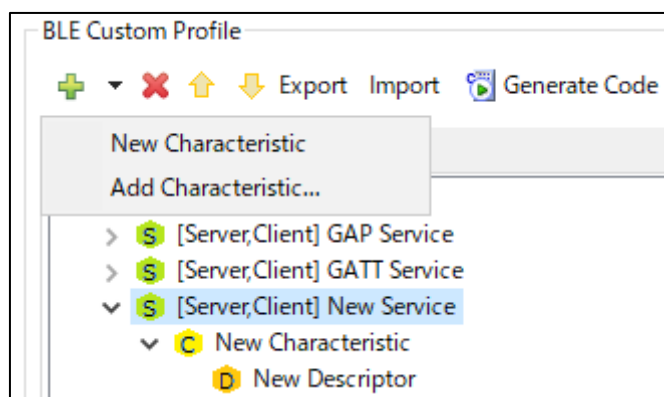


Figure 3.9 Adding characteristic

3.2.3 Characteristic

When you select characteristic [C] in [Profile Tree], characteristic configuration screen (Figure 3.10) will be shown in [Detail Settings Screen]. Table 3.2 and Table 3.3 describes each item on the configuration screen.

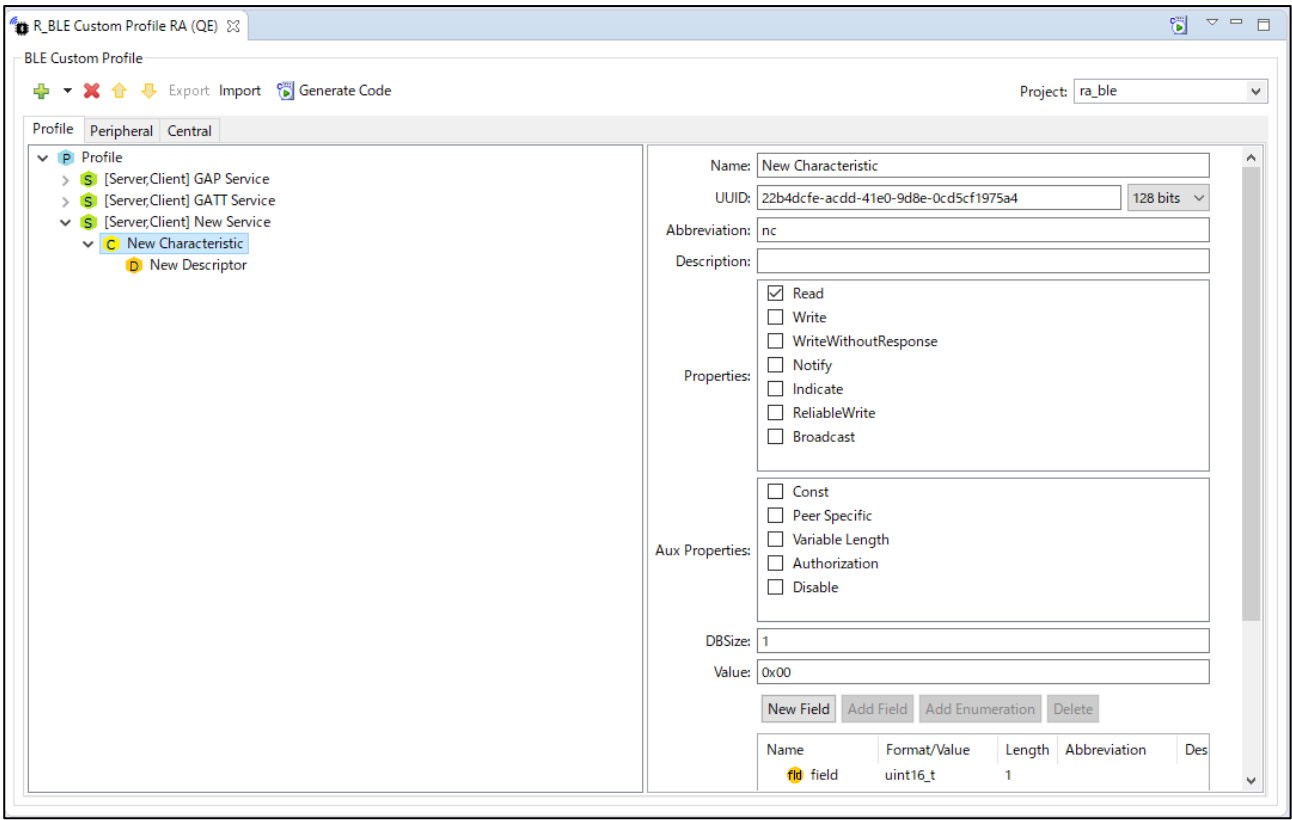


Figure 3.10 Characteristic configuration screen

You can add a descriptor by clicking [+] button with the characteristic selected. Select [New Descriptor] to add a custom descriptor or [Add Descriptor] to add SIG adopted descriptor.

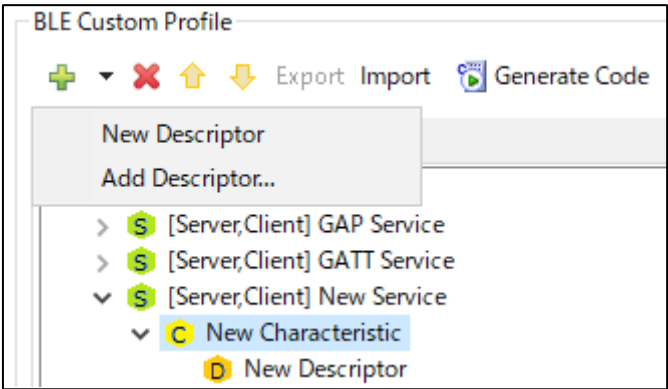


Figure 3.11 Adding descriptor

Table 3.2 Characteristic configuration

Item	Description	
Name	Name of characteristic. Example) Custom Characteristic	
UUID	UUID of characteristic. Select 128bit if service is custom characteristic. Initial value will be entered randomly. Example) 16bit : 0xe237 128bit : 96FE7990-2C76-89AB-DC49-AB7F123DEF9C	
Abbreviation	Abbreviation of characteristic. This value is used in function name and variable name. Beware not to conflict with other characteristics. Example) cc	
Description	Description of Characteristic. Explain usage if needed. This description will be used as comment of generated program. Example) This Characteristic is used for sending sensor data	
Properties	Properties of characteristic. Items below can be configured.	
	Read	Enable Read operation.
	Write	Enable Write operation.
	WriteWithoutResponse	Enable WriteWithoutResponse operation.
	Notify	Enable Notify operation. [Client Characteristic Configuration Descriptor] will be added to characteristic.
	Indicate	Enable Indicate operation. [Client Characteristic Configuration Descriptor] will be added to characteristic.
	ReliableWrite	Enable ReliableWrite operation. This Item will not generate API in Profile API Program. User need to use GATT API for operation. Also please add "Characteristic Extended Properties Descriptor" to characteristic.
	Broadcast	Enable Broadcast operation. This Item will not generate API in Profile API Program. User need to use GAP API for operation.
Aux Properties	AUX properties of characteristic. Items below can be configured.	
	Const	Value will not be able to change.
	Peer Specific	Value will be kept individually for each connection.
	Variable Length	Value length will be variable.
	Authorization	Enable authorization. Use function R_BLE_GAP_AuthorizeDev() to authorize.
	Disable	Disable attribute.
DBSize	Size of characteristic. Unit of value is byte. Note: The Maximum size of DBSize is 244 bytes.	
Value	Initial value of characteristic. If you want to enter a number, enter it separated by 8bit digit. If you want to enter string, you can easily enter it by enclosing it in "". Example) For numbers: 0x12, 0x34, 56,78 For string: "example"	
Field	Set value field used in application. Please refer Table 3.3 for configuration.	

Table 3.3 Characteristic Field configuration

New Field	Add new field. Items below can be configured	
	Name	Name of field. Example) field_name
	Format/Value	Format of field. Value can be selected from below.
		bool Boolean type
		char char type
		uint8_t unsigned 8bit data type
		uint16_t unsigned 16bit data type
		uint32_t unsigned 32bit data type
		int8_t signed 8bit data type
		int16_t signed 16bit data type
		int32_t signed 32bit data type
		st_ble_ieee_11073_float_t IEEE-11073 32bit FLOAT type
		st_ble_ieee_11073_sfloat_t IEEE-11073 16bit SFLOAT type
		st_ble_date_time_t Structure for setting date and time information.
		st_ble_dev_addr_t Structure for setting Bluetooth LE address data.
		st_ble_seq_data_t Structure for array. Select this when only one field is set, and length is set more than 2.
		struct Structure type. Select this when selecting [Add Field].
	Length	Length of field Array. Example) 1 → field 5 → field[5]
	Abbreviation	Abbreviation of field.
	Description	Description of field. Explain usage if needed
Add Field	Adds a new Field inside the selected Field. Please use it if you configure data that has hierarchy. The Format/Value of the selected Field is set to [struct]. Added Field can be configured same items explained in [New Field].	
Add Enumeration	Defines enumeration usable for selected field. Items below can be configured.	
	Name	Name of enumeration. Example) enable
	Format/Value	Value code of enumeration. Example) 0x01
	Description	Description of enumeration.
Delete	Delete selected field.	

3.2.4 Descriptor

When you select descriptor [D] in [Profile Tree], descriptor configuration screen (Figure 3.12) will be shown in [Detail Settings Screen]. Table 3.4 and

Table 3.5 describe each item on the configuration screen.

Note: If “Client Characteristic Configuration Descriptor” is added as descriptor, please line up “Client Characteristic Configuration Descriptor” on the top of descriptors.

Note: If “ReliableWrite” is selected in characteristic, please add “Characteristic Extended Properties Descriptor” to characteristic. Please refer website of Bluetooth SIG for detail: <https://www.bluetooth.com>

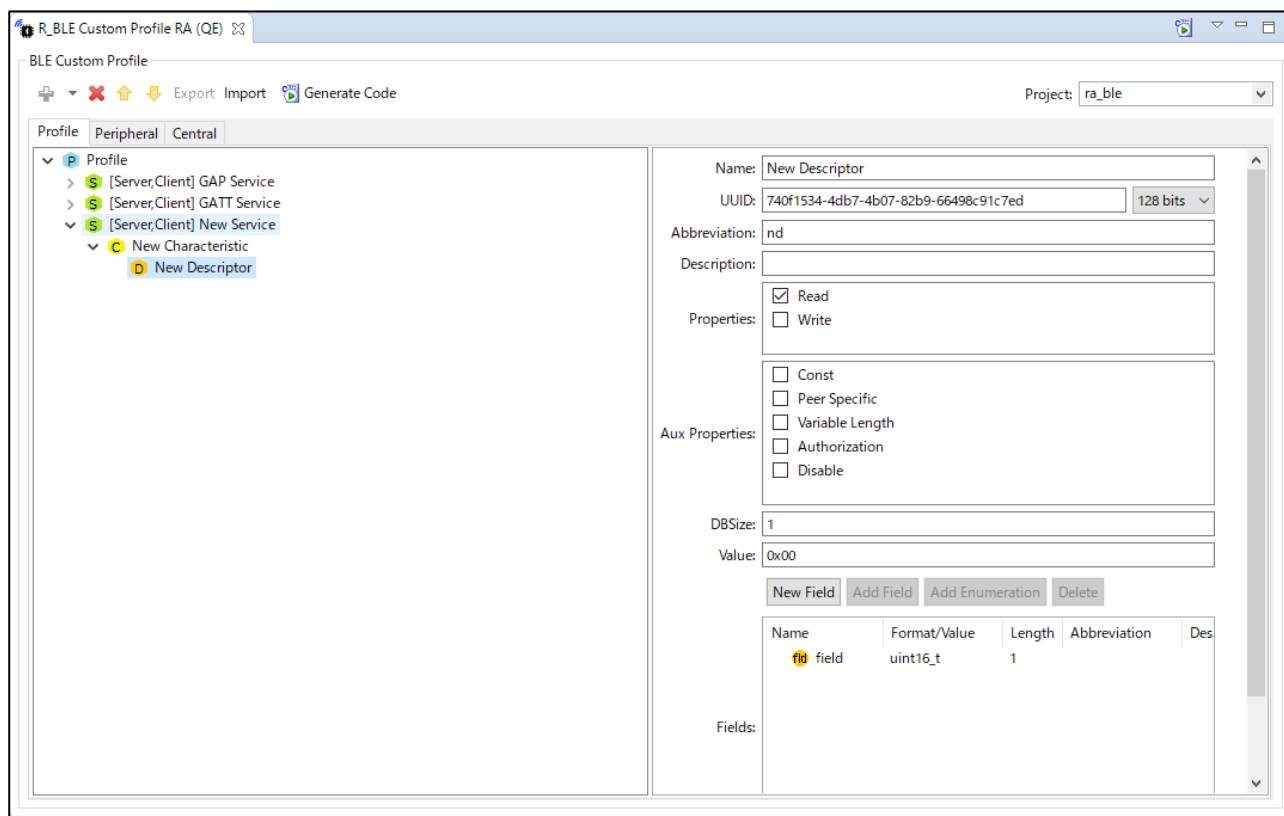


Figure 3.12 Descriptor configuration screen

Table 3.4 Descriptor configuration

Item	Description
Name	Name of descriptor. Example) Custom Descriptor
UUID	UUID of descriptor. Select 128bit if service is custom descriptor. Initial value is entered randomly. Please modify if needed. Example) 16bit : 0xe237 128bit : 96FE7990-2C76-89AB-DC49-AB7F123DEF9C
Abbreviation	Abbreviation of descriptor. This value is used in function name and variable name. Beware not to conflict with other descriptors. Example) cd
Description	Description of descriptor. Explain usage if needed. This description will be used as comment of generated program. Example) This descriptor is used for sending sensor data
Properties	Properties of descriptor. Items below can be configured
	Read Enable Read operation.
	Write Enable Write operation.
Aux Properties	AUX properties of descriptor. Items below can be configured.
	Const Value will not be able to change.
	Peer Specific Value will be kept individually for each connection.
	Variable Length Value length will be variable.
	Authorization Enable authorization. Use function R_BLE_GAP_AuthorizeDev() to authorize.
	Disable Disable attribute.
DBSize	Size of descriptor. Unit of value is byte. Note: The Maximum size of DBsize is 244 bytes.
Value	Initial value of descriptor. If you want to enter a number, enter it separated by 8bit digit. If you want to enter string, you can easily enter it by enclosing it in "". Example) For numbers: 0x12, 0x34, 56,78 For string: "example"
Field	Set value field used in application. Please refer Table 3.5 for configuration.

Table 3.5 Descriptor Field configuration

New Field	Add new field. Items below can be configured.	
	Name	Name of field. Example) field_name
	Format/Value	Format of field. Value can be selected from below.
		bool Boolean type
		char char type
		uint8_t unsigned 8bit data type
		uint16_t unsigned 16bit data type
		uint32_t unsigned 32bit data type
		int8_t signed 8bit data type
		int16_t signed 16bit data type
		int32_t signed 32bit data type
		st_ble_ieee_11073_float_t IEEE-11073 32bit FLOAT type
		st_ble_ieee_11073_sfloat_t IEEE-11073 16bit SFLOAT type
		st_ble_date_time_t Structure for setting date and time information.
		st_ble_dev_addr_t Structure for setting Bluetooth LE address data.
		st_ble_seq_data_t Structure for array. Select this when only one field is set, and length is set more than 2.
		struct Structure type. Select this when adding field inside field.
	Length	Length of field Array. Example) 1 → field 5 → field[5]
	Abbreviation	Abbreviation of field.
	Description	Description of field. Explain usage if needed.
Add Field	Add a new Field inside the selected Field. Please use it if you configure data that has hierarchy. The Format/Value of the selected Field is set to [struct]. Added Field can be configured same items explained in [New Field].	
Add Enumeration	Defines enumeration usable for selected field. Items below can be configured.	
	Name	Name of enumeration. Example) enable
	Format/Value	Value code of enumeration. Example) 0x01
	Description	Description of enumeration.
Delete	Delete selected field.	

3.3 Configuration of peripheral

In [Peripheral] tab, you can configure parameters for GAP peripheral role. Parameters set in this tab are used in application framework when you select [Peripheral] in [Profile] tab. In this tab, you can configure following settings.

Table 3.6 Configurable items in Peripheral

Item	Description
Advertising Data	You can configure Advertising data that will be sent in Advertising event.
Scan Response Data	You can configure Scan response data that will be sent in Advertising event.
Advertising Parameter	You can set parameters for Advertising operation.

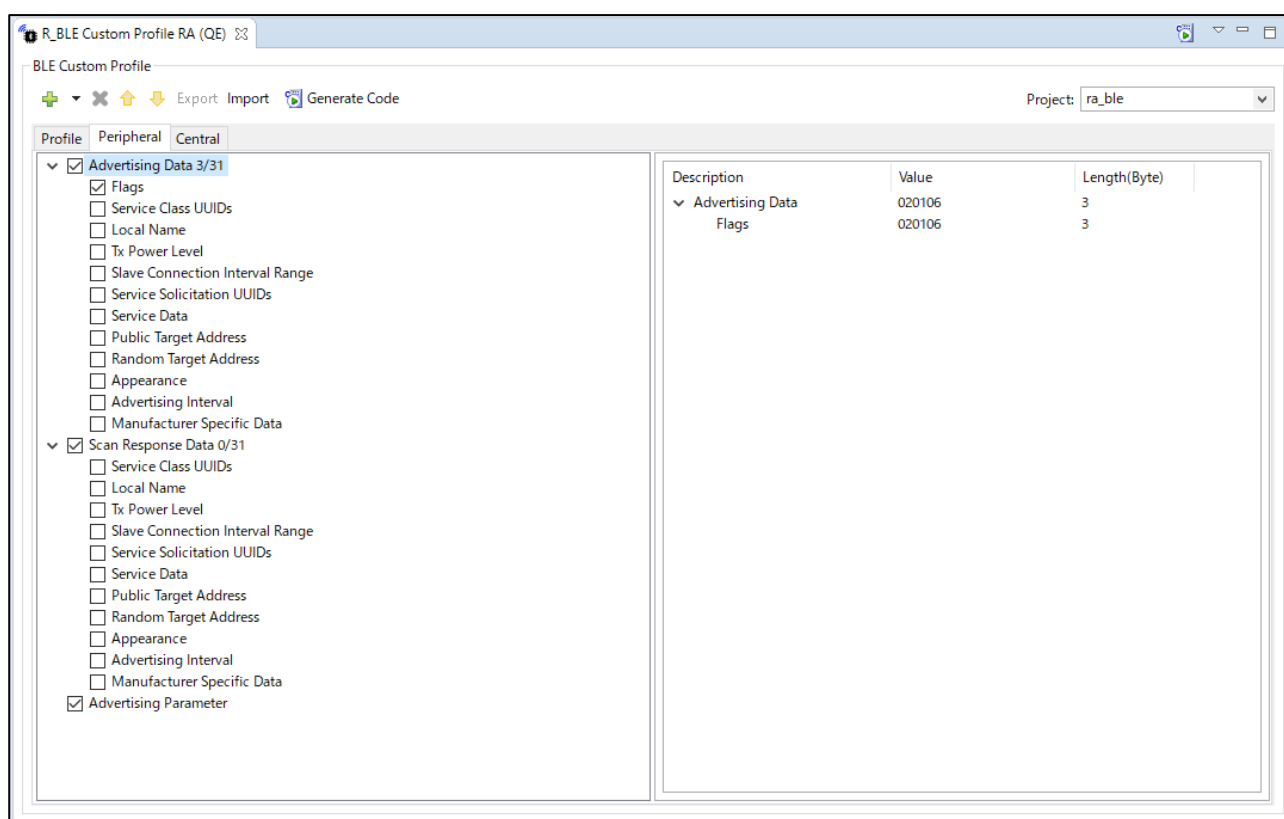


Figure 3.13 Peripheral parameter configuration screen

3.3.1 Advertising Data

Advertising Data can be configured by this section. The Data type that are checked will be added as advertising data. User can also input data value by selecting each data type. Data type that user can select is listed in Table 3.7. Maximum size of Advertising data is 31 bytes, so please add data which will not exceed this size. Please configure [3.3.2 Scan Response Data] for additional data.

Table 3.7 List of Selectable Data Type

Item	Description	
Flags	This data describes flag of advertising data. Including this data type is necessary for connectable Advertising. This data type can't be selected for scan response data. Select discoverable mode and check for additional information.	
	LE Limited Discoverable Mode	Device will be discoverable for certain period.
	LE General Discoverable Mode	Device will be discoverable all the time.
	Non-Discoverable Mode	Device will not be discovered.
	BR/EDR Not Supported	Check if only Bluetooth LE function is supported.
	Simultaneous LE and BR/EDR to same Device Capable (Controller)	Check if function as Controller roll of Bluetooth LE and BR/EDR can be operated at same time.
	Simultaneous LE and BR/EDR to same Device Capable (Host)	Check if function as Host roll of Bluetooth LE and BR/EDR can be operated at same time.
Service Class UUIDs	This data shows the list of services device offers. You can select services that will be added to the list. Services those are added in Profile tab can be selected.	
Local Name	This data type describes name of advertising device. Select local name type and Input the name. Local name can be selected from the below.	
	Short local name	This type describes shortened device name. Please use this type when device name is long and extends the size advertising data
	Complete local name	This type describes complete device name.
TX Power Level	This data type describes TX power of advertising device.	
Slave Connection Interval Range	This data type describes connection interval that is recommended from advertising device. Please input both MAX/MIN of connection interval.	
Service Solicitation UUIDs	This data type shows the list of service that advertising device requires. You can select services that will be added to the list. Services those are added in Profile tab can be selected.	
Service Data	This data type describes data of service. Value of this data type consists from service UUID and service Data. ex) Service UUID [0x1234] Service Data [0x56, 0x78, 0x9a, 0xbc] →Input data [123456789abc]	
Public Target Address	This data type describes Public BD Address of device that are target of advertising data. ex) Public BD Address [0x12:0x34:0x56:0x78:0x9a:0xbc] →Input data [12345678]	
Random Target Address	This data type describes Random BD Address of device that are target of advertising data. ex) Random BD Address [0x12:0x34:0x56:0x78:0x9a:0xbc] →Input data [12345678]	
Appearance	This data type describes appearance of Advertising device. The value of each appearance is listed in Bluetooth SIG.	
Advertising Interval	This data type describes advertising interval of advertising event. The value input in this item will not be used as the advertising parameter.	
Manufacturer Specific Data	This data type describes data that manufacturer specifies by their own. Value of this data type consists from company ID and specific data. ex) Company ID [0x1234] Specific Data [0x56, 0x78, 0x9a, 0xbc] →Input data [341256789abc]	

3.3.2 Scan Response Data

Scan response data can be configured by this section. The data type that are checked will be added as scan response data. User can also input data value by selecting each data type. Data type that user can select is listed in Table 3.7.

3.3.3 Advertising Parameter

You can configure parameters used for Advertising operation. The list of parameters that can be configured

Note: If difficult to connect with default setting, please change parameter of "Slow Advertising Interval".

Table 3.8 Configurable items of Advertising events

Item	Description	
Fast	You can configure timing information of advertising event. This parameter will be configurable if [Enable Fast Advertising] is checked. If not checked, parameter will be ignored. You can set following items.	
	Advertising Interval	Set Advertising Interval.
	Advertising period	Set Advertising Period. Parameters set in [Fast] will be used for this period.
Slow	You can configure timing information of advertising event. If [Enable Fast Advertising] is checked, this parameter will be used after Fast Advertising period. If not checked, this parameter will be used from the beginning of advertising operation. You can set following items.	
	Advertising Interval	Set Advertising Interval.
	Advertising period	Set Advertising Period. This parameter will be configurable if [Set Advertising Period] is checked. If you want to send Advertising only for certain period, please set this parameter.
Advertising channel	You can select Advertising channel that will be used in Advertising. Advertising event will be sent in all channels that is selected.	
Address type	You can select address type that will be used in advertising. Address type can be selected from below.	
	Public address	Public address will be used in advertising event. To configure public address, please use BDAAddrWriter.
	Random Address	Random address will be used in advertising event. Device static address will be used as BD address.

3.4 Configuration of central

In [Central] tab, you can configure parameters for GAP central role. Parameters set in this tab are used in application framework when you select [central] in [Profile] tab. In this tab, you can configure following settings.

Table 3.9 Configurable items of Central

Item	Description
Scan Parameter	You can set parameters for scan operation such as Scan Interval.
Scan filter data	You can configure Scan filter data that will be used during Scan operation.
Connection Parameter	You can set parameters for Connection such as Advertising Interval. Parameter set here will be used in Connection Request.

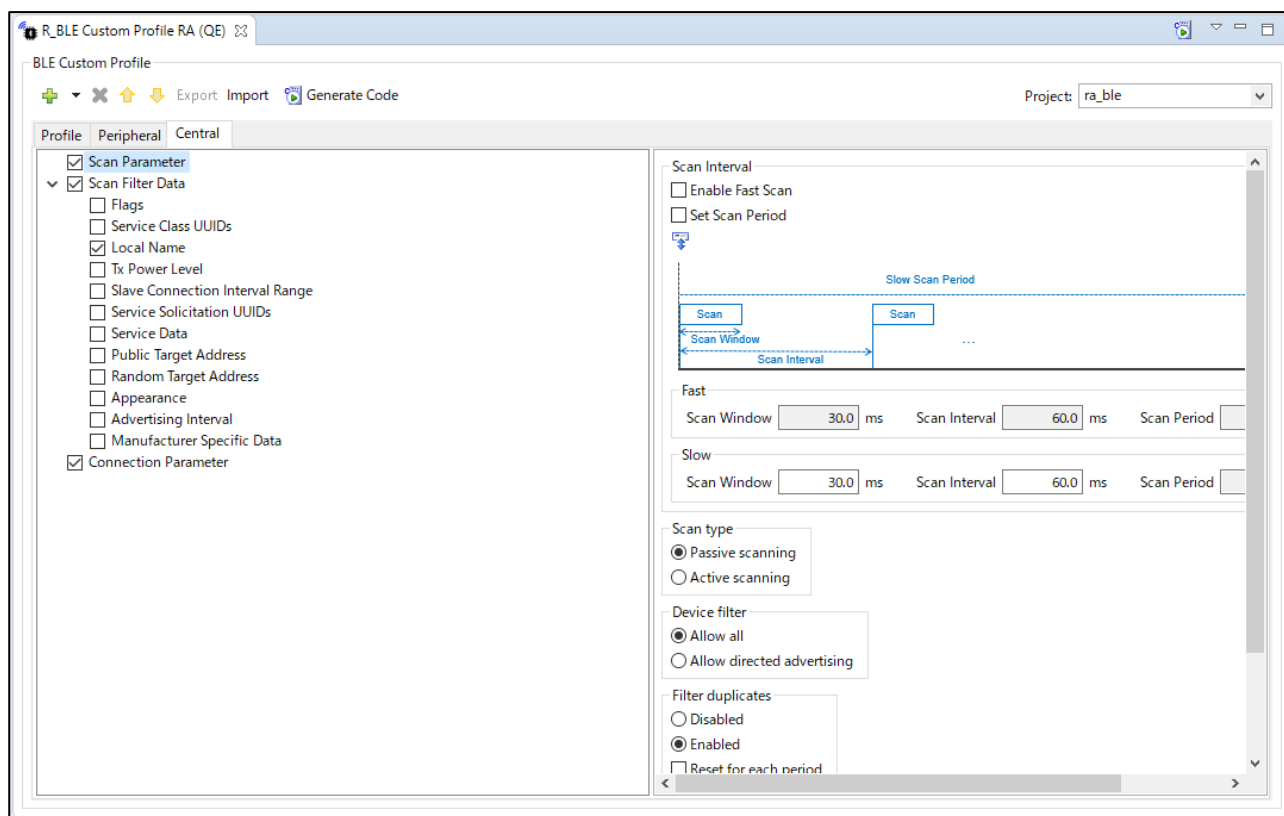


Figure 3.14 Central parameter configuration screen

3.4.1 Scan Parameter

You can configure parameters that will be used in scan operation.

Note: If difficult to connect with default setting, please change parameter of “Slow Scan Interval” and “Slow Scan window”.

Table 3.10 Configurable items of Scan Parameter

Item	Description	
Fast	You can configure timing information of scan operation. This parameter will be configurable if [Enable Fast Scan] is checked. If not checked, parameter will be ignored. You can set following items.	
	Scan Window	Set Scan Window.
	Scan Interval	Set scan Interval.
	Scan Period	Set scan Period. Parameters set in [Fast] will be used for this period.
Slow	You can configure timing information of scan operation. If [Enable Fast Scan] is checked, this parameter will be used after Fast scan period. If not checked, this parameter will be used from the beginning. You can set following items.	
	Scan Window	Set Scan Window.
	Scan Interval	Set scan Interval.
	Scan Period	Set scan Period. This parameter will be configurable if [Set Scan Period] is checked. If you want to operate scan only for certain period, please set this parameter.
Scan type	You can select scan type. Scan type can be selected from below.	
	Passive Scanning	Passive scan will operate as scan operation.
	Active Scanning	Active scan will operate as scan operation.
Device filter	You can select device filter that will be used in scan operation. Device filter can be selected from below.	
	Allow all	Scan operation will accept all advertising and scan response PDUs except directed advertising PDUs not addressed to local device.
	Allow directed advertising	Scan operation will accept all advertising and scan response PDUs except directed advertising PDUs whose target address is identity address but doesn't address local device. However, directed advertising PDUs whose target address is the local resolvable private address are accepted.
Filter duplicates	You can select filter duplicate parameter that will be used in scan operation. Filter duplicates can be selected from below.	
	Disable	Duplicate filter will be disabled.
	Enabled	Duplicate filter will be enabled. If you check [Reset for each period], duplicate filter will reset for each scan period.

3.4.2 Scan Filter Data

Filter data for scan operation can be configured by this section. Only advertising event which has data that matches filter data will be notified to the application framework. The data type which is checked will be used as filter data. User can also input data value by selecting data type. Data type that user can select is listed in Table 3.7.

Note: Only one data type can be selected as Scan Filter Data

3.4.3 Connection Parameter

You can configure parameter used for connection event. This parameter will be used in connection request.

Table 3.11 Configurable item of connection

Item	Description	
Parameter	You can configure connection parameter. Parameter set here will be sent with connection request and used after connection established. You can set following items.	
	Connection Interval	Set connection interval.
	Connection Latency	Set slave latency.
	Connection Supervision Timeout	Set supervision timeout.
Connection cancel	You can configure connection cancel parameter. You can set following items.	
	Connection Timeout	Set connection timeout. If peripheral device doesn't respond to connection request for connection timeout, connection will be canceled.

3.5 Setting to connect between two evaluation boards

If you use two evaluation board, they can establish Bluetooth LE connection each other. For this operation, some configuration must be done in QE for BLE. Following is the points needed to be configured.

- **Set Peripheral for one device and Central for the other device**

Application framework which QE for BLE generates is made to communicate between Peripheral program and Central program. To communicate between two devices, each program must be written in different device.

- **Match Advertising Data and Scan Filter Data**

In Central Application Framework, only the advertising event that has advertising data which matches Scan Filter Data will be found. If advertising event is found, Central Application Framework tries to connect with device which sends advertising event. So, to connect between Central and Peripheral device, Advertising data and scan filter data must match. Preferred Advertising data type to match is "local name".

- **Set [Enable Fast Advertising/Scan]**

With default setting, parameters which is set in "Slow" will be used for Advertising and Scan operation. This parameter is set to low duty and reduce energy consumption. So, using this parameter may result to be difficult to connect. For high duty, check [Enable Fast Advertising/Scan].

4. Implementation of program

In this chapter, we will guide how to implement user application to software generated from QE for BLE.

Beware that files generated from QE for BLE will be regenerated each time code generation operates. To protect user code from regeneration, please implement user code inside of following comment.

```
/* Start user code for XXXX. Do not edit comment generated here */

    Implement user code here

/* End user code. Do not edit comment generated here */
```

4.1 Implementation of custom service

API programs for services are generated in `r_ble_[abbreviation][s or c].c` from QE for BLE. But If you want to use features that are not defined in the SIG adopted service, you must edit a custom service. This chapter guides you how to implement API programs for custom services generated from QE for BLE.

4.1.1 Implementing encode/decode function

The application layer handles characteristic and descriptor value in accordance with the format specified by the "Fields" of QE for BLE. On the other hand, the GATT database maintains characteristic and descriptor value in 8-bit data array which size is specified by the [DBsize] of QE for BLE, and data in the array is sent and received as bit-stream by the BLE Protocol Stack. For this reason, the API program has to convert the value between structured data format for application and 8bit-serialized data for GATT Database and BLE Protocol Stack by using the encode/decode function.

Figure 4.1 shows the feature of encode/decode function.

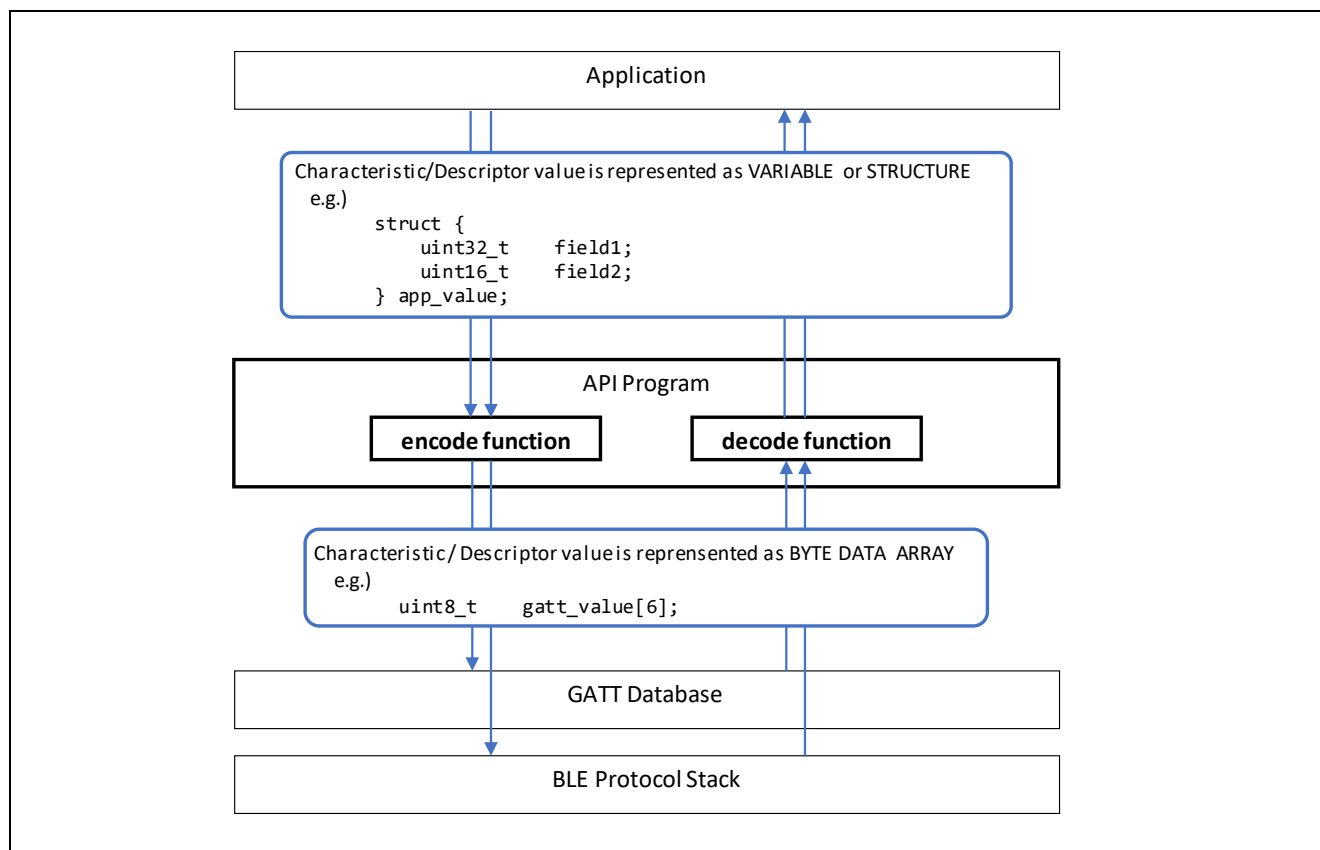


Figure 4.1 Feature of encode/decode function

The encode function is used by the API Program when API to send characteristic or descriptor value or to change characteristic or descriptor value of own GATT Database is called. Also, the decode function is used by the API Program before callback function to notify characteristic or descriptor value received.

Figure 4.2 shows a use-case of the encode/decode function that GATT Client writes new Characteristic value to peer GATT Server. The encode function is used by API Program of the client side and then the decode function is used by API Program of the server side.

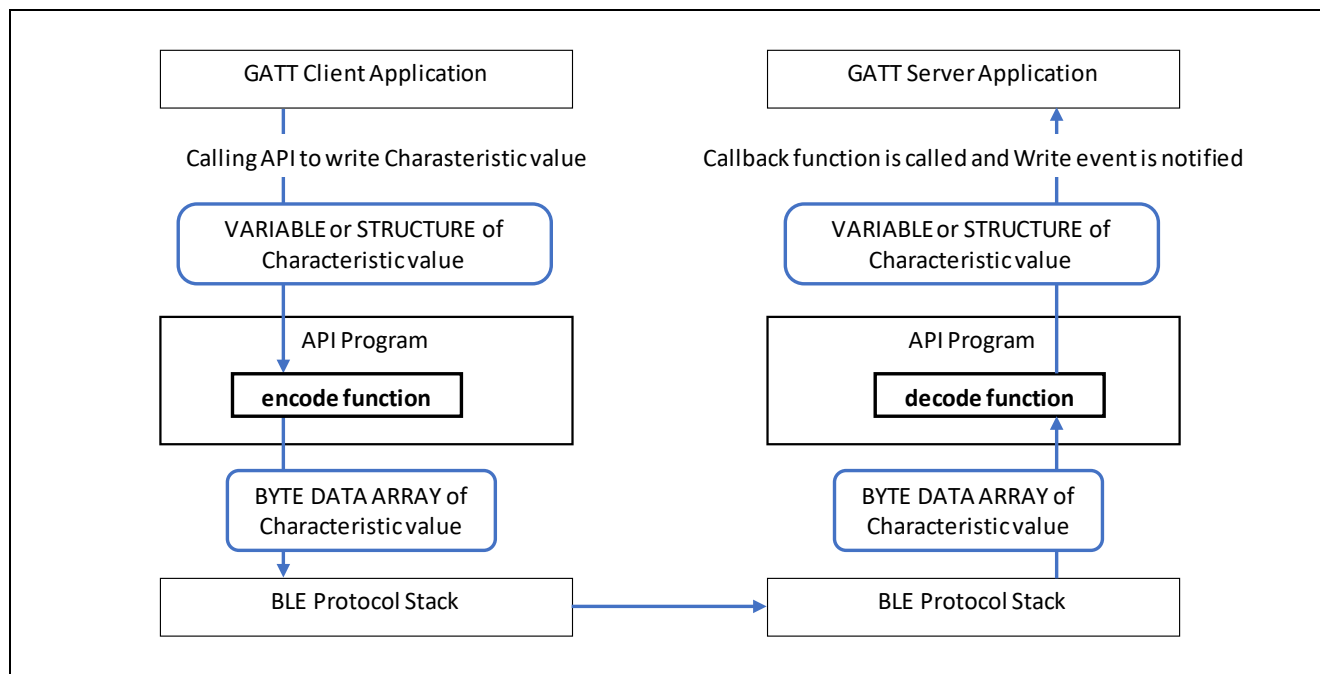


Figure 4.2 Use-Case of the encode/decode Function writing Characteristic value

Similarly, Figure 4.3 shows a use-case of the encode/decode function that GATT Server notifies new Characteristic value to peer GATT Client. The encode function is used by API Program of the server side and then the decode function is used by API Program of the client side.

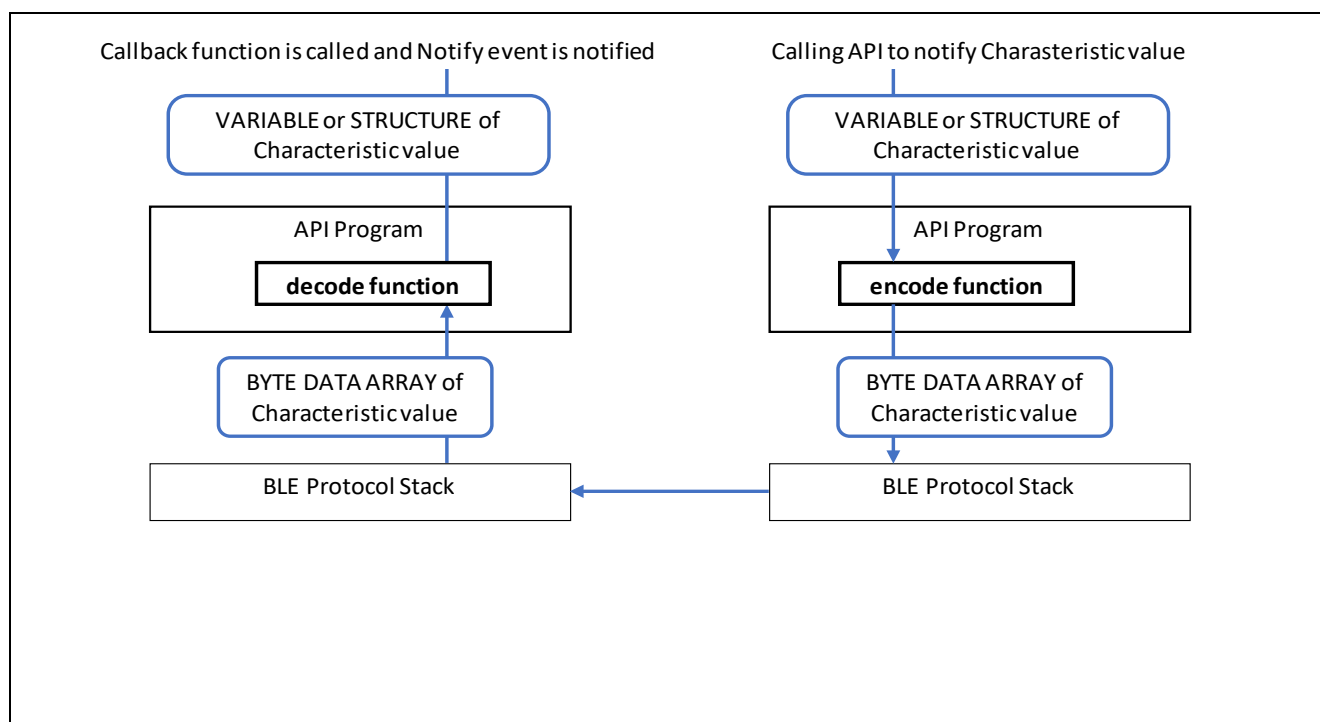


Figure 4.3 Use-Case of the encode/decode Function notifying Characteristic value

In API program of custom service, encode/decode function is created but their contents are not implemented. Therefore, implementation of the encode/decode function for each data structure is needed. For basic data structures such as `uint8_t` type and commonly used data structures such as `ieee11073 SFLOAT` type, you can implement encode/decode function by calling appropriate encode/decode macros and functions. Table 4.1 describes the list of provided encode/decode macros and functions.

Table 4.1 encode/decode macro or function

Type of Field	encode	decode
char uint8_t int8_t	BT_PACK_LE_1_BYTE(*dst, *src)	BT_UNPACK_LE_1_BYTE(*dst, *src)
uint16_t int16_t	BT_PACK_LE_2_BYTE(*dst, *src)	BT_UNPACK_LE_2_BYTE(*dst, *src)
uint32_t int32_t	BT_PACK_LE_4_BYTE(*dst, *src)	BT_UNPACK_LE_4_BYTE(*dst, *src)
st_ble_ieee11073_sfloat_t	pack_st_ble_ieee11073_sfloat_t(*p_dst, *p_src)	unpack_st_ble_ieee11073_sfloat_t(*p_dst, *p_src)
st_ble_date_time_t	pack_st_ble_date_time_t(*p_dst, *p_src)	unpack_st_ble_date_time_t(*p_dst, *p_src)

Following example shows implementation of a encode function for characteristic which has field shown in Figure 4.4. In this encode function, encode macros and functions provided in Table 4.1 are used.

```
typedef struct {
    uint16_t field_u16; /**<field_u16 */
    uint8_t field_u8; /**< field_u8 */
    st_ble_date_time_t field_date; /**< field_date */
} st_ble_css_cc_t;

static ble_status_t encode_st_ble_css_cc_t(const st_ble_css_cc_t *p_app_value,
st_ble_gatt_value_t *p_gatt_value)
{
    /* Start user code for Custom Characteristic characteristic value encode function.
    Do not edit comment generated here */
    uint8_t pos = 0;
    BT_PACK_LE_2_BYTE(&p_gatt_value->p_value[pos], &p_app_value->field_u16);
    pos += 2;

    BT_PACK_LE_1_BYTE(&p_gatt_value->p_value[pos], &p_app_value->field_u8);
    pos += 1;

    pack_st_ble_date_time_t(&p_gatt_value->p_value[pos], &p_app_value->field_date);
    pos += 7

    p_gatt_value->value_len = pos;
    /* End user code. Do not edit comment generated here */
    return BLE_SUCCESS;
}
```

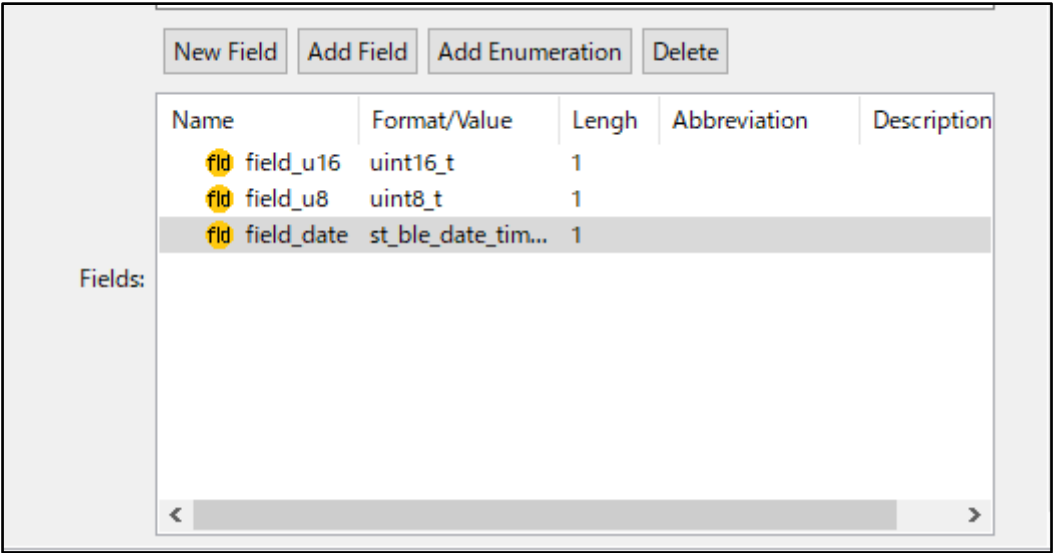


Figure 4.4 Example of field

4.1.2 Implementing callback

Bluetooth LE software generates events when Bluetooth LE communication such as receiving data or establishing connection occurs. You can implement application by implementing callback for those events. Callback for events can be implemented in 2 ways.

- Callback in the application.
- Callback in the service.

Beware that if you implement callback in the service, callback in application won't be called. This section guides you how to implement callback in the service.

Depending on the specifications of the custom service you implement, you may be required to implement following operations:

- Returns an error when an incorrect value is written to a characteristic or descriptor.
- Returns another characteristic value when specific instruction is written to a characteristic or descriptor.

Implementing these features in custom service API program improves portability and can be used for various applications.

Each characteristic has a structure defined as follows.

```
static const st_ble_servs_char_info_t gs_nc_char = {
    .start_hdl = BLE_CSS_CC_DECL_HDL,
    .end_hdl   = BLE_CSS_CC_CLI_CNFG_DESC_HDL,
    .char_idx  = BLE_CSS_CC_IDX,
    .app_size  = sizeof(st_ble_css_cc_t),
    .db_size   = BLE_CSS_CC_LEN,
    .decode    = (ble_servs_attr_decode_t)decode_st_ble_css_cc_t,
    .encode    = (ble_servs_attr_encode_t)encode_st_ble_css_cc_t,
    .pp_descs  = gspp_cc_descs,
    .num_of_descs = ARRAY_SIZE(gspp_cc_descs),
};
```

You can create a callback function for a characteristic event in a custom service by editing this structure as follows.

```
static void css_cc_write_req_cb(const void *p_attr, uint16_t conn_hdl, ble_status_t
result, const void *p_app_value)
{
    /*.....*/
}

static const st_ble_servs_char_info_t gs_nc_char = {
    .start_hdl = BLE_CSS_CC_DECL_HDL,
    .end_hdl   = BLE_CSS_CC_CLI_CNFG_DESC_HDL,
    .char_idx  = BLE_CSS_CC_IDX,
    .app_size  = sizeof(st_ble_css_cc_t),
    .db_size   = BLE_CSS_CC_LEN,
    .decode    = (ble_servs_attr_decode_t)decode_st_ble_css_cc_t,
    .encode    = (ble_servs_attr_encode_t)encode_st_ble_css_cc_t,
    .pp_descs  = gspp_cc_descs,
    .num_of_descs = ARRAY_SIZE(gspp_cc_descs),
    .write_req_cb = css_cc_write_req_cb,
};
```


The callbacks that can be registered are different in server program and client program. Table 4.2 shows callback functions that server program can register and Table 4.3 shows a callback functions that the client program can register. For more information about each event, refer the [RA Flexible Software Package Documentation].

Table 4.2 Callback available for server characteristic

Callback	description
write_req_cb	This callback occurs when Write Request or Prepare Write Request is received. It is used in Write Characteristic Value operation or Write Characteristic Long Value operation. GATT event: BLE_GATTS_OP_CHAR_PEER_WRITE_REQ
write_comp_cb	This callback occurs when Write Response or Execute Write Response is sent. It is used in Write Characteristic Value operation or Write Characteristic Long Value operation. GATT event: BLE_GATTS_EVENT_WRITE_RSP_COMP BLE_GATTS_EVENT_EXE_WRITE_RSP_COMP
write_cmd_cb	This callback occurs when Write Command or Signed Write Command is received. It is used in Write Characteristic Without Response operation or Signed Write operation. GATT event: BLE_GATTS_OP_CHAR_PEER_WRITE_CMD
read_req_cb	This callback occurs when Read Request is received. It is used in Read Characteristic Value operation or Read Characteristic Long Value operation. GATT event: BLE_GATTS_OP_CHAR_PEER_READ_REQ
hdl_val_cnf_cb	This callback occurs when Handle Value Confirmation is received. It is used in Indication operation. GATT event: BLE_GATTS_EVENT_HDL_VAL_CNF
flow_control_cb	This callback occurs when TX flow event is noticed. VS event: BLE_VS_EVENT_TX_FLOW_STATE_CHG

Table 4.3 Callback available for client characteristic

Callback	Event
write_rsp_cb	This callback occurs when Write Response or Prepare Write Response is received. It is used in Write Characteristic Value operation or Write Characteristic Long Value operation. GATT event: BLE_GATTC_EVENT_CHAR_WRITE_RSP BLE_GATTC_EVENT_LONG_CHAR_WRITE_COMP
read_rsp_cb	This callback occurs when Read Response or Read Blob Response is received. It is used in Read Characteristic Value operation or Read Characteristic Long Value operation. GATT event: BLE_GATTC_EVENT_CHAR_READ_RSP BLE_GATTC_EVENT_LONG_CHAR_READ_COMP
hdl_val_ntf_cb	This callback occurs when Handle Value Notification is received. It is used in Notification operation. GATT event: BLE_GATTC_EVENT_HDL_VAL_NTF
hdl_val_ind_cb	This callback occurs when Handle Value Indication is received. It is used in Indication operation. GATT event: BLE_GATTC_EVENT_HDL_VAL_IND

Similar to characteristic, each descriptor has structure defined as the follows. By editing this structure, you can also register callback functions in the descriptor.

```
static const st_ble_servs_desc_info_t gs_cc_cd = {
    .attr_hdl = BLE_CSS_CC_CD_DESC_HDL,
    .app_size = sizeof(uint8_t),
    .desc_idx = BLE_CSS_CC_CD_IDX,
    .db_size = BLE_CSS_CC_CD_LEN,
    .decode = (ble_servs_attr_decode_t)decode_uint8_t,
    .encode = (ble_servs_attr_encode_t)encode_uint8_t,
};
```

Descriptors can register different types of callbacks than characteristics. Table 4.4 shows callbacks that can be registered on the server side, and Table 4.5 shows callbacks that can be registered on the client side. For more information about each event, refer "RA Flexible Software Package Documentation".

Table 4.4 Callback available for server descriptor

Callback	description
write_req_cb	This callback occurs when Write Request or Prepare Write Request is received. It is used in Write Characteristic Value operation or Write Characteristic Long Value operation. GATT event: BLE_GATTS_OP_CHAR_PEER_CLI_CNFG_WRITE_REQ BLE_GATTS_OP_CHAR_PEER_SER_CNFG_WRITE_REQ BLE_GATTS_OP_CHAR_PEER_USR_CNFG_WRITE_REQ BLE_GATTS_OP_CHAR_PEER_HLD_CNFG_WRITE_REQ
write_comp_cb	This callback occurs when Write Response or Execute Write Response is sent. It is used in Write Characteristic Value operation or Write Characteristic Long Value operation. GATT event: BLE_GATTS_EVENT_WRITE_RSP_COMP BLE_GATTS_EVENT_EXE_WRITE_RSP_COMP
read_req_cb	This callback occurs when Read Request is received. It is used in Read Characteristic Value operation or Read Characteristic Long Value operation. GATT event: BLE_GATTS_OP_CHAR_PEER_CLI_CNFG_READ_REQ BLE_GATTS_OP_CHAR_PEER_SER_CNFG_READ_REQ BLE_GATTS_OP_CHAR_PEER_USR_CNFG_READ_REQ BLE_GATTS_OP_CHAR_PEER_HLD_CNFG_READ_REQ

Table 4.5 Callback available for client descriptor

Callback	description
write_rsp_cb	This callback occurs when Write Response or Prepare Write Response is received. It is used in Write Characteristic Value operation or Write Characteristic Long Value operation. GATT event: BLE_GATTC_EVENT_CHAR_WRITE_RSP BLE_GATTC_EVENT_LONG_CHAR_WRITE_RSP
read_rsp_cb	This callback occurs when Read Response or Read Blob Response is received. It is used in Read Characteristic Value operation or Read Characteristic Long Value operation. GATT event: BLE_GATTC_EVENT_CHAR_READ_RSP BLE_GATTC_EVENT_LONG_CHAR_READ_COMP

4.1.3 Definition of service API

The APIs defined in SIG standard service API program and custom service API program are named according to certain rules. So, you can determine which API to use in user application just by checking the name of API.

API for operation about value of characteristics and descriptor is named as follows.

R_BLE_[service][S or C]_[operation]

[service] is the string set to [abbreviation] of the service in QE for BLE. For [S or C], S is set if service is configured as server, C is set if service is configured as client.

The string set to [operation] is sending and receiving behavior of the value of characteristics and descriptors in Bluetooth LE communication. Table 4.6 lists strings set to [operation] generated in the server side API program and Table 4.7 lists strings set to [operation] generated in the client side API program. In both tables, [characteristic] is the string set to [abbreviation] of the characteristic in QE for BLE, [descriptor] is the string set to the [abbreviation] of the descriptor in QE for BLE.

Table 4.6 Server API

operation	description
Get[characteristic]	Get characteristic/descriptor value from GATT database.
Get[characteristic][descriptor]	You can check database value after operation such as Write Characteristic Value.
Set[characteristic]	Set characteristic/descriptor value to GATT database.
Set[characteristic][descriptor]	Value set to database is used in operation such as Read Characteristic Value.
Notify[characteristic]	Start Notification operation by sending Handle Value Notification. Characteristic value will not be stored to GATT database by calling this API.
Indicate[characteristic]	Start Indication operation by sending Handle Value Indication. Characteristic value will not be stored to GATT database by calling this API.

Table 4.7 Client API

operation	description
Get[characteristic]AttrHdl	Get characteristic attribute handle discovered in Discovery operation. You can also get Attribute handle of descriptor included in characteristic. Complete Discovery operation before calling this function.
Write[characteristic] Write[characteristic][descriptor]	Start Write Characteristic Value operation by sending Write Request. If value length exceeds MTU size, this function will start Write Long Characteristic Value operation by sending Write Prepare request.
Read[characteristic] Read[characteristic][descriptor]	Start Read Characteristic Value operation by sending Read Request. If value length exceeds MTU size, this function will start Write Long Characteristic Value operation by sending Read Blob Request.

Each service generated from QE for BLE defines the function listed in Table 4.8, regardless of its configuration. In this table, [service] is string set to [Abbreviation] of the service in QE for BLE, For [S or C], S is set if service is configured as server, C is set if service is configured as client.

Table 4.8 API defined in each service API program

API	description
R_BLE_[service][S or C]_Init	Initialization function for the service. Calling this function is necessary before using service API program.
R_BLE_[service][S or C]_GetServAttrHdl	Returns service attribute handle which is discovered in discovery operation. Call this function after discovery operation is completed. This function is implemented only on client API program.
R_BLE_[service][S or C]_ServDiscCb	Function to operate discovery operation. This function is used as callback function when using discovery library. This function is implemented only on client API program.

4.2 Implementation of app_main.c

app_main.c is the underlying framework for implementing user applications and profiles. This chapter guides you on how to implement user applications and profiles.

4.2.1 Implementing callback

Bluetooth LE software generates events when Bluetooth LE communication such as receiving data or establishing connection occurs. You can implement application by implementing callback for those events. Callback for events can be implemented in 2 ways.

- Callback in the application.
- Callback in the service.

Beware that if you implement callback in the service, callback in application won't be called. This section guides you how to implement callback in the application.

Handling of basic events for Bluetooth LE communication is implemented in application.

For events that comply with Bluetooth specifications, such as the establishment of connection or the completion of pairing, please refer "RA Flexible Software Package Documentation".

For events that exchanges each data of characteristic or descriptor included in the profile is implemented in the callback function output as a skeleton program. For information about the events that occur, refer [4.2.1.1 Service events]. The following is an example of implementing a custom service callback function.

```
static void lss_cb(uint16_t type, ble_status_t result, st_ble_servs_evt_data_t *p_data)
{
    switch (type)
    {
        /* Hint: Add cases of LED Switch Service server events defined in e_ble_lss_event_t */
        /* Start user code for LED Switch Service Server callback function event process. Do not
        edit comment generated here */

        case BLE_LSS_EVENT_BLINK_RATE_WRITE_REQ:
        {
            uint8_t rate = *(uint8_t *)p_data->p_param;
            R_BLE_TIMER_UpdateTimeout(gs_timer_hdl, rate*100);
        } break;

        /* End user code. Do not edit comment generated here */
    }
}
```

4.2.1.1 Service events

API program for all services, including custom service, have events defined for sending and receiving data in Bluetooth LE communications. Users can develop applications by implementing behavior responding to defined events in callback functions.

Each defined event is named based on the type of data and behavior in communication.

Events about characteristic value are named as follows.

BLE_[service][S or C]_EVENT_[characteristic]_[event type]

[service] is the string set to [abbreviation] of the service in QE for BLE, and [characteristic] is the string set to [abbreviation] of the characteristic in QE for BLE. [S or C] is S if the service is set to server, C if the service is set to client. [event type] is determined by the type of event described below.

Events about descriptor value are named as follows.

[service] is the string set to [abbreviation] of the service in QE for BLE, [characteristic] is the string set to [abbreviation] of the characteristic in QE for BLE, [descriptor] is the string set to [abbreviation] of the descriptor. [S or C] is S if the service is set to server, C if the service is set to client. [event type] is determined by the type of event described below.

BLE_[service][S or C]_EVENT_[characteristic]_[descriptor]_[event type]
--

The string set to [event type] is determined by sending and receiving events in Bluetooth LE communication. The type of event that occurs in Bluetooth LE communication is different on the server side and client side. Table 4.9 lists the events that occur on the server side, and Table 4.10 lists the event that occur on the client side.

Table 4.9 Server event

Event	description
WRITE_REQ	Event that occurs when Write Request or Prepare Write Request is received. It is used in Write Characteristic Value operation or Write Characteristic Long Value operation. GATT event: BLE_GATTS_OP_CHAR_PEER_WRITE_REQ
WRITE_COMP	Event that occurs after Write Response or Execute Write Response is sent. It is used in Write Characteristic Value operation or Write Characteristic Long Value operation. GATT event: BLE_GATTS_EVENT_CHAR_WRITE_RSP_COMP BLE_GATTS_EVENT_EXE_WRITE_RSP_COMP
WRITE_CMD	Event that occurs when Write Command or Signed Write Command is received. It is used in Write Characteristic Without Response operation or Signed Write operation. GATT event: BLE_GATTS_OP_CHAR_PEER_WRITE_CMD
READ_REQ	Event that occurs when Read Request is received. It is used in Read Characteristic Value operation or Read Characteristic Long Value operation. GATT event: BLE_GATTS_OP_CHAR_PEER_READ_REQ
HDL_VAL_CNF	Event that occurs when Handle Value Confirmation is received. It is used in Indication operation. GATT event: BLE_GATTS_EVENT_HDL_VAL_CNF

Table 4.10 Client event

Event	description
WRITE_RSP	Event that occurs when Write Response or Prepare Write Response is received. It is used in Write Characteristic Value operation or Write Characteristic Long Value operation. If error response is received, attribute handle will be sent with event. GATT event: BLE_GATTC_EVENT_WRITE_RSP BLE_GATTC_EVENT_LONG_CHAR_WRITE_COMP
READ_RSP	Event that occurs when Read Response or Read Blob Response is received. It is used in Read Characteristic Value operation or Read Characteristic Long Value operation. If error response is received, attribute handle will be sent with event. GATT event: BLE_GATTC_EVENT_CHAR_READ_RSP BLE_GATTC_EVENT_CHAR_PART_READ_RSP (If operation failed) BLE_GATTC_EVENT_LONG_CHAR_READ_COMP
HDL_VAL_NTF	Event that occurs when Handle Value Notification is received. It is used in Notification operation. GATT event: BLE_GATTC_EVENT_HDL_VAL_NTF
HDL_VAL_IND	Event that occurs when Handle Value Indication is received. It is used in Indication operation. GATT event: BLE_GATTC_EVENT_HDL_VAL_IND

Example of defined event in custom service is shown below.

```
/* LED Switch Service (Abbreviation:lsc) Client Event Type Definition */
typedef enum {

    /* Switch State Characteristic (Abbreviation:switch state) */
    /* Handle Value Notification */
    BLE_LSC_EVENT_SWITCH_STATE_HDL_VAL_NTF
    = BLE_SERVC_ATTR_EVENT(BLE_LSC_SWITCH_STATE_IDX, BLE_SERVC_HDL_VAL_NTF),

    /* Client Characteristic Configuration Descriptor (Abbreviation:cli_cnfg) */
    /* Read response */
    BLE_LSC_EVENT_SWITCH_STATE_CLI_CNFG_READ_RSP
    = BLE_SERVC_ATTR_EVENT(BLE_LSC_SWITCH_STATE_CLI_CNFG_IDX, BLE_SERVC_READ_RSP),
    /* Write response */
    BLE_LSC_EVENT_SWITCH_STATE_CLI_CNFG_WRITE_RSP
    = BLE_SERVC_ATTR_EVENT(BLE_LSC_SWITCH_STATE_CLI_CNFG_IDX,
    BLE_SERVC_WRITE_RSP),

    /* LED Blink Rate Characteristic (Abbreviation:blink rate) */
    /* Read Response */
    BLE_LSC_EVENT_BLINK_RATE_READ_RSP
    = BLE_SERVC_ATTR_EVENT(BLE_LSC_BLINK_RATE_IDX, BLE_SERVC_READ_RSP),
    /* Write Response */
    BLE_LSC_EVENT_BLINK_RATE_WRITE_RSP
    = BLE_SERVC_ATTR_EVENT(BLE_LSC_BLINK_RATE_IDX, BLE_SERVC_WRITE_RSP),

} e_ble_lsc_event_t;
```

4.3 Notice

4.3.1 Implementation of multiple services

When implementing multiple services, take care of the characteristic and descriptor code sizes contained in the service. If the code size exceeds the RAM/ROM size of target device, it cannot be compiled.

4.3.2 Implementation of same service

If you add multiple same SIG standard services to a profile, QE for BLE cannot correctly generate programs due to problem such as conflicts of file name. Therefore, if you want to implement multiple same services, you need to add only one service as SIG standard service and add the others as custom service on QE for BLE. For example, assume that you want to implement 2 Human Interface Device Service (HIDS), which is SIG standard service.

First, you need to add 2 HIDS as SIG standard service in QE for BLE. Change 1 of these HIDS from SIG standard service to custom service. To change from SIG standard service to custom service, click the customize button on the service setting screen. You need to make the following changes to the service that you changed to the custom service:

- Change [UUID] of service so that service UUID matches between the same service. If you want to treat the custom service as SIG standard service, set [UUID] to 16bit and change the value.
- Change [abbreviation] of service so that it does not conflict with other services. This is to prevent conflicts on file name, function name, and variable name because [abbreviation] is used for them. Similarly, set [abbreviation] of characteristic and descriptor to string which do not conflict with others.
- Change [Name] of service so that it does not conflict with other services.

Setting on QE for BLE is over. Figure 4.5 shows how to configure multiple SIG standard services on QE for BLE.

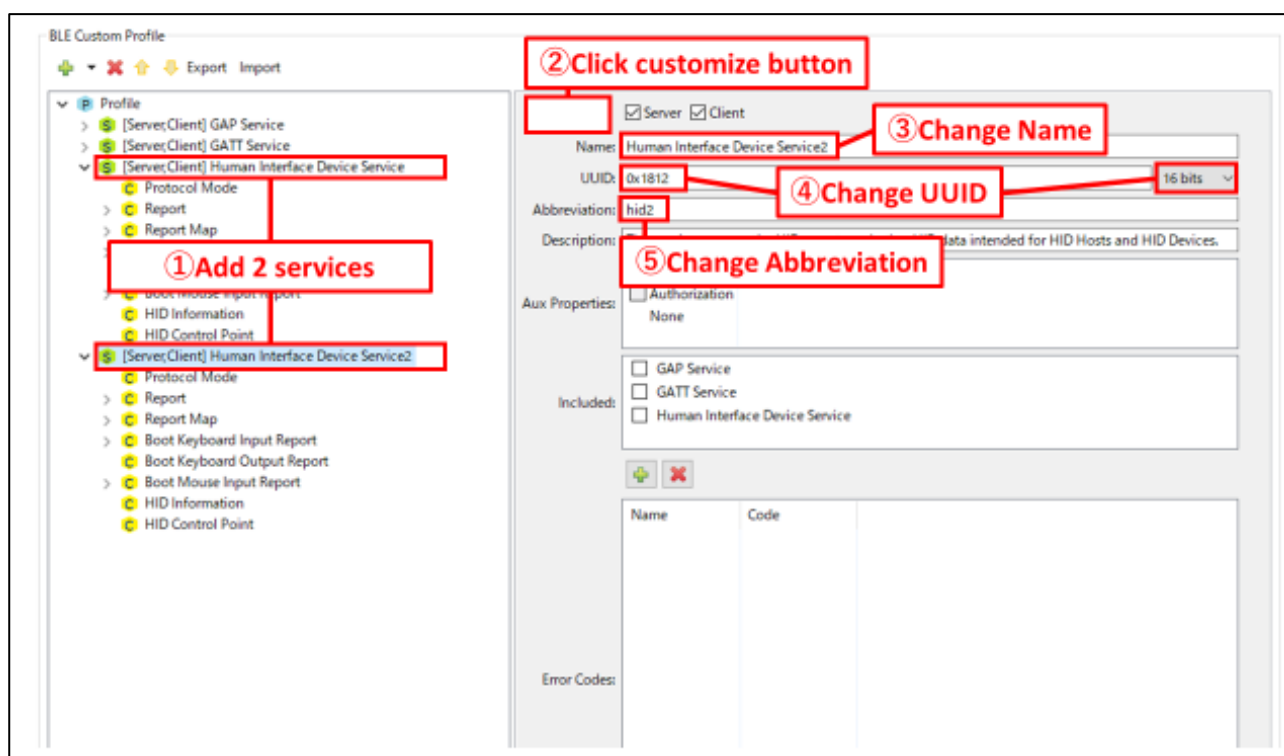


Figure 4.5 Configure multiple service on QE for BLE

Because the program generated from custom services are skeleton program, it is necessary to implement the actual state of process. Program generated from SIG standard services has same mechanism and is implemented according to the defined specification, so refer this program to implement skeleton program of custom service. The parts that must be implemented vary from service to service, but in many cases, following implementation is needed:

- Implements encode/decode function. Since the structure of the characteristic or descriptor remains the same, you can port many parts of implementation. Beware of differences in function name and variable name.
- Implements callback function in service. This is used when you want to automatically return error for invalid value written or automatically return certain value for specific value written. Implementation is needed according to functionality of each service.

In addition, if the profile has at least one service selected as a [client] except the GAP service, discovery operation program using discovery library is implemented in file app_main.c. Among them, the array gs_disc_entries[] defines UUID and discovery callback function for each service included in profile. To discover services those have same service UUID, you need to add element idx which is index number for them. The following is example of implementing a program with 2 HIDS.

```
/* Human Interface Device Service UUID */
static uint8_t HIDS_UUID[] = { 0x12, 0x18 }; //HIDS specific service UUID
/* Human Interface Device Service2 UUID */
static uint8_t HID2C_UUID[] = { 0x12, 0x18 }; //Same service UUID

/* Service discovery parameters */
static st_ble_disc_entry_t gs_disc_entries[] = {
    {
        .p_uuid      = HIDS_UUID,
        .uuid_type    = BLE_GATT_16_BIT_UUID_FORMAT,
        .serv_cb      = R_BLE_HIDS_ServDiscCb,
        /* Add member [idx] */
        .idx          = 0, /* Set index number if service UUID is same */
    },
    {
        .p_uuid      = HID2C_UUID,
        .uuid_type    = BLE_GATT_16_BIT_UUID_FORMAT,
        .serv_cb      = R_BLE_HID2C_ServDiscCb,
        /* Add member [idx] */
        .idx          = 1, /* Set index number if service UUID is same */
    },
};
```

4.3.3 Implementation of secondary service

QE for BLE treats all services as primary services. Therefore, if you want to use secondary service, you need to modify the generated program. How to change program is different on the server side and client side.

Server Side

QE for BLE generates GATT database which stores information of services which have check in [server]. Since QE for BLE treats all services as primary service, generated GATT database defines all services as primary service. You need to modify service information defined in GATT database.

Change the array `gs_gatt_type_table[ ]` defined in file `gatt_db.c`. In this array, following 2 point needs to be changed:

- Add definition for secondary service. Refer to the other elements of the array and create element that has [UUID_Offset] is 2 and correct attribute handles of secondary services.
- Change element which defines [Primary Service Declaration]. Change it to specify the correct attribute handle.

The following is the example of implementation on array `gs_gatt_type_table[ ]`.

```
static const st_ble_gatts_db_uuid_cfg_t gs_gatt_type_table[] =
{
    /* 0 : Primary Service Declaration */
    {
        /* UUID Offset */
        0,

        /* First Occurrence for type */
        /* Change this value to proper handle */
        0x000C,

        /* Last Occurrence for type */
        /* Change this value to proper handle */
        0x0026,
    },

    /* Add from here */
    /* 2 : Secondary Service Declaration */
    {
        /* UUID Offset */
        /* set 2 for this value */
        2,

        /* First Occurrence for type */
        /* Change this value to proper handle */
        0x0010,

        /* Last Occurrence for type */
        /* Change this value to proper handle */
        0x0000,
    },
    /* Add until here */
}
```

Also, change array `gs_gatt_db_attr_table[ ]`. In this array, following 2 points need to be changed:

- Change [UUID_Offset] section of service declaration which you want to change to secondary service. [UUID_offset] determines attribute type of data. In [UUID_Offset], 0 stands for primary service and 2 stands for secondary service. Set 2 for [UUID_Offset].
- change element [Next Attribute Type Index] to indicate correct attribute handle. [Next Attribute Type Index] holds attribute handle of next data which has same attribute type. If modified data was the last data with same attribute type, enter 0x0000 for [Next Attribute Type Index].

The example of implementation on array `gs_gatt_type_table[ ]` is shown on the next page.

Note: Make sure that the service which you changed to secondary service is included from at least one primary service.

```

static const st_ble_gatts_db_attr_cfg_t gs_gatt_db_attr_table[] =
{
    /* Handle: 0x000C */
    /* GATT Service: Primary Service Declaration */
    {
        /* Properties */
        BLE_GATT_DB_READ,
        /* Auxiliary Properties */
        BLE_GATT_DB_FIXED_LENGTH_PROPERTY,
        /* Value Size */
        2,

        /* Next Attribute Type Index */
        /* change this value to handle of next primary service declaration */
        0x0026,      /* 0x0010 → 0x0026 */

        /* UUID Offset */
        0,
        /* Value */
        (uint8_t *) (gs_gatt_const_uuid_arr + 20),
    },

    /* Example: Secondary Service Declaration */
    /* Handle: 0x0010 */
    /* Human Interface Device Service: Primary Service Declaration */
    {
        /* Properties */
        BLE_GATT_DB_READ,
        /* Auxiliary Properties */
        BLE_GATT_DB_FIXED_LENGTH_PROPERTY,
        /* Value Size */
        2,

        /* Next Attribute Type Index */
        /* Change this value to proper handle */
        /* Last secondary service declared: 0x0000 */
        /* Not last secondary service declared: handle of next secondary service
declaration */
        0x0000,      /* 0x0026 → 0x0000 */

        /* UUID Offset */
        /* Change this value to proper Attribute type */
        /* Primary service declaration: 0 */
        /* Secondary service declaration: 2 */
        2,      /* 0 → 2 */

        /* Value */
        (uint8_t *) (gs_gatt_const_uuid_arr + 26),
    },

    /* Handle: 0x0026 */
    /* Human Interface Device Service2: Primary Service Declaration */
}

```

Client Side

If the profile has at least one service selected as a [client] except the GAP service, QE for BLE generate the code to perform the discovery operation. Generated program performs discovery operation only to primary service using Discovery Library provided by BLE Protocol Stack. When you need to discovery secondary service, perform discovery operation as the included service because secondary service is included from other primary service, Refer to [4.3.4 Implementation of discovery operation about included service].

When you perform secondary service discovery operation to debug, call `R_BLE_GATTC_DiscAllSecondServ()` in GATT Client API provided by BLE Protocol Stack. For more information about GATT Client API, refer [RA Flexible Software Package Documentation].

4.3.4 Implementation of discovery operation about included service

Specifying included service

If the profile has at least one service selected as a [client] except the GAP service, QE for BLE generate the code to perform the discovery operation. Generated program performs discovery operation only to primary service using Discovery Library provided by BLE Protocol Stack.

If service has specific service as an included service, you need to confirm its structure to perform discovery operation to specific service. Discovery library provide feature to perform discovery operation confirming this structure. Discovery library perform discovery operation to attribute handle range that included service declaration has if included service entries are registered in discovery entry of parent service. Modify the variable `gs_disc_entries` in the `app_main.c` as the following, in order to register included service entries to discovery entry of parent service.

The code generated by QE for BLE

```
/*PRIMARY service entry */
static st_ble_disc_entry_t gs_disc_entries[] =
{
    {
        /*Weight Scale service disc entry */
        .p_uuid = (uint8_t *)BLE_WSC_UUID,
        .uuid_type = BLE_GATT_16_BIT_UUID_FORMAT,
        .serv_cb = R_BLE_WSC_ServDiscCb,
    },
    {
        /*Body Composition service disc entry */
        .p_uuid = (uint8_t *)BLE_BCC_UUID,
        .uuid_type = BLE_GATT_16_BIT_UUID_FORMAT,
        .serv_cb = R_BLE_BCC_ServDiscCb,
    },
};
```

The code modified to discover included service.

```
/*Add INCLUDE service entry*/
static st_ble_disc_entry_t gs_disc_wsc_inc_entries[] =
{
    /*Body Composition service disc entry AS A INCLUDE SERVICE IN WSS*/
    {
        .p_uuid = (uint8_t *)BLE_BCC_UUID,
        .uuid_type = BLE_GATT_16_BIT_UUID_FORMAT,
        .serv_cb = R_BLE_BCC_ServDiscCb,
        .num_of_inc_servs = 0,
    },
};
/*PRIMARY service entry */
static st_ble_disc_entry_t gs_disc_entries[] =
{
    /*Weight Scale service disc entry as a primary service*/
    {
        .p_uuid = (uint8_t *)BLE_WSC_UUID,
        .uuid_type = BLE_GATT_16_BIT_UUID_FORMAT,
        .serv_cb = R_BLE_WSC_ServDiscCb,
        /* Register include service entry*/
        .inc_servs = gs_disc_wsc_inc_entries,
        .num_of_inc_servs = 1
    },
};
```


Store Attribute handle of included service

Discovered attribute handle of included service will be passed to parent service API program. But parent service API program don't store attribute handle of included service. Therefore, in case Service YYY is discovered as included service that Service XXX has, you can't get range of its attribute handle by calling service YYY's API `R_BLE_YYY_GetServAttrhdl()`.

If service YYY's range of attribute handle is needed, modify service XXX's API program (`r_ble_xxx.c`) so that the notification that service YYY is discovered as a include service is delivered to service YYY's discovery callback function.

The following show example in case Service XXX have 16bit UUID and have service YYY as included service. Take care the data type is different in 128bit UUID and in 16bit UUID.

```
#include <string.h>
#include "r_ble_xxx.h"
#include "profile_cmn/r_ble_servc_if.h"

/* ADD : including discovery library and include service yyy */
#include "discovery/r_ble_disc.h"
#include "r_ble_yyy.h"

void R_BLE_XXX_ServDiscCb(uint16_t conn_hdl, uint8_t serv_idx, uint16_t type, void
*p_param)
{
    /* ADD : */
    uint16_t YYY_UUID = 0x0000;
    if (type == BLE_DISC_INC_SERV_FOUND)
    {
        st_disc_inc_serv_param_t * evt_param =
            (st_disc_inc_serv_param_t *)p_param;

        if (evt_param->uuid_type == BLE_GATT_16_BIT_UUID_FORMAT)
        {
            if(YYY_UUID == evt_param->value.inc_serv_16.service.uuid_16)
            {
                st_disc_serv_param_t serv_param = {
                    .uuid_type          = BLE_GATT_16_BIT_UUID_FORMAT,
                    .value.serv_16.range =
                        evt_param->value.inc_serv_16.service.range,
                    .value.serv_16.uuid_16 =
                        evt_param->value.inc_serv_16.service.uuid_16,
                };
                R_BLE_YYY_ServDiscCb(
                    /* Connection handle */
                    conn_hdl,
                    /* idx */
                    0,
                    /* Notify as a primary service */
                    BLE_DISC_PRIM_SERV_FOUND,
                    /* Service handle information */
                    &serv_param);
            }
        }
    }
    /* Generated code */
}
```

5. Running created project

If you run program generated by QE for BLE, you need to call `app_main()` function in `hal_entry.c` file. Example of implementation is shown below.

```
extern void app_main(void);

void hal_entry(void) {
    /* TODO: add your own code here */
    app_main();
}
```

Revision History

Rev.	Date	Description	
		Page	Summary
1.00	Apr.24.20	—	First edition issued.

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

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

1. Precaution against Electrostatic Discharge (ESD)

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

2. Processing at power-on

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

3. Input of signal during power-off state

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

4. Handling of unused pins

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

5. Clock signals

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

6. Voltage application waveform at input pin

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

7. Prohibition of access to reserved addresses

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

8. Differences between products

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

Notice

1. Descriptions of circuits, software and other related information in this document are provided only to illustrate the operation of semiconductor products and application examples. You are fully responsible for the incorporation or any other use of the circuits, software, and information in the design of your product or system. Renesas Electronics disclaims any and all liability for any losses and damages incurred by you or third parties arising from the use of these circuits, software, or information.
2. Renesas Electronics hereby expressly disclaims any warranties against and liability for infringement or any other claims involving patents, copyrights, or other intellectual property rights of third parties, by or arising from the use of Renesas Electronics products or technical information described in this document, including but not limited to, the product data, drawings, charts, programs, algorithms, and application examples.
3. No license, express, implied or otherwise, is granted hereby under any patents, copyrights or other intellectual property rights of Renesas Electronics or others.
4. You shall not alter, modify, copy, or reverse engineer any Renesas Electronics product, whether in whole or in part. Renesas Electronics disclaims any and all liability for any losses or damages incurred by you or third parties arising from such alteration, modification, copying or reverse engineering.
5. Renesas Electronics products are classified according to the following two quality grades: "Standard" and "High Quality". The intended applications for each Renesas Electronics product depends on the product's quality grade, as indicated below.

"Standard": Computers; office equipment; communications equipment; test and measurement equipment; audio and visual equipment; home electronic appliances; machine tools; personal electronic equipment; industrial robots; etc.

"High Quality": Transportation equipment (automobiles, trains, ships, etc.); traffic control (traffic lights); large-scale communication equipment; key financial terminal systems; safety control equipment; etc.

Unless expressly designated as a high reliability product or a product for harsh environments in a Renesas Electronics data sheet or other Renesas Electronics document, Renesas Electronics products are not intended or authorized for use in products or systems that may pose a direct threat to human life or bodily injury (artificial life support devices or systems; surgical implantations; etc.), or may cause serious property damage (space system; undersea repeaters; nuclear power control systems; aircraft control systems; key plant systems; military equipment; etc.). Renesas Electronics disclaims any and all liability for any damages or losses incurred by you or any third parties arising from the use of any Renesas Electronics product that is inconsistent with any Renesas Electronics data sheet, user's manual or other Renesas Electronics document.

6. When using Renesas Electronics products, refer to the latest product information (data sheets, user's manuals, application notes, "General Notes for Handling and Using Semiconductor Devices" in the reliability handbook, etc.), and ensure that usage conditions are within the ranges specified by Renesas Electronics with respect to maximum ratings, operating power supply voltage range, heat dissipation characteristics, installation, etc. Renesas Electronics disclaims any and all liability for any malfunctions, failure or accident arising out of the use of Renesas Electronics products outside of such specified ranges.
7. Although Renesas Electronics endeavors to improve the quality and reliability of Renesas Electronics products, semiconductor products have specific characteristics, such as the occurrence of failure at a certain rate and malfunctions under certain use conditions. Unless designated as a high reliability product or a product for harsh environments in a Renesas Electronics data sheet or other Renesas Electronics document, Renesas Electronics products are not subject to radiation resistance design. You are responsible for implementing safety measures to guard against the possibility of bodily injury, injury or damage caused by fire, and/or danger to the public in the event of a failure or malfunction of Renesas Electronics products, such as safety design for hardware and software, including but not limited to redundancy, fire control and malfunction prevention, appropriate treatment for aging degradation or any other appropriate measures. Because the evaluation of microcomputer software alone is very difficult and impractical, you are responsible for evaluating the safety of the final products or systems manufactured by you.
8. Please contact a Renesas Electronics sales office for details as to environmental matters such as the environmental compatibility of each Renesas Electronics product. You are responsible for carefully and sufficiently investigating applicable laws and regulations that regulate the inclusion or use of controlled substances, including without limitation, the EU RoHS Directive, and using Renesas Electronics products in compliance with all these applicable laws and regulations. Renesas Electronics disclaims any and all liability for damages or losses occurring as a result of your noncompliance with applicable laws and regulations.
9. Renesas Electronics products and technologies shall not be used for or incorporated into any products or systems whose manufacture, use, or sale is prohibited under any applicable domestic or foreign laws or regulations. You shall comply with any applicable export control laws and regulations promulgated and administered by the governments of any countries asserting jurisdiction over the parties or transactions.
10. It is the responsibility of the buyer or distributor of Renesas Electronics products, or any other party who distributes, disposes of, or otherwise sells or transfers the product to a third party, to notify such third party in advance of the contents and conditions set forth in this document.
11. This document shall not be reprinted, reproduced or duplicated in any form, in whole or in part, without prior written consent of Renesas Electronics.
12. Please contact a Renesas Electronics sales office if you have any questions regarding the information contained in this document or Renesas Electronics products.

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

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

(Rev.4.0-1 November 2017)

Corporate Headquarters

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

Trademarks

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

Contact information

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