GR533x Developer Guide

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Shenzhen Goodix Technology Co., Ltd.

Headquarters: Floor 12-13, Phase B, Tengfei Industrial Building, Futian Free Trade Zone, Shenzhen, China

TEL: +86-755-33338828 Zip Code: 518000

Website: www.goodix.com

Preface

Purpose

This document introduces the Software Development Kit (SDK) of the Goodix GR533x Bluetooth Low Energy (Bluetooth LE) System-on-Chip (SoC) and Keil for program development and debugging, to help you quickly get started with secondary development of Bluetooth LE applications.

Audience

This document is intended for:

- Device user
- Developer
- Test engineer
- Technical support engineer

Release Notes

This document is the third release of *GR533x Developer Guide*, corresponding to GR533x SDK.

Revision History

Version	Date	Description
1.0	2023-10-18	Initial release
1.1	2023-11-08	• Updated the SDK directory. • Added the section "Tools".
1.2	2024-01-16	• Updated the descriptions of parameters in *custom_config.h*. • Revised the code example for bsp_log_int(). • Revised the approach to obtain GRToolbox installation file.

Contents

1 Introduction

The Goodix GR533x series is a System-on-Chip (SoC) that supports Bluetooth 5.3 and Bluetooth Mesh, making it an ideal choice for applications including Internet of Things (IoT).

Based on 64 MHz ARM® Cortex®-M4F CPU core, the GR533x series integrates a 2.4 GHz RF transceiver, Bluetooth LE 5.3 Protocol Stack, on-chip 512 KB Flash, 96 KB system SRAM, and multiple peripherals. It also features excellent RF performance, with up to +15 dBm TX power, -99 dBm RX sensitivity, and up to 114 dB link budget in Bluetooth LE 1 Mbps mode.

The GR533x series supports connection between multiple centrals and multiple peripherals. It can be configured as a Broadcaster, an Observer, a Peripheral, or a Central, and supports the combination of all the above roles.

GR533x series comes in two package choices: QFN32 and QFN48 packages. The specific configurations are listed below.

Table 1-1 Configuration of GR533x series

GR533x Series	GR5331AENI	GR5331CENI	GR5332AENE	GR5332CENE
CPU	Cortex®-M4F	Cortex®-M4F	Cortex®-M4F	Cortex®-M4F
RAM	96 KB	96 KB	96 KB	96 KB
SiP Flash	512 KB	512 KB	512 KB	512 KB
I/O Number	16	32	16	32
Operating Temperature	-40°C to 85°C	-40°C to 85°C	-40°C to 105°C	-40°C to 105°C
Package (mm)	QFN32 (4 x 4 x 0.75)	QFN48 (6 x 6 x 0.75)	QFN32 (4 x 4 x 0.75)	QFN48 (6 x 6 x 0.75)

1.1 GR533x SDK

The GR533x Software Development Kit (SDK) provides comprehensive software development support for GR533x SoCs. The SDK contains Bluetooth LE APIs, Mesh APIs, System APIs, peripheral drivers, a tool for debugging and download, project example code, and related user documents.

Tip:

The GR533x SDK version mentioned in this document is applicable to all GR533x SoCs.

1.2 Bluetooth LE Protocol Stack

The Bluetooth LE Protocol Stack (Bluetooth LE Stack) architecture is as shown in the figure below.

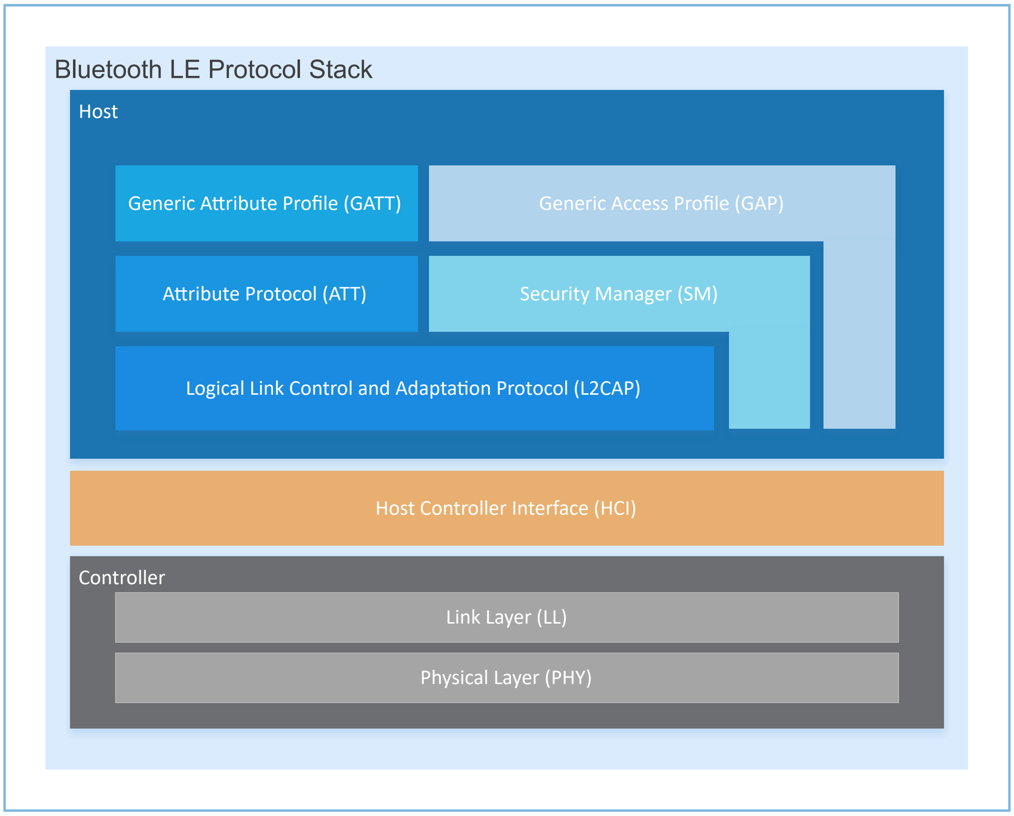

Figure 1-1 Bluetooth LE Stack architecture

The Bluetooth LE Stack consists of the Controller, the Host Controller Interface (HCI), and the Host.

Controller

- Physical Layer (PHY): Supports 1-Mbps and 2-Mbps adaptive frequency hopping and Gaussian Frequency Shift Keying (GFSK).
- Link Layer (LL): Controls the RF state of devices. Devices are in one of the following five states, and can switch between the states on demand: Standby, Advertising, Scanning, Initiating, and Connection.

HCI

- HCI: Enables communication between Host and Controller, supported by software interfaces or standard hardware interfaces, for example, UART, Secure Digital (SD), or USB. HCI commands and events are transferred between Host and Controller through HCI.

Host

- Logical Link Control and Adaptation Protocol (L2CAP): Provides channel multiplexing and data segmentation and reassembly services for upper layers. It also supports logic end-to-end data communication.
- Security Manager (SM): Defines pairing and key distribution methods, providing upper-layer protocol stacks and applications with end-to-end secure connection and data exchange functionalities.

- Generic Access Profile (GAP): Provides upper-layer applications and profiles with interfaces to communicate and interact with protocol stacks, fulfilling functionalities such as advertising, scanning, connection initiation, service discovery, connection parameter update, secure process initiation, and response.
- Attribute Protocol (ATT): Defines service data interaction protocols between a server and a client.
- Generic Attribute Profile (GATT): Based on the top of ATT, it defines a series of communication procedures for upper-layer applications, profiles, and services to exchange service data between GATT Client and GATT Server.

Tip:

- For more information about Bluetooth LE technologies and protocols, visit the Bluetooth SIG official website: https://www.bluetooth.com.
- Specifications of GAP, SM, L2CAP, and GATT are provided in *Bluetooth Core Spec*. Specifications of other profiles/ services at the Bluetooth LE application layer are available on the GATT Specs page. Assigned numbers, IDs, and code which may be used by Bluetooth LE applications are listed on the Assigned Numbers page.

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2 GR533x Bluetooth LE Software Platform

The GR533x SDK is designed for GR533x SoCs, to help users develop Bluetooth LE applications. It integrates Bluetooth LE 5.3 APIs, System APIs, and peripheral driver APIs, with various example projects and instruction documents for Bluetooth and peripheral applications. Application developers are able to quickly develop and iterate products based on example projects in the GR533x SDK.

2.1 Hardware Architecture

The GR533x hardware architecture is shown as follows.

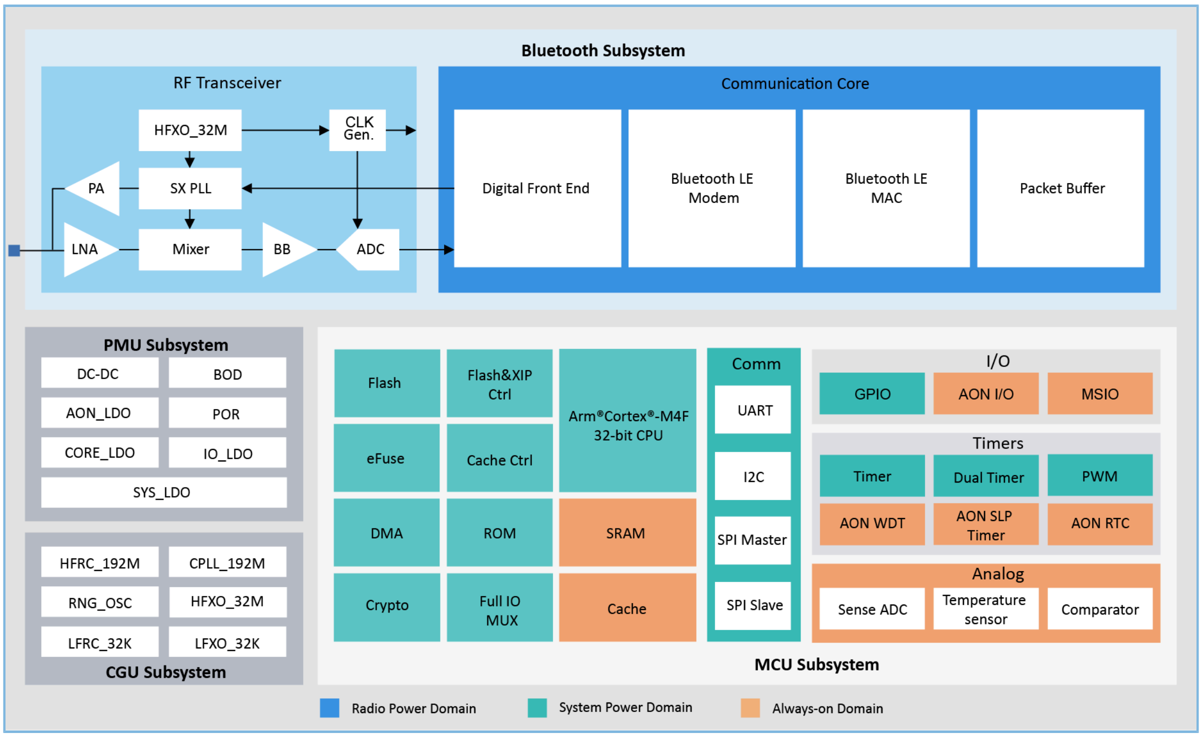


Figure 2-1 GR533x hardware architecture

- Arm® Cortex®-M4F: GR533x CPU. Bluetooth LE Stack and application code run on the CPU.
- SRAM: static random access memory that provides memory space for program execution
- ROM: read-only memory, containing the software code (cannot be modified after being programmed) for Bootloader and Bluetooth LE Stack
- Flash: Flash memory unit embedded in the SoC. It stores user code and data, and supports the Execute in Place (XIP) mode for user code.
- Peripherals: GPIO, DMA, I2C, SPI, UART, PWM, Timer, ADC, TRNG, and more
- RF Transceiver: 2.4 GHz RF transceiver
- Communication Core: PHY of Bluetooth 5.3 Protocol Stack Controller, enabling communication between the software protocol stack and 2.4 GHz RF hardware

- Power Management Unit (PMU): It supplies power for system modules, and sets reasonable parameters for modules, including DC-DC, SYS_LDO, IO-LDO, CORE_LDO, and RF Subsystem, based on configuration parameters and the current operating state of the system, so that the power can be managed automatically.

Tip:

For more details about device modules, refer to *GR533x Datasheet* .

2.2 Software Architecture

The software architecture of GR533x SDK is shown below.

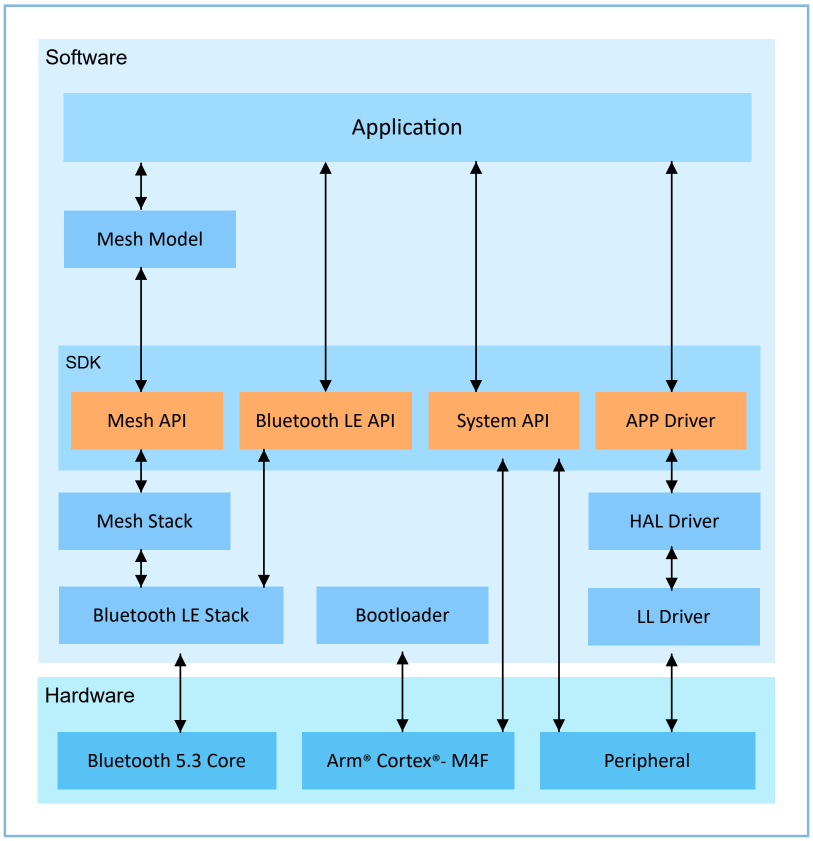


Figure 2-2 GR533x software architecture

- Bootloader

  A boot program built in GR533x SoCs, used for GR533x software and hardware environment initialization, and to check and start applications

- Bluetooth LE Stack

  The core to implement Bluetooth LE protocols. It consists of Controller, HCI, and Host protocols (including LL, HCI, L2CAP, GAP, SM, and GATT), and supports roles of Broadcaster, Observer, Peripheral, and Central.

- Mesh Stack

  The core to implement Bluetooth LE Mesh protocols. It integrates Bearer Layer, Network Layer, Lower Transport Layer, Upper Transport Layer, Access Layer, and some functionalities of the Foundation Model Layer.

- LL Driver

  Low Layer (LL) drivers which control and manage peripherals by registers

- HAL Driver

  Hardware Abstraction Layer (HAL) drivers; the HAL Driver layer is between the APP Driver layer and the LL Driver layer. HAL drivers offer a set of standard APIs, to allow the APP driver layer to access the LL peripheral resources by calling HAL APIs.

Note:

Generally, HAL APIs are used for developing LL drivers and system services, not for developing common applications. Therefore, it is not recommended for developers to directly call HAL APIs.

- Bluetooth LE SDK

  SDK that provides easy-to-use Mesh APIs, Bluetooth LE APIs, system APIs, and APP Driver APIs

  - Mesh APIs: Include APIs required for developing Mesh applications.
  - Bluetooth LE APIs: Include L2CAP, GAP, SM, and GATT APIs.
  - System APIs: Provide APIs for Non-volatile Data Storage (NVDS), Device Firmware Update (DFU), system power management, and generic system-level access.
  - APP Driver APIs: Provide definitions for APIs of common peripherals such as UART, I2C, and ADC. APP Driver APIs call HAL/LL APIs to enable the corresponding functionalities.

- Mesh Model

  It contains example implementation code for standard Mesh Model (such as Lightness Model) from Bluetooth SIG. You can refer to the example code to develop Mesh applications.

- Application

  The SDK provides abundant Bluetooth and peripheral example projects. Each project contains compiled binary files; you can download these files to GR533x SoCs for operation and test. In addition, GRToolbox (Android) provides rich functionalities to allow users to test most Bluetooth applications with ease.

2.3 Memory Mapping

The memory mapping of a GR533x SoC is shown below.

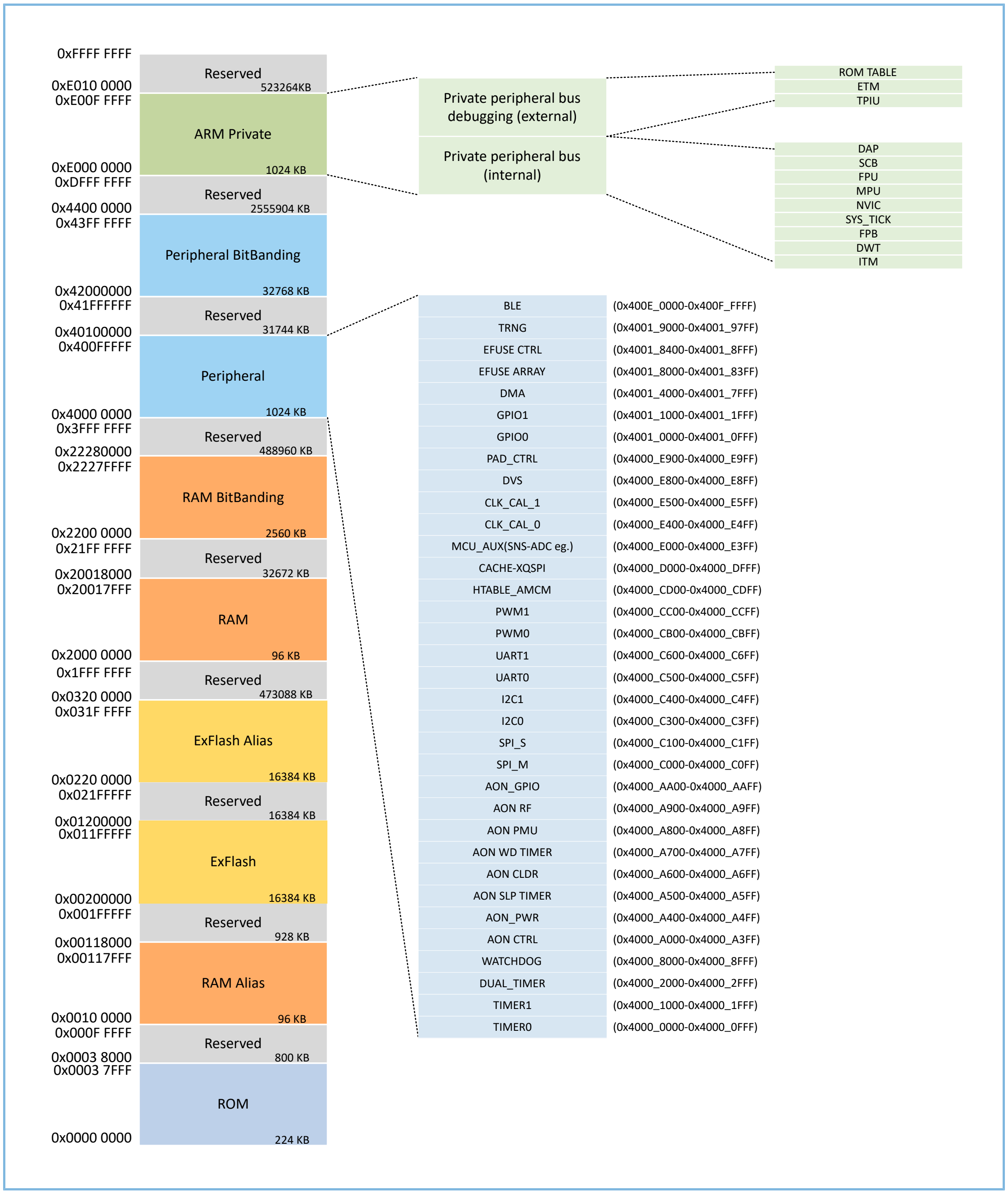


Figure 2-3 GR533x memory mapping

- RAM: 96 KB in total; 0x0010_0000 to 0x0011_7FFF, or 0x2000_0000 to 0x2001_7FFF.
    - 0x2000_0000 to 0x2001_7FFF: Variables of the SDK including RW, ZI, HEAP, and STACK are in this range. The 16 KB storage area at the end of SRAM can be used as Exchange Memory (EM) for baseband when you configure Bluetooth LE projects. The actual area used as EM is determined by the maximum Bluetooth LE service volume configured in *custom_config.h*. The unused EM area will form a contiguous address space with other SRAM areas. In addition, bit field operations are supported in the region from 0x2000_0000 to 0x2001_3FFF, mapping to the region from 0x2200_0000 to 0x2227_FFFF, in which atomic operations are supported.

- ◦ 0x0010_0000 to 0x0011_7FFF: This region features higher access efficiency thanks to the Cortex®-M4F architecture. Therefore, executable code RAM_CODE is in this area.

- Flash: Internal Flash of GR533x SoCs is 512 KB, from 0x0020_0000 to 0x0027_FFFF.

2.4 Flash Memory Mapping

GR533x packages an on-chip erasable Flash memory, which supports XQSPI bus interface. This Flash memory physically consists of several 4 KB Flash sectors; it can be logically divided into storage areas for different purposes based on application scenarios.

The Flash memory layout for typical GR533x application scenarios is shown below.

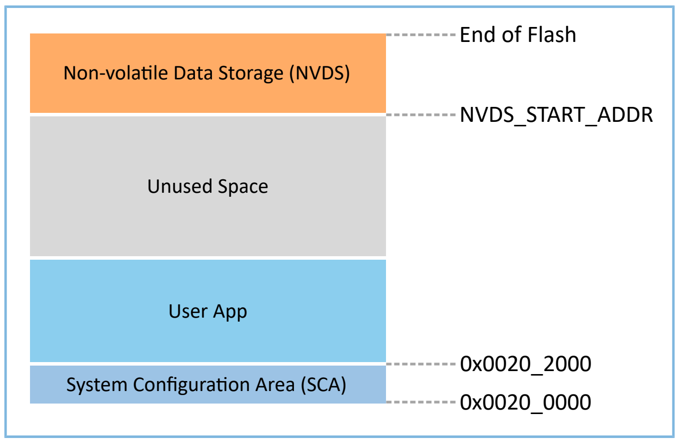


Figure 2-4 Flash memory layout

- System Configuration Area (SCA): an area to store configurations such as system boot parameters
- User App: an area to store application firmware
- Unused Space: a free area for developers. For example, developers can store new application firmware in the Unused Space temporarily during DFU.
- NVDS: non-volatile data storage area

Note:

- By default, NVDS occupies the last two sectors of Flash memory. You can configure the start address of NVDS and the number of occupied sectors according to Flash memory layout of products. For more information about the configuration, refer to "Section 4.3.2.1 Configuring custom_config.h".
- The start address of NVDS shall be aligned with that of the Flash sectors.

2.4.1 SCA

SCA is in the first two sectors (8 KB in total; 0x0020_0000 to 0x0020_2000) of Flash memory. It mainly stores flags and other system configuration parameters used during system boot.

During firmware download, the download algorithm or GProgrammer will generate Image Info based on the BUILD_IN_APP_INFO structure in the application firmware, and program the Image Info (stored in SCA) to Flash along with the application firmware. During system boot, Bootloader will check the boot information in SCA, and then jump to the entry address of the firmware if the check passes.

The BUILD_IN_APP_INFO structure is defined and configured as follows:

Tip:

The BUILD_IN_APP_INFO structure is in `SDK_Folder\platform\soc\common\gr_platform.c`, and SDK_Folder is the root directory of GR533x SDK.

```
const APP_INFO_t BUILD_IN_APP_INFO __attribute__((at(APP_INFO_ADDR))) = {
    .app_pattern = APP_INFO_PATTERN_VALUE,
    .app_info_version = APP_INFO_VERSION,
    .chip_ver = CHIP_VER,
    .load_addr = APP_CODE_LOAD_ADDR,
    .run_addr = APP_CODE_RUN_ADDR,
    .app_info_sum = CHECK_SUM,
    .check_img = BOOT_CHECK_IMAGE,
    .boot_delay = BOOT_LONG_TIME,
    .sec_cfg = SECURITY_CFG_VAL,
#ifdef APP_INFO_COMMENTS
    .comments = APP_INFO_COMMENTS,
#endif
};
```

- app_pattern: a fixed value 0x47525858
- app_info_version: firmware version information, corresponding to APP_INFO_VERSION
- chip_ver: version of the SoC that the firmware runs on, corresponding to CHIP_VER in *custom_config.h*
- load_addr: firmware load address, corresponding to APP_CODE_LOAD_ADDR in *custom_config.h*
- run_addr: firmware run address, corresponding to APP_CODE_RUN_ADDR in *custom_config.h*
- app_info_sum: checksum of firmware information, which is automatically calculated by CHECK_SUM
- check_img: system boot configuration parameter, corresponding to BOOT_CHECK_IMAGE in *custom_config.h*. When check_img is set to **1**, Bootloader will check the firmware at booting.
- boot_delay: boot configuration parameter, corresponding to BOOT_LONG_TIME in *custom_config.h*. When boot_delay is set to **1**, the system cold boot will be launched after a one-second delay.
- sec_cfg: security configuration parameter, reserved
- comments: firmware information, up to 12 bytes

The SCA layout is shown below.

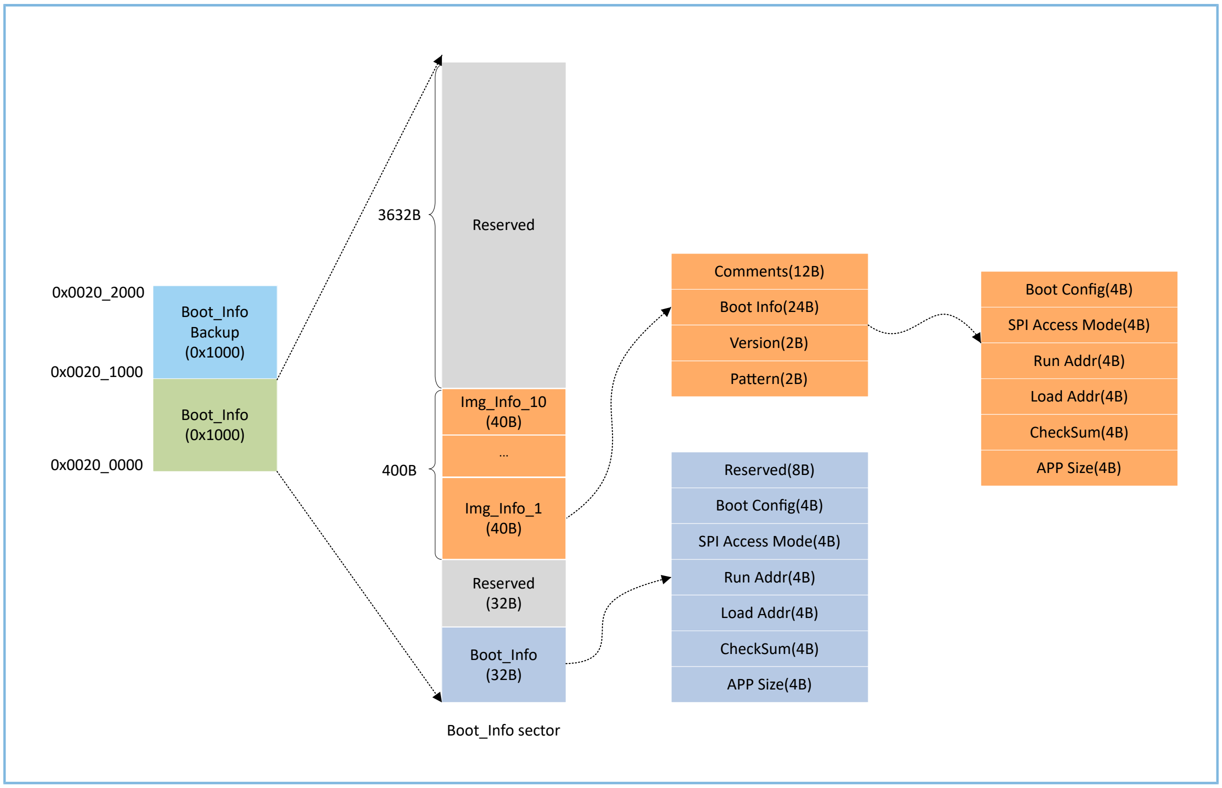


Figure 2-5 SCA layout

- Boot_Info and Boot_Info Backup store the same information. The latter is the backup of the Boot_Info.
- The firmware boot information is stored in the Boot_Info (32 B) area. During system boot, Bootloader will check the boot information, and then jump to the entry address of the firmware if the check passes.
    - Boot Config: This area stores the system boot configuration information.
    - SPI Access Mode: This area stores the SPI access mode configuration. It is a fixed configuration of the system and cannot be modified.
    - Run Addr: Indicates the firmware run address, corresponding to run_addr of BUILD_IN_APP_INFO.
    - Load Addr: Indicates the firmware load address, corresponding to load_addr of BUILD_IN_APP_INFO.
    - CheckSum: This area stores the firmware checksum which is calculated automatically by the download algorithm after firmware is generated.
    - APP Size: This area stores the firmware size which is calculated automatically by the download algorithm after firmware is generated.
- Up to 10 pieces of firmware information can be stored in Img_Info areas. Firmware information is stored in Img_Info areas when you use GProgrammer to download firmware or update firmware in DFU mode.
    - Comments: This area stores the descriptive information (up to 12 characters) about firmware. Every time a firmware file is generated, the file name will be saved in the Comments area by the download algorithm.

    - Boot Info (24 B): This area stores the firmware boot information which is the same as the low 24-byte information in the Boot_Info (32 B) area mentioned above.
    - Version: This area stores the firmware version, corresponding to VERSION in the *custom_config.h*.
    - Pattern: This area stores a fixed value 0x4744.

2.4.2 NVDS

NVDS is a lightweight logical data storage system based on Flash HAL. NVDS is located in the Flash memory and data in it will not be lost in power-off state. By default, NVDS uses the last two sectors of the Flash memory. You can also configure the number of Flash sectors to be occupied. In NVDS, the last sector is for defragmentation, and the other sector(s) for data storage.

NVDS is an ideal choice to store small data blocks, for example, application configuration parameters, calibration data, states, and user information. Bluetooth LE Stack stores parameters such as device binding parameters in NVDS.

NVDS features:

- Each storage item (TAG) has a unique TAG ID for identification. User applications can read and change data according to TAG IDs, regardless of physical storage addresses.
- It is optimized based on medium characteristics of Flash memory and supports data check, word alignment, defragmentation, and erase/write balance.
- The size and start address of NVDS are configurable. NVDS can be in several Flash sectors as configured. Make sure the start address of NVDS is 4 KB aligned.

Note:

- You can configure the start address and size of the NVDS area by adding the NVDS_START_ADDR macro and modifying the NVDS_NUM_SECTOR macro respectively in *custom_config.h*. NVDS_NUM_SECTOR has a default value of 1, which will be automatically increased by 1 during NVDS initialization. That is, NVDS occupies two Flash sectors.
- Bluetooth LE Stack and the application share the same NVDS storage area. However, TAG ID namespace is divided into different categories. You can only use the TAG ID name category assigned to an application.
    - Applications have to use NV_TAG_APP(idx) to obtain the TAG ID of application data. The TAG ID is used as an NVDS API parameter.
    - Applications cannot use idx as the NVDS API parameter directly. The idx value ranges from 0x4000 to 0x7FFF.
- Before running an application for the first time, you can use GProgrammer to write the initial TAG ID value used by Bluetooth LE Stack and the application to NVDS.
- If you specify an NVDS area, instead of using the default NVDS area in the GR533x SDK, make sure the start address of the NVDS area configured in GProgrammer is 4 KB aligned.

Data stored in NVDS is in the format below.

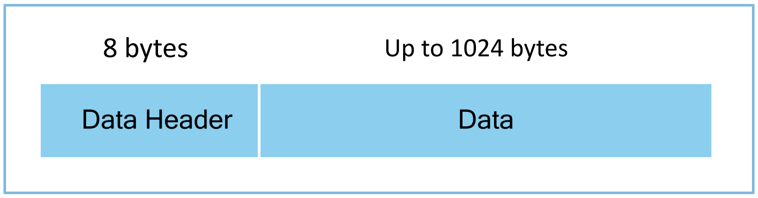


Figure 2-6 Data format in NVDS

Details of data header are described below.

Table 2-1 Data header format

Byte	Name	Description
0–1	tag	Data tag
2–3	len	Data length
4–4	checksum	Checksum of data header
5–5	value_cs	Checksum of data
6–7	reserved	Reserved bits

GR533x SDK provides the following NVDS APIs to allow developers to manipulate non-volatile data in Flash.

Table 2-2 NVDS APIs

Function Prototype	Description
uint8_t nvds_init(uint32_t start_addr, uint8_t sectors)	Initialize the Flash sectors used by NVDS.
uint8_t nvds_get(NvdsTag_t tag, uint16_t *p_len, uint8_t *p_buf)	Read data according to TAG IDs from NVDS.
uint8_t nvds_put(NvdsTag_t tag, uint16_t len, const uint8_t *p_buf)	Write data to NVDS and mark the data with TAG IDs. You need to create a TAG ID when writing data for the first time.
uint8_t nvds_del(NvdsTag_t tag)	Remove the corresponding data of a TAG ID in NVDS.
uint16_t nvds_tag_length(NvdsTag_t tag)	Obtain the data length of a specified TAG ID.
uint8_t nvds_drv_func_replace(nvds_drv_func_t *p_nvds_drv_func)	Replace the APIs that can directly control Flash.
uint8_t nvds_func_replace(nvds_func_t *p_nvds_func)	Replace the APIs that control NVDS.
void nvds_retention_size(uint8_t bond_dev_num)	Reserve space for device bonding. The space reserved depends on the number of devices to be bonded.

Note:

For details of NVDS APIs, refer to the NVDS header file (in `SDK_Folder\components\sdk\gr533x_nvds.h`).

2.5 RAM Mapping

The RAM start address is 0x2000_0000, and it comprises six RAM blocks, each with a size of 16 KB, totaling 96 KB. Each RAM block can be independently powered on or off by software.

The 96 KB RAM layout is shown below.

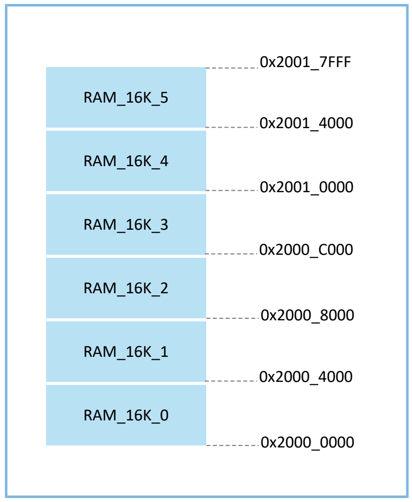


Figure 2-7 96 KB RAM layout

Applications run in Execute in Place (XIP) mode. User applications are stored in on-chip Flash, and applications use the same space for running and loading. When the system is powered on, it fetches and executes commands from Flash directly through the Cache Controller.

2.5.1 Typical RAM Layout

The typical RAM layout with Bluetooth LE projects in running is shown below. Developers are able to modify the RAM layout based on product needs.

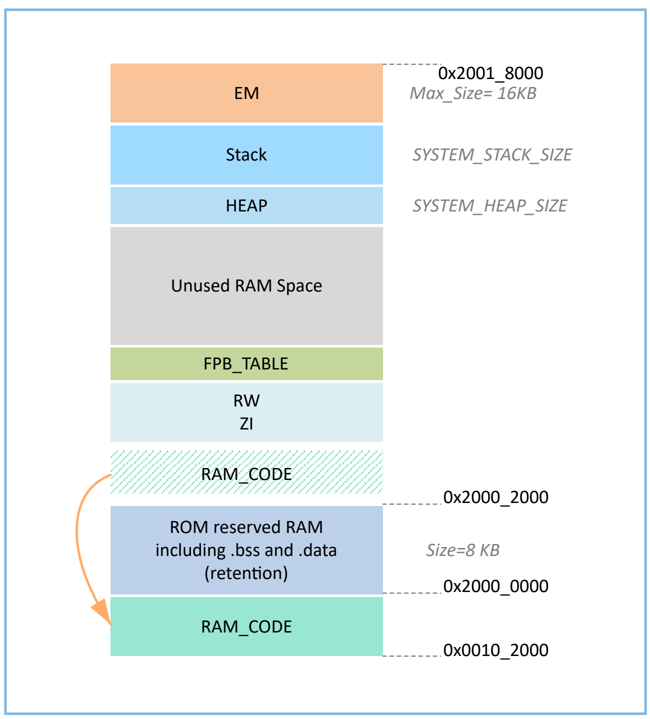


Figure 2-8 RAM layout in XIP mode (with Bluetooth LE projects)

- RAM_CODE saves code that is executed in RAM. To boost the efficiency in execution, it is recommended to define this region in the Aliasing memory (at physical address 0x00100000).
- EM is used by the Bluetooth LE core. It is managed together with SRAM used by the MCU, located at the highest address space of SRAM. EM size is determined by the Bluetooth service volume configured in *custom_config.h*. If no Bluetooth LE service is included in the project, the value of the EM_BUFF_ENABLE macro in *custom_config.h* can be set to 0.
- Stack stores the task call stack. In peripheral projects without Bluetooth LE services, Stack is defined at the highest address of RAM. In projects with Bluetooth LE services, Stack is defined after the address of EM. The Stack size is defined by the SYSTEM_STACK_SIZE macro. You need to determine the size according to the function call depth and the consumption of the call stack in the project.

2.5.2 RAM Power Management

Each RAM block has three power modes: Full Power, Retention Power, and Power Off.

- Full Power: The system is in active state; MCU is permitted to read from and write to RAM blocks.
- Retention Power: The system is in sleep state; data in RAM blocks does not get lost and is ready for use by the system when it switches from sleep state to active state.
- Power off: The system is in power-off state; RAM blocks will be powered off and the data in the blocks will get lost. Therefore, you need to save the data before the system is powered off.

By default, the PMU in the GR533x enables all RAM power sources when the system starts. The GR533x SDK also provides a complete set of RAM power management APIs. You can configure the power state of RAM blocks based on application needs.

By default, the system enables automatic RAM power management mode during boot: It automatically implements power mode control of RAM blocks according to RAM usage of applications. The configuration rules are provided as follows:

- When the system is in active state, set the unused RAM blocks to **Power off** mode, and RAM blocks to be used to **Full Power** mode.
- When the system is in sleep state, set the unused RAM blocks to **Power off** mode, and RAM blocks to be used to **Retention Power** mode.

Recommended RAM configurations in practice are described below:

- In Bluetooth LE applications, the first 8 KB of RAM_16K_0 are reserved for Bootloader and Bluetooth LE Stack only, not available for applications. When the system is in active state, RAM_16K_0 shall be in **Full Power** mode; when the system is in sleep state, RAM_16K_0 shall be in **Retention Power** mode. Non-Bluetooth LE MCU applications can use this RAM block.
- Purposes of RAM_16K_1 and subsequent RAM blocks are defined by applications. The GR533x RAM has been reasonably arranged according to execution efficiency and SRAM utilization. You can also re-configure it according to actual application requirements. The power mode of these RAM blocks can be enabled, or be controlled by applications.

Note:

- An MCU access is permitted only when a RAM block is in **Full Power** mode.
- Details about RAM power management APIs are in `SDK_Folder\components\sdk\platform_sdk.h`.

2.6 SDK Directory Structure

The folder directory structure of GR533x SDK is shown as follows.

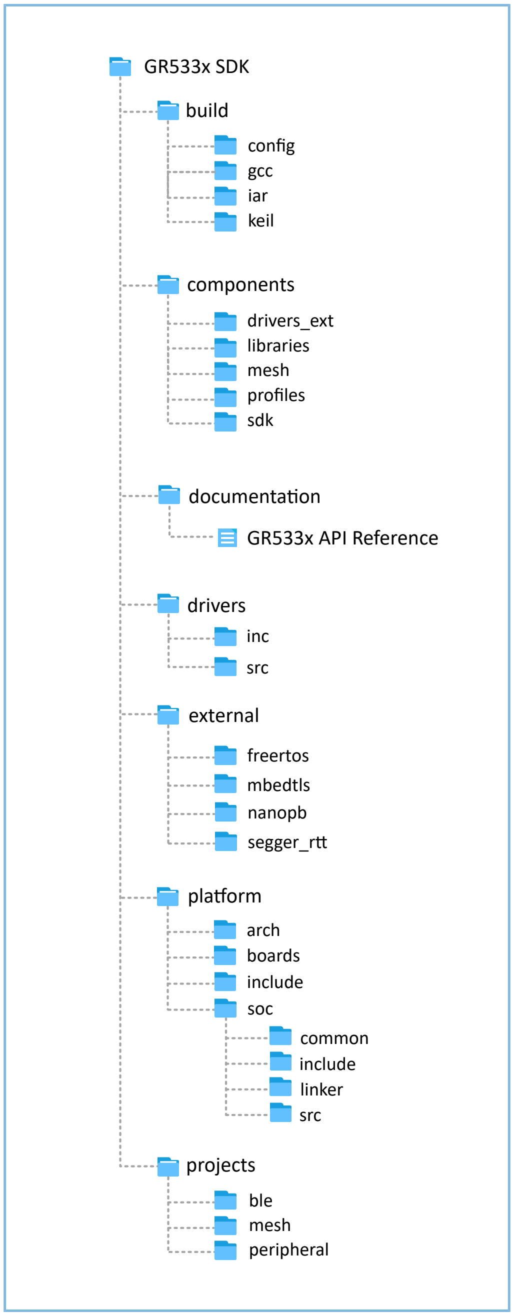


Figure 2-9 GR533x SDK directory structure

Detailed description of folders in GR533x SDK is shown below.

Table 2-3 GR533x SDK folders

Folder	Description
build\config	Project configuration directory that stores the *custom_config.h* template file. This file is used to configure project parameters.
build\gcc	GCC tools
build\keil	Keil MDK tools
build\iar	IAR tools
components\drivers_ext	Drivers of third-party components on the development board
components\libraries	Libraries provided in GR533x SDK
components\profiles	Source files of GATT Services/Service Clients implementation examples
components\mesh	Source files to implement Mesh applications
components\sdk	API header files
documentation	*GR533x API Reference Manual*
drivers\inc	Driver API header files which are easy to use for application developers
drivers\src	Driver API source code which is easy to use for application developers
external\freertos	Source code of FreeRTOS (a third-party program)
external\mbedtls	Source code of Mbed TLS (a third-party program)
external\nanopb	Source code of Nanopb (a third-party program)
external\segger_rtt	Source code of SEGGER RTT (a third-party program)
platform\arch	Toolchain files of CMSIS
platform\boards	Source files for initializing GR533x Starter Kit Board. The files are used for initializing basic peripherals at board level.
platform\include	Common header files related to platform
platform\soc\common	Public source files compatible to GR533x SoCs. The files include *gr_interrupt.c*, *gr_platform.c*, and *gr_system.c*.
platform\soc\linker	Symbol table files and library files for the linker
platform\soc\include	Common header files closely related to underlying driver configurations such as registers and clock configurations
platform\soc\src	*gr_soc.c* which is about initialization processes closely related to SoC implementation. The processes include initializing Flash and NVDS, configuring crystal, and calibrating PMU.
projects\ble	Bluetooth LE application project examples, such as Heart Rate Sensor and Proximity Reporter
projects\mesh	Mesh project examples
projects\peripheral	Peripheral project examples of a GR533x SoC

2.7 Tools

Developers can use the following tools to develop and debug GR533x applications.

Table 2-4 Development/Debugging tools

Name	Description	Recommended Version
GProgrammer	A firmware programming tool that supports functionalities such as firmware download, Flash read/write, and eFuse download. Available on both Windows and Linux platforms.	V1.2.41 and later
GRUart	A serial port debugging tool. Available on Windows platform only.	V2.1 and later
GRDirect Test Mode Tool	An RF test tool that controls the Device Under Test (DUT) to perform Direct Test Mode (DTM) tests by delivering HCI commands. Available on Windows platform only.	V1.5.2 and later
GRPLT Lite Config Tool	A mass production configuration tool for the offline mass production programming board that supports batch firmware download, resource download, parameter configuration, and functionality testing. Available on Windows platform only.	V1.1.4 and later
GRToolbox	A mobile APP that enables users to scan for Bluetooth devices, set connection parameters, demonstrate standard profiles, and debug profiles/services from Goodix Bluetooth LE platform. Both Android and iOS versions are supported.	V2.16 and later

3 Bootloader

The GR533x code runs in XIP mode. When the system is powered on, the Bootloader first reads the system boot configuration information from SCA, then performs application firmware integrity check and initialize Cache and XIP controller accordingly, and finally jumps to the code running space to run firmware.

The application boot procedures of the GR533x SDK are shown as follows.

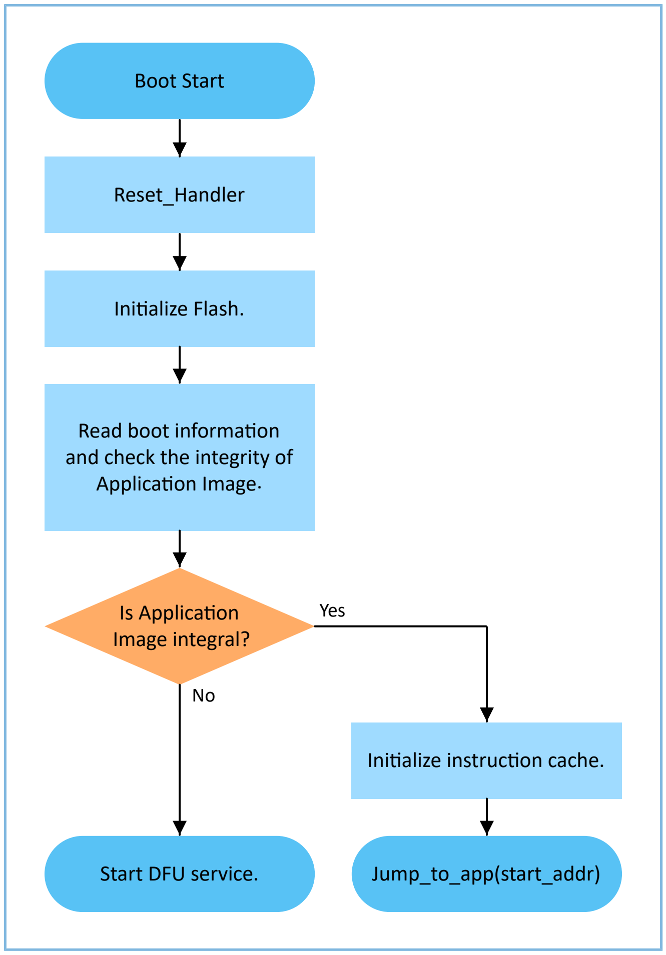


Figure 3-1 Application boot procedures of the GR533x SDK

1. When the device is powered on, CPU jumps to 0x0000_0000 to extract the extended stack pointer (ESP) of C-Stack and assigns the value to the main stack pointer (MSP). Then, the program counter (PC) jumps to 0x0000_004, and executes Reset_Handler in ROM to enter the Bootloader.
2. Bootloader initializes Flash.
3. Bootloader reads boot information from SCA in Flash and checks application firmware integrity.
4. If the integrity check fails, the Bootloader enters J-Link DFU mode. You can update application firmware in Flash with GProgrammer and J-Link.
5. If the integrity check passes, the Bootloader jumps to the run address of the application firmware in Flash to execute the code after completing the XIP configuration.

4 Development and Debugging with SDK in Keil

This chapter introduces how to build, compile, download, and debug Bluetooth LE applications with the SDK in Keil.

4.1 Installing Keil MDK

Keil MDK-ARM IDE (Keil) is an Integrated Development Environment (IDE) provided by ARM® for Cortex® and ARM devices. You can download and install the Keil installation package from the Keil official website https://www.keil.com/demo/eval/arm.htm. For the GR533x SDK, Keil V5.20 or a later version shall be installed.

Note:

For more information about how to use Keil MDK-ARM IDE, refer to online manuals provided by ARM: https://www.keil.com/support/man_arm.htm.

The main interface of Keil is as shown below.

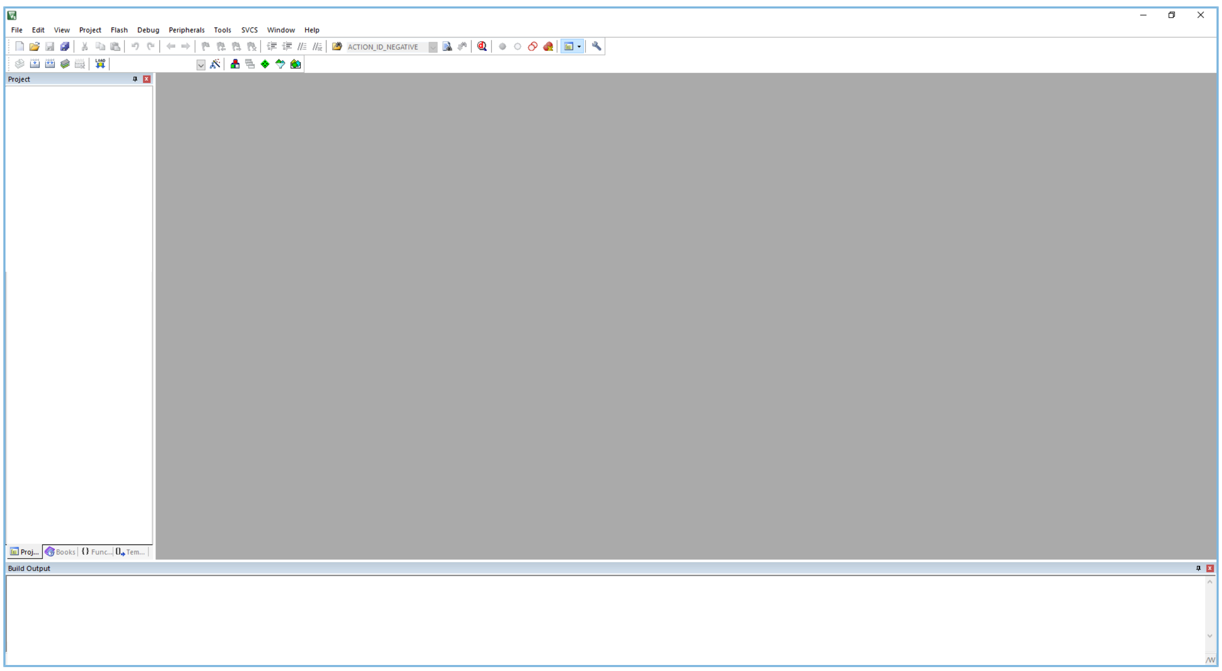


Figure 4-1 Keil interface

Frequently used function buttons of Keil are listed below:

Table 4-1 Frequently used function buttons of Keil

Button	Description
	Options for Target
	Start/Stop Debug Session
	Download
	Build

4.2 Installing SDK

GR533x SDK is in a .zip file. You can access the details after extracting the file.

Note:

- SDK_Folder is the root directory of GR533x SDK.
- Keil_Folder is the root directory of Keil.

4.3 Building a Bluetooth LE Application

This section introduces how to quickly build a custom Bluetooth LE application with Keil and GR533x SDK.

4.3.1 Preparing ble_app_example

This section elaborates on how to create a project based on the template project provided in GR533x SDK.

Open `SDK_Folder\projects\ble\ble_peripheral\`, copy ble_app_template to the current directory, and rename it as **ble_app_example**. Change the base name of *.uvoptx* and *.uvprojx* files in `ble_app_example\Keil_5` to **ble_app_example**.

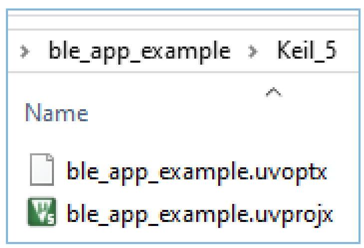


Figure 4-2 ble_app_example folder

Double-click *ble_app_example.uvprojx* to open the project example in Keil. Click , and the **Options for Target 'GRxx_Soc'** window opens. Choose the **Output** tab, and type **ble_app_example** in the **Name of Executable** field, to name the output file as **ble_app_example**.

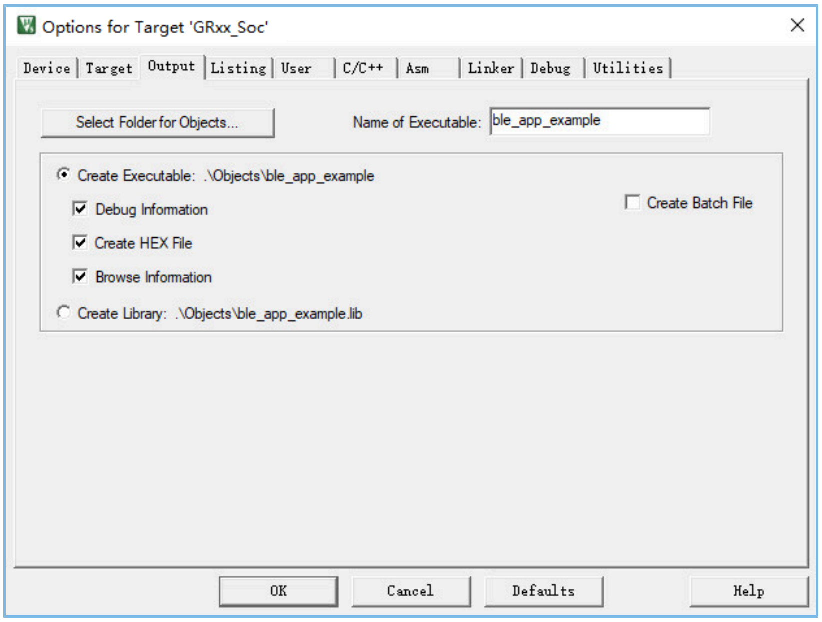


Figure 4-3 Modifications to **Name of Executable**

All groups of the ble_app_example project are available in the **Project** window of Keil.

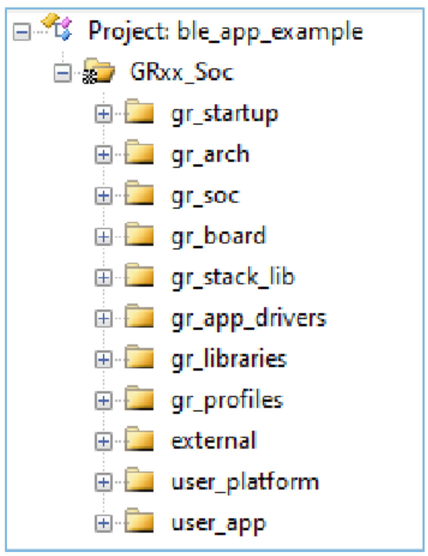


Figure 4-4 ble_app_example groups

Groups of the ble_app_example project are mainly in two categories: SDK groups and User groups.

- SDK groups

  The SDK groups include gr_startup, gr_arch, gr_soc, gr_board, gr_stack_lib, gr_app_drivers, gr_libraries, gr_profiles, and external.

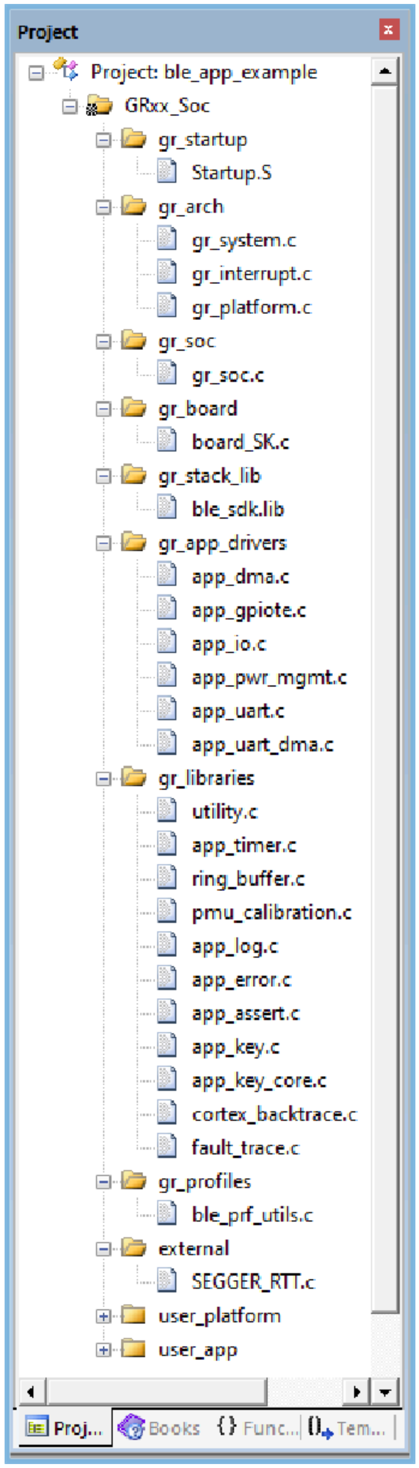


Figure 4-5 SDK groups

Source files in the SDK groups are not required to be modified. Group descriptions are provided below:

Table 4-2 SDK groups

SDK Group Name	Description
gr_startup	System boot file
gr_arch	Initialization configuration files and system interrupt API implementation files for System Core and PMU
gr_soc	*gr_soc.c* which is used for initializing and calibrating modules such as Clock, PMU, and Vector before entering the main() function
gr_board	Board-level description file which is used for implementing components such as log, key, and LED
gr_stack_lib	A SDK .lib file
gr_app_drivers	Driver API source files which are easy to use for application developers. You can add related application drivers on demand.
gr_libraries	Open source files of common assistant software modules and peripheral drivers provided in the SDK
gr_profiles	Source files of GATT Services/Service Clients. You can add necessary GATT source files for projects on demand.
external	Source files for third-party programs, such as FreeRTOS and SEGGER RTT. You can add third-party programs on demand.

- User groups

  User groups include user_platform and user_app.

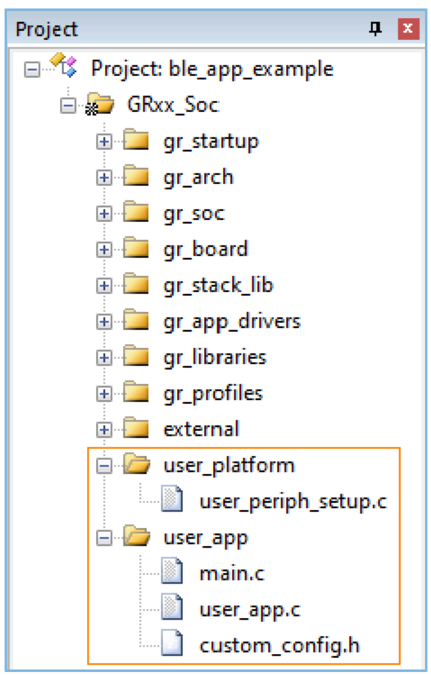


Figure 4-6 User groups

Functionalities for source files in User groups need to be implemented by developers. Group descriptions are provided below:

Table 4-3 User groups

User Group Name	Description
user_platform	Software and hardware resource setting and application initialization; you need to execute corresponding APIs on demand.
user_app	main() function entries and other source files created by developers, which are used to configure runtime parameters of Bluetooth LE Stack and execute event handlers of GATT Services/Service Clients

4.3.2 Configuring a Project

You should configure corresponding project options according to product characteristics, including NVDS, code running mode, memory layout, After Build, and other configuration items.

4.3.2.1 Configuring *custom_config.h*

custom_config.h is used to configure parameters of application projects. Developers can directly modify the configurations in the file or configure parameters in the **Configuration Wizard** interface of Keil.

Tip:

custom_config.h of each application example project is in `Src\config` under project directory.

- Modify the configurations in *custom_config.h*.

  GR533x SDK provides a template configuration file *custom_config.h* (in `SDK_Folder\build\config\custom_config.h`). You can directly modify the template file to configure parameters for application projects.

Table 4-4 Parameters in *custom_config.h*

Macro	Description
SOC_GR533X	Define the SoC version number.
CHIP_TYPE	Specify the SoC model. ◦ 1: GR5331AENI ◦ 2: GR5331CENI ◦ 3: GR5332AENE ◦ 4: GR5331CENI **Note**: During project compilation, configure this macro according to the SoC model in use.
SYS_FAULT_TRACE_ENABLE	Enable/Disable trace info printing. If printing is enabled, the trace info is printed when a HardFault occurs. ◦ 0: Disable ◦ 1: Enable

Macro	Description
ENABLE_BACKTRACE_FEA	Enable/Disable the stack backtrace functionality. ◦ 0: Disable ◦ 1: Enable
APP_LOG_ENABLE	Enable/Disable the APP LOG module. ◦ 0: Disable ◦ 1: Enable
APP_LOG_STORE_ENABLE	Enable/Disable the APP LOG STORE module. ◦ 0: Disable ◦ 1: Enable
APP_LOG_PORT	Set the output mode of APP LOG module. ◦ 0: UART ◦ 1: J-Link RTT ◦ 2: ARM ITM **Note:** By default, this macro is removed from *custom_config.h*. It can be redefined by developers on demand.
PLATFORM_SDK_INIT_ENABLE	Enable/Disable platform initialization. ◦ 0: Enable ◦ 1: Disable
PMU_CALIBRATION_ENABLE	Enable/Disable PMU calibration. When PMU calibration is enabled, the system monitors temperature and voltage automatically with adaptive adjustment. It is recommended to enable macro by default. ◦ 0: Enable ◦ 1: Disable **Note:** PMU calibration shall be enabled in high/low temperature scenarios.
NVDS_START_ADDR	Start address of NVDS in Flash. **Note**: By default, this macro is removed from *custom_config.h*. If you need to reconfigure the NVDS address, enable the macro and set the address as needed (4-KB alignment is compulsory).
NVDS_NUM_SECTOR	Number of Flash sectors for NVDS
SYSTEM_STACK_SIZE	Size of Call Stack required by applications. The default value is 8 KB.

Macro	Description
	You can set the value as needed. **Note:** After compilation of ble_app_example, the Maximum Stack Usage is provided in `Keil_5\Objects\ble_app_example.htm` for reference.
SYSTEM_HEAP_SIZE	Size of Heap required by applications. The default value is 0 KB. You can set the value as needed.
CHIP_VER	Version of the SoC that the firmware runs on; default: 0x5332
APP_CODE_LOAD_ADDR*	Start address of the application storage area **Note:** This address shall be within the Flash address range.
APP_CODE_RUN_ADDR*	Start address of the application running space **Note:** The value shall be the same as APP_CODE_LOAD_ADDR, and applications run in XIP mode.
SYSTEM_CLOCK*	Set the system clock frequency. ◦ 0: 64 MHz ◦ 1: 32 MHz ◦ 2: 16 MHz (XO) ◦ 3: 16 MHz ◦ 4: 8 MHz ◦ 5: 2 MHz
SYSTEM_POWER_MODE	Set the system power supply mode. ◦ 0: Supplied by DC-DC ◦ 1: Supplied by SYS_LDO
CFG_LF_ACCURACY_PPM	Bluetooth LE low-frequency sleep clock accuracy. The value shall range from 1 to 500 (unit: ppm).
CFG_LPCLK_INTERNAL_EN	Enable/Disable the OSC inside an SoC as the Bluetooth LE low-frequency sleep clock. If the OSC clock is enabled, CFG_LF_ACCURACY_PPM will be set to 500 ppm by force. ◦ 0: Disable ◦ 1: Enable
BOOT_LONG_TIME*	Set 1-second delay (during SoC boot before implementing the second half Bootloader). ◦ 0: No delay ◦ 1: Delay for 1 second.
BOOT_CHECK_IMAGE	Determine whether to check the image during cold boot in XIP mode. ◦ 0: Do not check.

Macro	Description
	◦ 1: Check.
BLE_SUPPORT	Support Bluetooth LE or not. ◦ MCU only, no Bluetooth LE supported ◦ Support Bluetooth LE.
DTM_TEST_ENABLE	Enable/Disable DTM test. ◦ 0: Disable ◦ 1: Enable
RF_TX_PA_SELECT	Select an RF power amplifier. ◦ 1: SPA (for GR533x; supported TX power: -20 dBm to 6 dBm for GR5331 and -20 dBm to 5 dBm for GR5332) ◦ 2: UPA (for GR5331 only; supported TX power: -15 dBm to 2 dBm) ◦ 3: HPA (for GR5332 only; supported TX power: -10 dBm to 15 dBm)
CFG_MATCHING_CIRCUIT	Matching network circuit configuration.
CFG_PATCH_ENABLE	Enable/Disable patch. ◦ 0: Disable ◦ 1: Enable
CFG_MAX_PRFS	Maximum number of supported GATT Profiles/Services. You can set the value on demand. A larger value means more RAM space will be occupied. Range: 1–64
CFG_MAX_BOND_DEVS	Maximum number of devices that can be bonded; default: 4
CFG_MAX_CONNECTIONS	Maximum number of devices that can be connected; the number shall be no greater than 10. You can set the value on demand. A larger value means more RAM space will be occupied by Bluetooth LE Stack Heaps. The size of Bluetooth LE Stack Heaps is defined by the following four macros in *flash_scatter_config.h*: ◦ ENV_HEAP_SIZE ◦ ATT_DB_HEAP_SIZE ◦ KE_MSG_HEAP_SIZE ◦ NON_RET_HEAP_SIZE **Note:** The above four macros cannot be changed by developers.
CFG_MAX_ADVS	Maximum number of supported Bluetooth LE legacy advertising and extended advertising Range: 0–5

<table>
<tr><th>Macro</th><th>Description</th></tr>
<tr><td></td><td>Note:
The maximum number of supported Bluetooth LE legacy advertising and extended advertising shall be no greater than 5.</td></tr>
<tr><td>CFG_MAX_SCAN</td><td>Maximum number of supported Bluetooth LE device used for scanning
Range: 0–1</td></tr>
<tr><td>CFG_MUL_LINK_WITH_SAME_DEV</td><td>Support multi-link functionality for a single device or not.
◦ 0: No
◦ 1: Yes</td></tr>
<tr><td>CFG_BT_BREDR</td><td>Support generating Bluetooth Classic link keys through the LE link or not.
◦ 0: No
◦ 1: Yes</td></tr>
<tr><td>CFG_CAR_KEY_SUPPORT</td><td>Support car key applications or not.
◦ 0: No
◦ 1: Yes</td></tr>
<tr><td>CFG_CONTROLLER_ONLY</td><td>Support Bluetooth LE controller (for external host or HCI UART transmission) only or not.
◦ 0: Support Bluetooth LE controller and host.
◦ 1: Support Bluetooth LE controller only.</td></tr>
<tr><td>CFG_MASTER_SUPPORT</td><td>Support master role or not.
◦ 0: No
◦ 1: Yes</td></tr>
<tr><td>CFG_SLAVE_SUPPORT</td><td>Support slave role or not.
◦ 0: No
◦ 1: Yes</td></tr>
<tr><td>CFG_LEGACY_PAIR_SUPPORT</td><td>Support legacy pairing or not.
◦ 0: No
◦ 1: Yes</td></tr>
<tr><td>CFG_SC_PAIR_SUPPORT</td><td>Support secure pairing or not.
◦ 0: No
◦ 1: Yes</td></tr>
<tr><td>CFG_COC_SUPPORT</td><td>Support Connection-oriented Channel (COC) or not.
◦ 0: No
◦ 1: Yes</td></tr>
<tr><td>CFG_GATTS_SUPPORT</td><td>Support GATT Server or not.</td></tr>
</table>

Macro	Description
	◦ 0: No ◦ 1: Yes
CFG_GATTC_SUPPORT	Support GATT Client or not. ◦ 0: No ◦ 1: Yes
CFG_CONN_AOA_AOD_SUPPORT	Support connection-based AoA/AoD or not. ◦ 0: No ◦ 1: Yes **Note**: The macro is configured to a fixed value of '0'.
CFG_CONNLESS_AOA_AOD_SUPPORT	Support connectionless AoA/AoD or not. ◦ 0: No ◦ 1: Yes **Note**: The macro is configured to a fixed value of '0'.
CFG_RANGING_SUPPORT	Support ranging or not. ◦ 0: No ◦ 1: Yes **Note**: The macro is configured to a fixed value of '0'.
CFG_MESH_SUPPORT	Support Mesh or not. ◦ 0: No ◦ 1: Yes
CFG_SNIFFER_SUPPORT	Support the RSSI listening functionality or not. ◦ 0: No ◦ 1: Yes **Note**: This functionality will be available in GR533x SDK in later versions.
SECURITY_CFG_VAL	Configure the algorithm security level. ◦ 0: Enable Level 1 algorithm. ◦ 1: Enable Level 2 algorithm.

Note:

*: Macros marked with an asterisk (*) in the table above are used to initialize the BUILD_IN_APP_INFO structure which is defined at 0x200 in the firmware and is initialized with the macros in *custom_config.h*. When system boots, the Bootloader reads value from 0x200 and uses it as a boot parameter.

- Configure parameters in the **Configuration Wizard** interface.

  Comments in *custom_config.h* are compliant with Configuration Wizard Annotations of Keil, making it possible for developers to open *custom_config.h* in Keil and configure application project parameters in the **Configuration Wizard** interface of Keil.

Tip:

It is recommended to configure parameters in the **Configuration Wizard** interface, to prevent inputting invalid parameters.

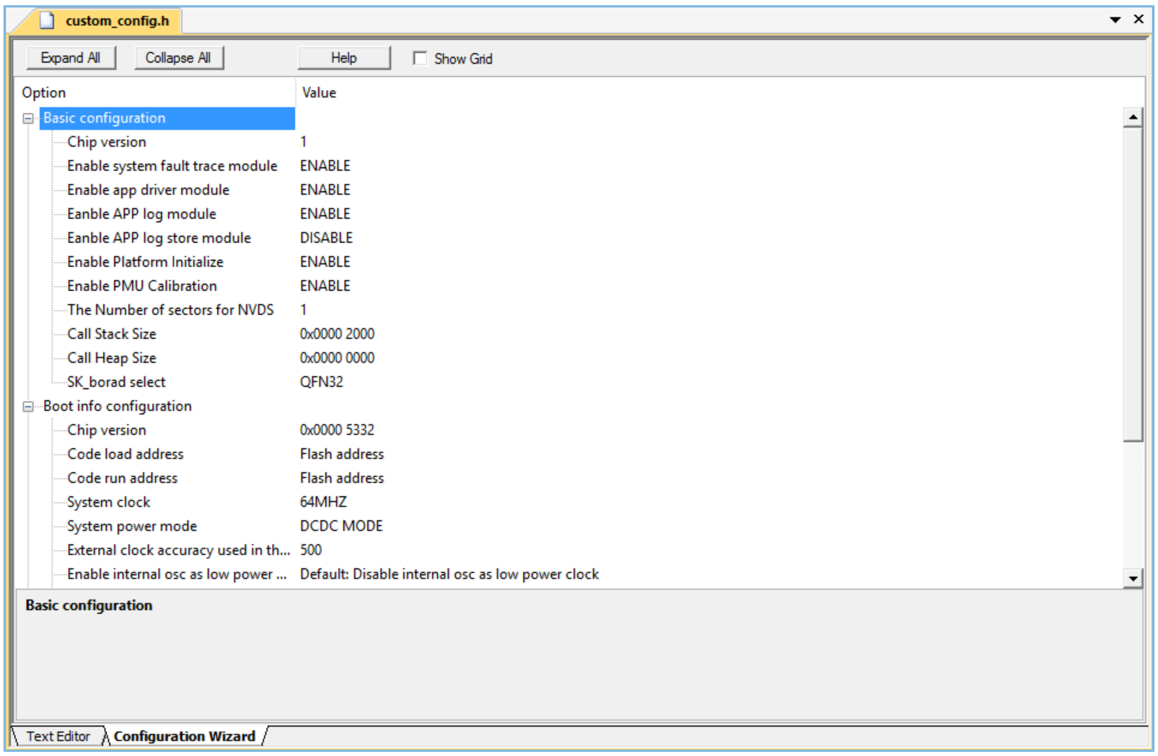


Figure 4-7 *custom_config.h* in the **Configuration Wizard** interface

4.3.2.2 Configuring Memory Layout

In a Keil project, the memory area for the linker is defined in Scatter (.sct) files. The GR533x SDK provides an example Scatter file (`SDK_Folder\platform\soc\linker\keil\flash_scatter_common.sct`) to help developers quickly configure memory layout. The macros used by *flash_scatter_common.sct* are defined in *flash_scatter_config.h*.

Note:

In Keil, `__attribute__((section("name")))` can be used to define a function or a variable in a specific memory segment, in which **name** can be customized by developers. The scatter (*.sct*) file defines the location for customized fields. For example, to define the Zero-Initialized (ZI) data of applications in the segment named as **.bss.app**, you can set **attribute** to **attribute ((section(".bss.app ")))**.

You can follow the steps below to configure the memory layout:

1. Click (**Options for Target**) on the Keil toolbar and open the **Options for Target 'GRxx_Soc'** dialog box. Select the **Linker** tab.

2. On the **Scatter File** bar of the **Linker** tab, click **...** to browse and select the *flash_scatter_common.sct* file in SDK_ `Folder\platform\soc\linker\keil`. You can also copy the scatter (.sct) file and the configuration (.h) file to the ble_app_example project directory and then select the scatter file.

Note:

- `#! armcc -E –I` in *flash_scatter_common.sct* specifies the directory of the header file on which *flash_scatter_common.sct* depends. A wrong path results in a linker error.
- In *flash_scatter_common.sct* of the GR533x SDK, you can use the macro definition EM_BUFF_ENABLE in *custom_config.h* to determine whether it is necessary to configure EM for Bluetooth LE in the end area of SRAM. You need to define EM_BUFF_ENABLE based on whether the project includes Bluetooth LE services.

3. Click **Edit...** to open the .sct file, and modify corresponding code based on practical product memory layout.

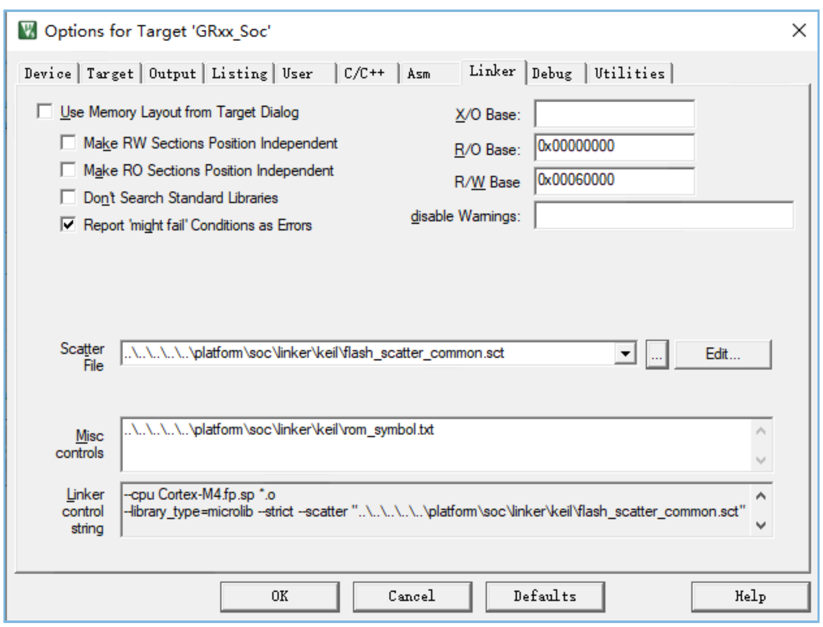


Figure 4-8 Configuration of scatter file

4. Click **OK** to save the settings.

4.3.2.3 Configuring After Build

After Build in Keil can specify the command to be executed after a project is built.

By default, After Build has been configured for the ble_app_template project. Therefore, ble_app_example, which is based on ble_app_template, does not require manual configuration of After Build.

If you build a project in Keil, follow the steps below to configure After Build:

1. Click (**Options for Target**) on the Keil toolbar and open the **Options for Target 'GRxx_Soc'** dialog box. Select the **User** tab.
2. From the options expanded from **After Build/Rebuild**, select **Run #1**, and type **fromelf.exe --text -c --output Listings\@L.s Objects\@L.axf** in the corresponding **User Command** field. This step helps you utilize Keil fromelf to generate a compiling file based on the selected .axf file.
3. From the options expanded from **After Build/Rebuild**, select **Run #2**, and type **fromelf.exe --bin --output Listings \@L.bin Objects\@L.axf** in the corresponding **User Command** field. This step helps you utilize Keil fromelf to generate a compiling file based on the selected .axf file.
4. Click **OK** to save the settings.

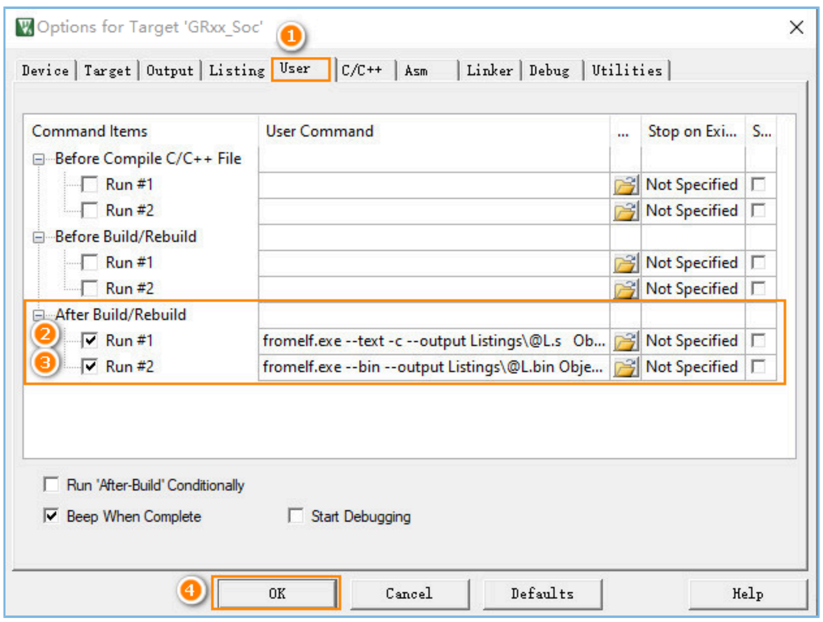


Figure 4-9 Configuration of After Build

4.3.3 Adding User Code

You can modify corresponding code in ble_app_example on demand.

4.3.3.1 Modifying the main() Function

Code of a typical *main.c* file is provided as follows:

```
/**@brief Stack global variables for Bluetooth protocol stack. */
 STACK_HEAP_INIT(heaps_table);
…
```

```
int main (void)
{
    // Initialize user peripherals.
    app_periph_init();

    // Initialize ble stack.
    ble_stack_init(ble_evt_handler, &heaps_table);

    // loop
    while (1)
    {
        app_log_flush();
        pwr_mgmt_schedule();
    }
}
```

- `STACK_HEAP_INIT(heaps_table)` defines seven global arrays as Heaps for Bluetooth LE Stack. Do not modify the definition; otherwise, Bluetooth LE Stack may not work properly. The Heap size is determined by the Bluetooth LE service volume in "Section 4.3.2.1 Configuring custom_config.h".
- `app_periph_init()` is used to initialize peripherals. In development and debugging phases, SYS_SET_BD_ADDR in this function can be used to set a temporary Public Address; pwr_mgmt_mode_set() sets the MCU operation mode (SLEEP/IDLE/ACTIVE) during automatic power management; app_periph_init() is implemented in *user_periph_setup.c*, and the example code is as follows.

```
/**@brief Bluetooth device address. */
static const uint8_t s_bd_addr[SYS_BD_ADDR_LEN] = {0x11, 0x11, 0x11, 0x11,0x11, 0x11};
…
void app_periph_init(void)
{
    SYS_SET_BD_ADDR(s_bd_addr);
    board_init();
    pwr_mgmt_mode_set(PMR_MGMT_SLEEP_MODE);
}
```

- Add main loop code of applications to `while(1) { }`, for example, code to handle external input and update GUI.
- To use the APP LOG module, call `app_log_flush()` in the main loop, to ensure logs are output completely before the system enters sleep state. For more information about the APP LOG module, refer to "Section 4.6.3 Outputting Debug Logs".
- Call `pwr_mgmt_shcedule()` to implement automatic power management to reduce system power consumption.

4.3.3.2 Implementing Bluetooth LE Service Logics

Bluetooth LE service logics of applications are driven by a number of Bluetooth LE events which are defined in GR533x SDK. Therefore, applications need to implement the corresponding event handlers in GR533x SDK to obtain operation results or state change notifications of Bluetooth LE Stack. The event handlers are called in the interrupt context of Bluetooth LE SDK IRQ. Therefore, do not perform long-running operations in handlers, for example, blocking function call and infinite loop; otherwise, the system is blocked, causing Bluetooth LE Stack and the SDK Bluetooth LE module unable to run in a normal timing.

Bluetooth LE events fall into eight categories: Common, GAP Management, GAP Connection Control, Security Manager, L2CAP, GATT Common, GATT Server, and GATT Client.

All Bluetooth LE events supported by GR533x SDK are listed below.

Table 4-5 Bluetooth LE events

Event Type	Event Name	Description
Common	BLE_COMMON_EVT_STACK_INIT	Bluetooth LE Stack init complete event
GAP Management	BLE_GAPM_EVT_CH_MAP_SET	Channel Map Set complete event
	BLE_GAPM_EVT_WHITELIST_SET	Whitelist Set complete event
	BLE_GAPM_EVT_PER_ADV_LIST_SET	Periodic Advertising List Set complete event
	BLE_GAPM_EVT_PRIVACY_MODE_SET	Privacy Mode for Peer Device Set complete event
	BLE_GAPM_EVT_LEPSM_REGISTER	LEPSM Register complete event
	BLE_GAPM_EVT_LEPSM_UNREGISTER	LEPSM Unregister complete event
	BLE_GAPM_EVT_DEV_INFO_GOT	Device Info Get event
	BLE_GAPM_EVT_ADV_START	Advertising Start complete event
	BLE_GAPM_EVT_ADV_STOP	Advertising Stop complete event
	BLE_GAPM_EVT_SCAN_REQUEST	Scan Request event
	BLE_GAPM_EVT_ADV_DATA_UPDATE	Advertising Data update event
	BLE_GAPM_EVT_SCAN_START	Scan Start complete event
	BLE_GAPM_EVT_SCAN_STOP	Scan Stop complete event
	BLE_GAPM_EVT_ADV_REPORT	Advertising Report event
	BLE_GAPM_EVT_SYNC_ESTABLISH	Periodic Advertising Synchronization Establish event
	BLE_GAPM_EVT_SYNC_STOP	Periodic Advertising Synchronization Stop event
	BLE_GAPM_EVT_SYNC_LOST	Periodic Advertising Synchronization Lost event
	BLE_GAPM_EVT_READ_RSLV_ADDR	Read Resolvable Address event
GAP Connection Control	BLE_GAPC_EVT_PHY_UPDATED	PHY Update event
	BLE_GAPC_EVT_CONNECTED	Connected event
	BLE_GAPC_EVT_DISCONNECTED	Disconnected event
	BLE_GAPC_EVT_CONNECT_CANCEL	Connect Cancel event
	BLE_GAPC_EVT_AUTO_CONN_TIMEOUT	Auto Connect Timeout event
	BLE_GAPC_EVT_CONN_PARAM_UPDATED	Connect Parameter Updated event
	BLE_GAPC_EVT_CONN_PARAM_UPDATE_REQ	Connect Parameter Request event
	BLE_GAPC_EVT_PEER_NAME_GOT	Peer Name Get event
	BLE_GAPC_EVT_CONN_INFO_GOT	Connect Info Get event
	BLE_GAPC_EVT_PEER_INFO_GOT	Peer Info Get event
	BLE_GAPC_EVT_DATA_LENGTH_UPDATED	Data Length Updated event

Event Type	Event Name	Description
	BLE_GAPC_EVT_DEV_INFO_SET	Device Info Set event
	BLE_GAPC_EVT_CONNECT_IQ_REPORT	Connection IQ Report info event
	BLE_GAPC_EVT_CONNECTLESS_IQ_REPORT	Connectionless IQ Report info event
	BLE_GAPC_EVT_LOCAL_TX_POWER_READ	Local transmit power read indication info event
	BLE_GAPC_EVT_REMOTE_TX_POWER_READ	Remote transmit power read indication info event
	BLE_GAPC_EVT_TX_POWER_CHANGE_REPORT	Transmit power change reporting info event
	BLE_GAPC_EVT_PATH_LOSS_THRESHOLD_REPORT	Path loss threshold reporting info event
	BLE_GAPC_EVT_RANGING_IND	Ranging indication event
	BLE_GAPC_EVT_RANGING_SAMPLE_REPORT	Ranging sample report event
	BLE_GAPC_EVT_RANGING_CMP_IND	Ranging complete indication event
	BLE_GAPC_EVT_DFT_SUBRATE_SET	Default subrate param set complete event
	BLE_GAPC_EVT_SUBRATE_CHANGE_IND	Subrate change indication event
GATT Common	BLE_GATT_COMMON_EVT_MTU_EXCHANGE	MTU Exchange event
	BLE_GATT_COMMON_EVT_PRF_REGISTER	Service Register event
GATT Server	BLE_GATTS_EVT_READ_REQUEST	GATTS Read Request event
	BLE_GATTS_EVT_WRITE_REQUEST	GATTS Write Request event
	BLE_GATTS_EVT_PREP_WRITE_REQUEST	GATTS Prepare Write Request event
	BLE_GATTS_EVT_NTF_IND	GATTS Notify or Indicate Complete event
	BLE_GATTS_EVT_CCCD_RECOVERY	GATTS CCCD Recovery event
	BLE_GATTS_EVT_MULT_NTF	GATTS Multiple Notifications event
	BLE_GATTS_EVT_ENH_READ_REQUEST	GATTS Enhanced Read Request event
	BLE_GATTS_EVT_ENH_WRITE_REQUEST	GATTS Enhanced Write Request event
	BLE_GATTS_EVT_ENH_PREP_WRITE_REQUEST	GATTS Enhanced Prepare Write Request event
	BLE_GATTS_EVT_ENH_NTF_IND	GATTS Enhanced Notify or Indicate Complete event
	BLE_GATTS_EVT_ENH_CCCD_RECOVERY	GATTS Enhanced CCCD Recovery event
	BLE_GATTS_EVT_ENH_MULT_NTF	GATTS Enhanced Multiple Notifications event
GATT Client	BLE_GATTC_EVT_SRVC_BROWSE	GATTC Service Browse event
	BLE_GATTC_EVT_PRIMARY_SRVC_DISC	GATTC Primary Service Discovery event
	BLE_GATTC_EVT_INCLUDE_SRVC_DISC	GATTC Include Service Discovery event
	BLE_GATTC_EVT_CHAR_DISC	GATTC Characteristic Discovery event
	BLE_GATTC_EVT_CHAR_DESC_DISC	GATTC Characteristic Descriptor Discovery event
	BLE_GATTC_EVT_READ_RSP	GATTC Read Response event
	BLE_GATTC_EVT_WRITE_RSP	GATTC Write Response event
	BLE_GATTC_EVT_NTF_IND	GATTC Notify or Indicate Receive event

Event Type	Event Name	Description
	BLE_GATTC_EVT_CACHE_UPDATE	GATTC Cache Update event
	BLE_GATTC_EVT_ENH_SRVC_BROWSE	GATTC Enhanced Service Browse event
	BLE_GATTC_EVT_ENH_PRIMARY_SRVC_DISC	GATTC Enhanced Primary Service Discovery event
	BLE_GATTC_EVT_ENH_INCLUDE_SRVC_DISC	GATTC Enhanced Include Service Discovery event
	BLE_GATTC_EVT_ENH_CHAR_DISC	GATTC Enhanced Characteristic Discovery event
	BLE_GATTC_EVT_ENH_CHAR_DESC_DISC	GATTC Enhanced Characteristic Descriptor Discovery event
	BLE_GATTC_EVT_ENH_READ_RSP	GATTC Enhanced Read Response event
	BLE_GATTC_EVT_ENH_WRITE_RSP	GATTC Enhanced Write Response event
	BLE_GATTC_EVT_ENH_NTF_IND	GATTC Enhanced Notify or Indicate Receive event
Security Manager	BLE_SEC_EVT_LINK_ENC_REQUEST	Link Encrypted Request event
	BLE_SEC_EVT_LINK_ENCRYPTED	Link Encrypted event
	BLE_SEC_EVT_KEY_PRESS_NTF	Key Press event
	BLE_SEC_EVT_KEY_MISSING	Key Missing event
L2CAP	BLE_L2CAP_EVT_CONN_REQ	L2CAP Connect Request event
	BLE_L2CAP_EVT_CONN_IND	L2CAP Connected Indicate event
	BLE_L2CAP_EVT_ADD_CREDITS_IND	L2CAP Credits Add Indicate event
	BLE_L2CAP_EVT_DISCONNECTED	L2CAP Disconnected event
	BLE_L2CAP_EVT_SDU_RECV	L2CAP SDU Receive event
	BLE_L2CAP_EVT_SDU_SEND	L2CAP SDU Send event
	BLE_L2CAP_EVT_ADD_CREDITS_CPLT	L2CAP Credits Add Completed event
	BLE_L2CAP_EVT_ENH_CONN_REQ	L2CAP Enhanced Connect Request event
	BLE_L2CAP_EVT_ENH_CONN_IND	L2CAP Enhanced Connected Indicate event
	BLE_L2CAP_EVT_ENH_RECONFIG_CPLT	L2CAP Enhanced Reconfig Completed event
	BLE_L2CAP_EVT_ENH_RECONFIG_IND	L2CAP Enhanced Reconfig Indicate event

You need to implement necessary Bluetooth LE event handlers according to functional requirements of your products. For example, if a product does not support Security Manager, you do not need to implement corresponding events; if the product supports GATT Server only, you do not need to implement the events corresponding to GATT Client. Only those event handlers required for products are to be implemented.

Tip:

For details about the usage of Bluetooth LE APIs and event APIs, refer to the source code of Bluetooth LE examples in `SDK_Folder\documentation\GR533x_API_Reference` and `SDK_Folder\projects\ble`.

4.3.3.3 Scheduling BLE_Stack_IRQ, BLE_SDK_IRQ, and Applications

Bluetooth LE Stack is the core to implement Bluetooth LE protocols. It can directly operate the Bluetooth 5.3 Core (refer to "Section 2.2 Software Architecture"). Therefore, BLE_Stack_IRQ has the second-highest priority after SVCall IRQ, which ensures that Bluetooth LE Stack runs strictly in a timing specified in *Bluetooth Core Spec*.

A state change of Bluetooth LE Stack triggers the BLE_SDK_IRQ interrupt with lower priority. In this interrupt handler, the Bluetooth LE event handlers (to be executed in applications) are called to send state change notifications of Bluetooth LE Stack and related service data to applications. Avoid time-consuming operations when using these event handlers. Perform such operations in the main loop or in user-level threads instead. You can use the module in `SDK_Folder\components\libraries\app_queue`, or your own application framework, to transfer events from Bluetooth LE event handlers to the main loop.

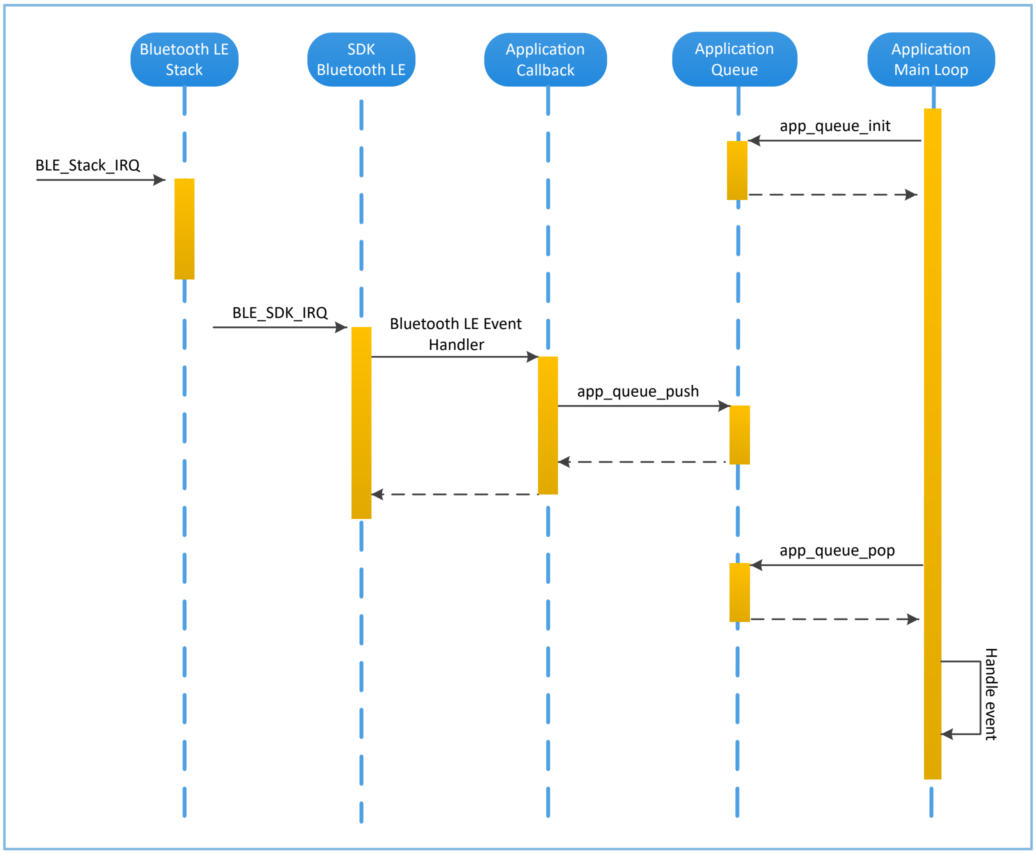


Figure 4-10 System schedule (without OS)

4.4 Generating Firmware

After building a Bluetooth LE application, you can directly click (**Build**) on the Keil toolbar to build a project.

After project compilation is completed, two firmware files (in .bin and .hex formats) are created in `Listings` and `Objects` respectively in the project directory.

Table 4-6 Firmware files generated

Name	Description
ble_app_example.bin	Binary application firmware, can be downloaded to Flash through GProgrammer for running

Name	Description
ble_app_example.hex	Binary application firmware, can be downloaded to Flash through Keil or GProgrammer for running

Tip:

Both the two types of firmware can be downloaded to Flash through GProgrammer for running. Refer to *GProgrammer User Manual* for details.

4.5 Downloading .hex Files to Flash

After a firmware file is are generated, you need to download the file to Flash. Specific steps are provided below:

1. Configure Keil Flash programming algorithm.

   (1). Copy `SDK_Folder\build\Keil\GR5xxx_16MB_Flash.FLM` to `Keil_Folder\ARM\Flash`.

   (2). Click (**Options for Target**) on the Keil toolbar, open the **Options for Target 'GRxx_Soc'** dialog box, and select the **Debug** tab. Click **Settings** on the right side of **Use: J-LINK/J-TRACE Cortex**.

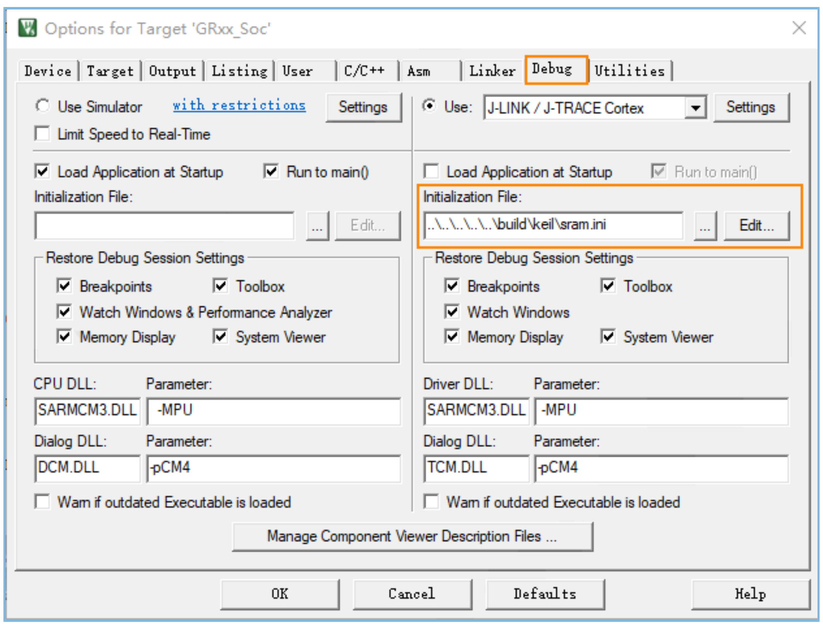


Figure 4-11 **Debug** tab

   (3). In the **Cortex JLink/JTrace Target Driver Setup** window, select **Flash Download**. In the **Download Function** pane, you can set the erase type and check optional items: **Program**, **Verify**, and **Reset and Run**. Default configurations of Keil are shown below:

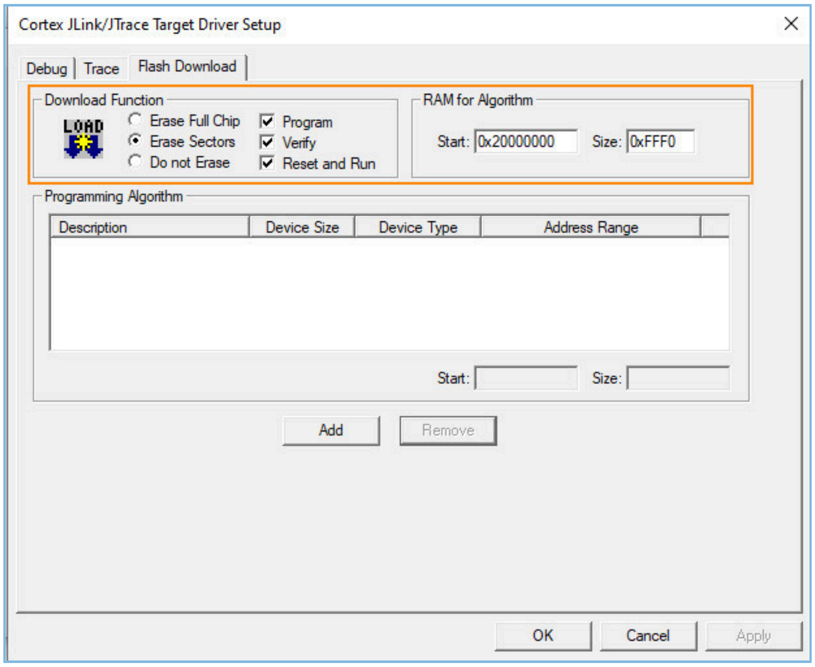


Figure 4-12 Default configurations in the **Download Function** pane

(4). Click **Add** to add `SDK_Folder\build\keil\GR5xxx_16MB_Flash.FLM` to **Programming Algorithm**.

Note:

To facilitate multi-chip inheritance development for users, *GR5xxx_16MB_Flash.FLM* is used for all the Goodix GR5xx Bluetooth LE SoC series which share the same download algorithm.

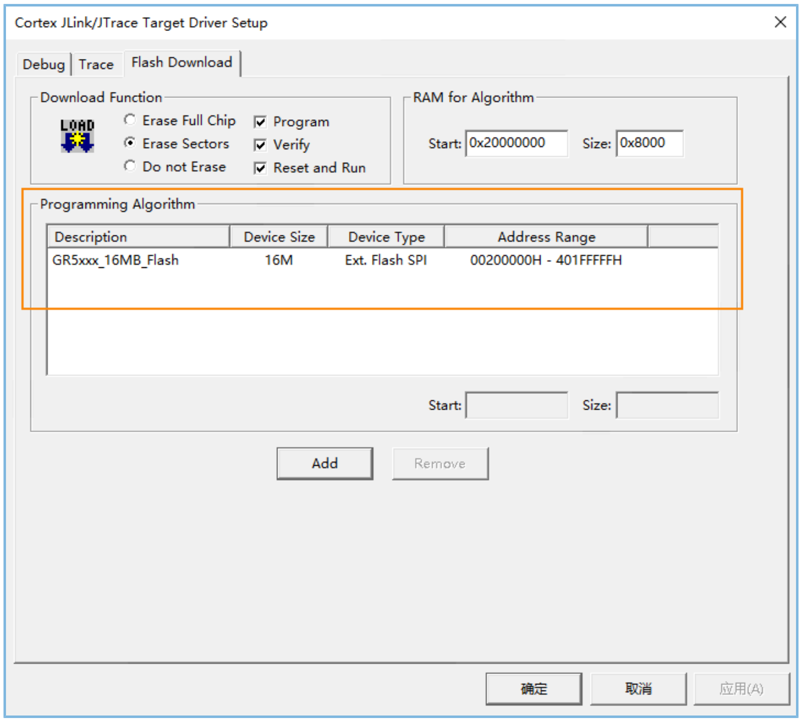


Figure 4-13 Adding *GR5xxx_16MB_Flash.FLM* to **Programming Algorithm**

(5). Configure **RAM for Algorithm**, which defines address space to load and implement the programming algorithm. Enter the start address of RAM in GR533x in the **Start** input field: **0x20000000**. Enter **0x8000** in the **Size** input field.

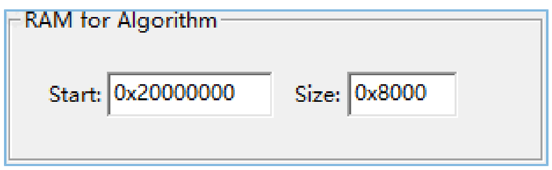
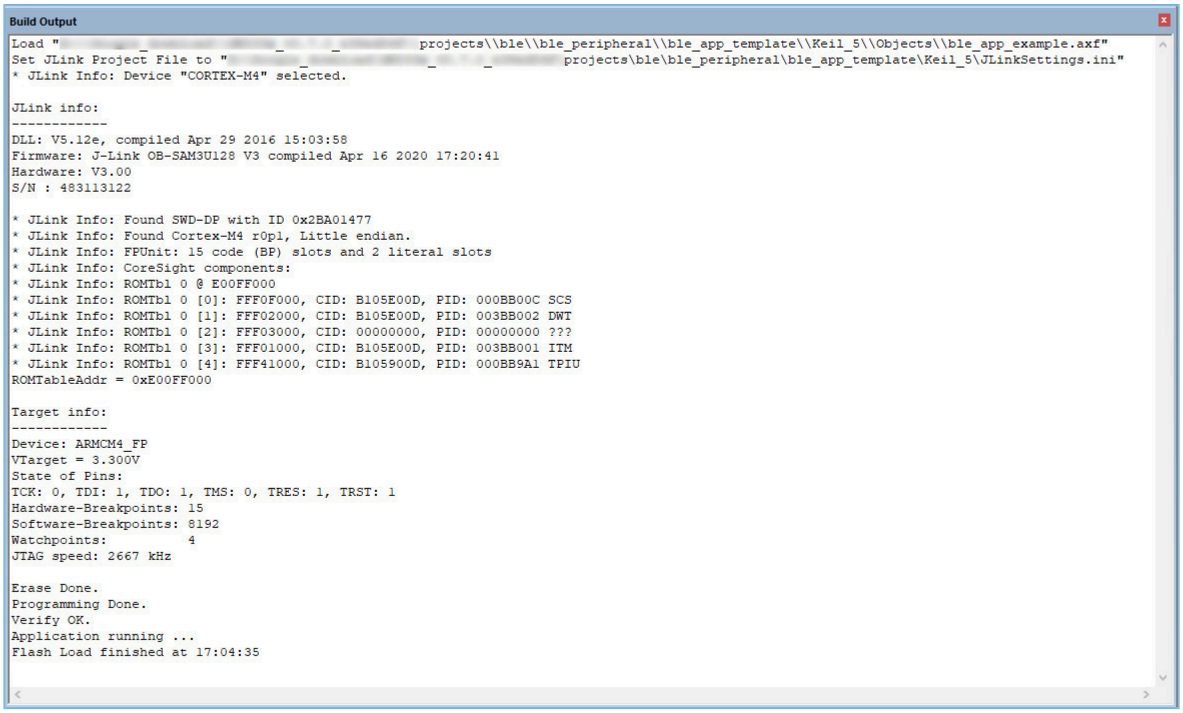


Figure 4-14 Settings of **RAM for Algorithm**

(6). Click **OK** to save the settings.

2. Download firmware.

After completing configuration, click (**Download**) on the Keil toolbar to download *ble_app_example.axf* to Flash. After download is completed, the following results are displayed in the **Build Output** window of Keil.



```
Build Output
Load "projects\\ble\\ble_peripheral\\ble_app_template\\Keil_5\\Objects\\ble_app_example.axf"
Set JLink Project File to "projects\ble\ble_peripheral\ble_app_template\Keil_5\JLinkSettings.ini"
* JLink Info: Device "CORTEX-M4" selected.

JLink info:
------------
DLL: V5.12e, compiled Apr 29 2016 15:03:58
Firmware: J-Link OB-SAM3U128 V3 compiled Apr 16 2020 17:20:41
Hardware: V3.00
S/N : 483113122

* JLink Info: Found SWD-DP with ID 0x2BA01477
* JLink Info: Found Cortex-M4 r0p1, Little endian.
* JLink Info: FPUnit: 15 code (BP) slots and 2 literal slots
* JLink Info: CoreSight components:
* JLink Info: ROMTbl 0 @ E00FF000
* JLink Info: ROMTbl 0 [0]: FFF0F000, CID: B105E00D, PID: 000BB00C SCS
* JLink Info: ROMTbl 0 [1]: FFF02000, CID: B105E00D, PID: 003BB002 DWT
* JLink Info: ROMTbl 0 [2]: FFF03000, CID: 00000000, PID: 00000000 ???
* JLink Info: ROMTbl 0 [3]: FFF01000, CID: B105E00D, PID: 003BB001 ITM
* JLink Info: ROMTbl 0 [4]: FFF41000, CID: B105900D, PID: 000BB9A1 TPIU
ROMTableAddr = 0xE00FF000

Target info:
------------
Device: ARMCM4_FP
VTarget = 3.300V
State of Pins:
TCK: 0, TDI: 1, TDO: 1, TMS: 0, TRES: 1, TRST: 1
Hardware-Breakpoints: 15
Software-Breakpoints: 8192
Watchpoints:          4
JTAG speed: 2667 kHz

Erase Done.
Programming Done.
Verify OK.
Application running ...
Flash Load finished at 17:04:35
```

Figure 4-15 Download results

Note:

During file download, if **No Cortex-M SW Device Found** pops up, it indicates the SoC may be in sleep state at that moment (the firmware with sleep mode enabled is running), so the .hex file cannot be downloaded to Flash. In this case, developers need to press **RESET** on the GR5331 SK Board and wait for about 1 second; then click (**Download**) to download the file again.

4.6 Debugging

Keil provides a debugger for online code debugging. The debugger supports setting six hardware breakpoints and multiple software breakpoints. It also provides developers with multiple methods to set debug commands.

4.6.1 Configuring the Debugger

Configure the debugger before debugging. Click (**Options for Target**) on the Keil toolbar, open the **Options for Target 'GRxx_Soc'** dialog box, and select the **Debug** tab. In the window, software simulation debugging configurations display on the left side, and online hardware debugging configurations display on the right side.

Bluetooth LE example projects adopt the online hardware debugging. Related default configurations of the debugger are shown as follows:

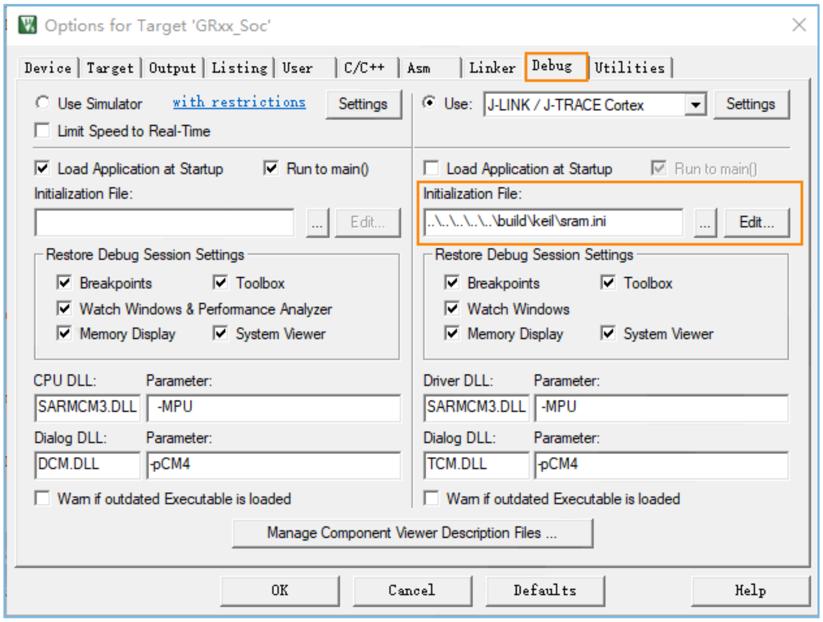


Figure 4-16 Configuring the debugger

The default initialization file *sram.ini* is in `SDK_Folder\build\keil`. You can use this file directly, or copy it to the project directory.

The initialization file *sram.ini* contains a set of debug commands, which are executed during debugging. On the **Initialization File** bar, click **Edit...** on the right side, to open *sram.ini*.

Example code of *sram.ini* is provided as follows:

```
/**
***********************************************************************
*GR55xx object loading script through debugger interface (e.g.Jlink, etc).
*The goal of this script is to load the Keils's object file to the GR55xx RAM
*assuring that the GR55xx has been previously cleaned up.
***********************************************************************
*/

//Debugger reset(check Keil debugger settings)
//Preselected reset type (found in Options->Debug->Settings)is Normal(0);
//-Normal:Reset core & peripherals via SYSRESETREQ & VECTRESET bit
RESET

//Load current object file
LOAD %L

//Load stack pointer
SP = _RDWORD(0x00000000)

//Load program counter
$ = _RDWORD(0x00000004)

//Write 0 to vector table register, remap vector
_WDWORD(0xE000ED08, 0x00000000)

//_WDWORD(0xE000E180, 0xFFFFFFFF)

//Write run address to 0xA000C578 register,For the debug mode;
```

```
//boot code will check the value of 0xA000C578 firstly,if the value of 0xA000C578 is
 valid,gr551x will jump to run

//_WDWORD(0xA000C578, 0x00810000)
```

Note:

Keil supports executing debugger commands set by developers in the following order:

1. When **Options for Target 'GRxx_Soc'** > **Debug** > **Load Application at Startup** is enabled, the debugger first loads the file under **Options for Target 'GRxx_Soc'** > **Output** > **Name of Executable**.
2. Execute the command in the file specified in **Options for Target 'GRxx_Soc'** > **Debug** > **Initialization File**.
3. When options under **Options for Target 'GRxx_Soc'** > **Debug** > **Restore Debug Session Settings** are checked, restore corresponding Breakpoints, Watch Windows, Memory Display, and other settings.
4. When **Options for Target 'GRxx_Soc'** > **Debug** > **Run to main()** is checked, or the command `g,main` is discovered in **Initialization File**, the debugger automatically starts executing CPU commands, until running to the main() function.

4.6.2 Starting Debugging

After completing debugger configuration, click (**Start/Stop Debug Session**) on the Keil toolbar, to start debugging.

Note:

Make sure that both options under **Connect & Reset Options** are set to **Normal**, as shown in Figure 4-17. This is to ensure when you click **Reset** on the Keil toolbar after enabling **Debug Session**, the program can run normally

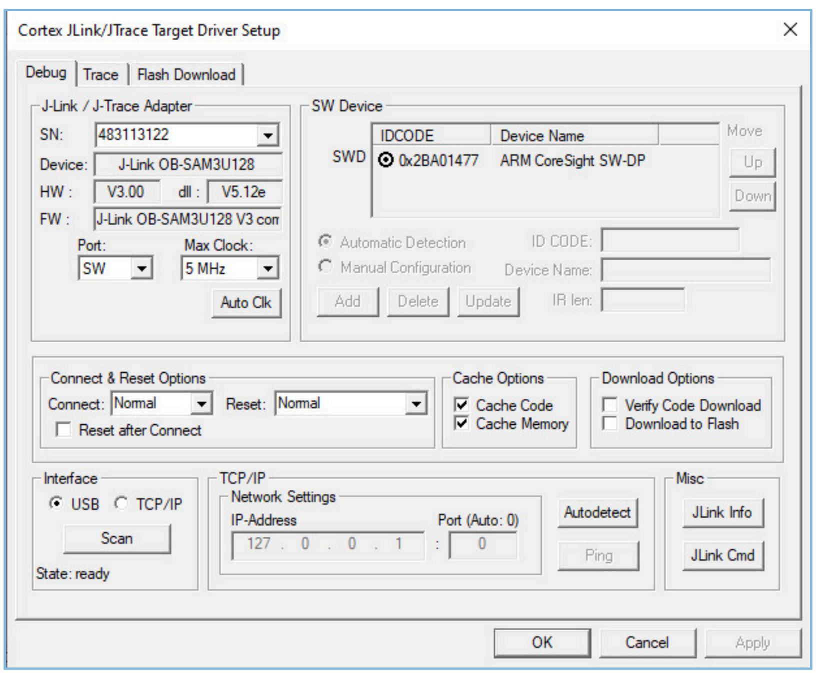


Figure 4-17 Setting **Connect** and **Reset**

4.6.3 Outputting Debug Logs

GR533x SDK provides an APP LOG module and supports outputting debug logs of applications from hardware ports based on customization. Hardware ports include UART, J-Link RTT, and ARM Instrumentation Trace Macrocell (ARM ITM).

To use the APP LOG module, enable APP_LOG_ENABLE in *custom_config.h*, and configure APP_LOG_PORT based on the output method as needed.

4.6.3.1 Module Initialization

After configuration, you need to call app_log_init() during peripheral initialization to initialize the APP LOG module, including setting log parameters, and registering log output APIs and flush APIs.

The APP LOG module supports using `printf()` (a C standard library function) and APP LOG APIs to output debug logs. If you choose APP LOG APIs, you can optimize logs by setting log level, log format, filter type, or other parameters; if you choose `printf()`, set log parameters as NULL.

Call the initialization function of corresponding module (refer to `SDK_Folder\platform\boards\board_SK.c` for details) and register corresponding log output and flush APIs (see bsp_log_init() for reference) according to the configured output port.

If UART is the output port, bsp_log_init() is implemented as follows:

```
void bsp_log_init(void)
{
#if APP_LOG_ENABLE

#if (APP_LOG_PORT == 0)
    bsp_uart_init();
#elif (APP_LOG_PORT == 1)
    SEGGER_RTT_ConfigUpBuffer(0, NULL, NULL, 0, SEGGER_RTT_MODE_NO_BLOCK_TRIM);
#endif

#if (APP_LOG_PORT <= 2)
    app_log_init_t   log_init;

    log_init.filter.level                 = APP_LOG_LVL_DEBUG;
    log_init.fmt_set[APP_LOG_LVL_ERROR]   = APP_LOG_FMT_ALL & (~APP_LOG_FMT_TAG);
    log_init.fmt_set[APP_LOG_LVL_WARNING] = APP_LOG_FMT_FUNC;
    log_init.fmt_set[APP_LOG_LVL_INFO]    = APP_LOG_FMT_NULL;
    log_init.fmt_set[APP_LOG_LVL_DEBUG]   = APP_LOG_FMT_NULL;

#if (APP_LOG_PORT == 0)
    app_log_init(&log_init, bsp_uart_send, bsp_uart_flush);
#elif (APP_LOG_PORT == 1)
    app_log_init(&log_init, bsp_segger_rtt_send, NULL);
#elif (APP_LOG_PORT == 2)
    app_log_init(&log_init, bsp_itm_send, NULL);
#endif

#endif
    app_assert_init();
#endif
}
```

Note:

- The input parameters of app_log_init() include the log initialization parameter, log output API, and flush API (optional for registration).
- GR533x SDK provides an APP LOG STORE module, which supports storing the debug logs in Flash and outputting the logs from Flash. To use the APP LOG STORE module, users need to enable APP_LOG_STORE_ENABLE in *custom_config.h*. This module is configured in the ble_app_rscs project (in `SDK_Folder\projects\ble\ble_peripheral\ble_app_rscs`). This configuration can be a reference when the APP LOG STORE module is used.
- Application logs output by using `printf()` cannot be stored by the APP LOG STORE module.

When debug logs are output through UART, the implemented log output API and flush API are bsp_uart_send() and bsp_uart_flush() respectively.

- bsp_uart_send() is the basis for two log output APIs: app_uart asynchronization (app_uart_transmit_async) and hal_uart synchronization (hal_uart_transmit). Users can choose the output methods as needed.
- bsp_uart_flush() is used to output the log data that is cached in memory in interrupt mode.

Note:

You can rewrite the above two APIs.

When debug logs are output through J-Link RTT or ARM ITM, the implemented log output API is bsp_segger_rtt_send() or bsp_itm_send(). No flush API is to be implemented in the two modes.

4.6.3.2 Application

After completing initialization of the APP LOG module, you can use any of the following four APIs to output debug logs:

- APP_LOG_ERROR()
- APP_LOG_WARNING()
- APP_LOG_INFO()
- APP_LOG_DEBUG()

In interrupt output mode, call app_log_flush() to output all the debug logs cached, to ensure that all debug logs are output before the SoC is reset or the system enters the sleep mode.

To output logs through J-Link RTT, it is recommended to make the following modifications in *SEGGER_RTT.c*:

```
SEGGER_RTT.c
*
*       Static data
*
**********************************************************************
*/
//
// RTT Control Block and allocate buffers for channel 0
//
__attribute__((section (".ARM.__at_0x20005000"))) SEGGER_RTT_CB _SEGGER_RTT;
//SEGGER_RTT_PUT_CB_SECTION(SEGGER_RTT_CB_ALIGN(SEGGER_RTT_CB _SEGGER_RTT));
```

Figure 4-18 Creating RTT Control Block and placing it at 0x20005000

The figure below shows the reference configurations for J-Link RTT Viewer.

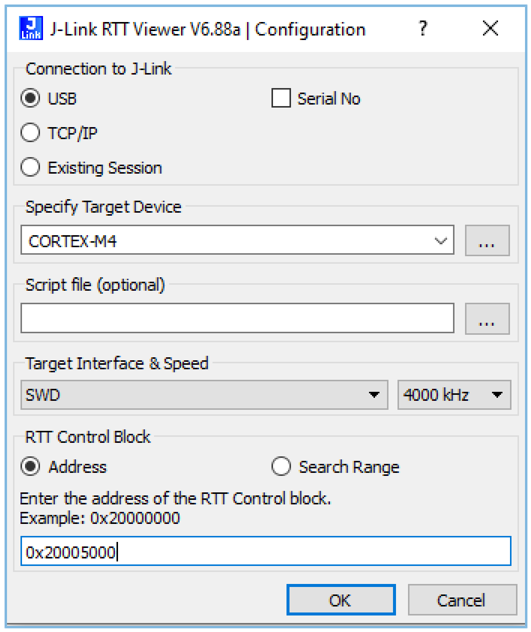


Figure 4-19 Configurations in J-Link RTT Viewer

The address of **RTT Control Block** can be specified by clicking **Address** and then entering a custom value, and the input value can be set to the address of the **_SEGGER_RTT** structure in the .map file generated by the compiled project, as shown in the figure below. If creating RTT Control Block through the method recommended in Figure 4-18 and placing it at 0x20005000, you need to set **Address** to **0x20005000**.

```
ultra_wfi_or_wfe                    0x200037ec   Data          0  rom_symbol.txt ABSOLUTE
sdk_gap_env                         0x200038ec   Data          0  rom_symbol.txt ABSOLUTE
_SEGGER_RTT                         0x20005000   Data        120  segger_rtt.o(.ARM.__at_0x20005000)
jlink_opt_info                      0x20006000   Data          0  rom_symbol.txt ABSOLUTE
SystemCoreClock                     0x2000b000   Data          4  system_gr55xx.o(.data)
__stdout                            0x2000b044   Data          4  app_log.o(.data)
```

Figure 4-20 Obtaining RTT Control Block address

4.6.4 Debugging with GRToolbox

GR533x SDK provides an Android App, GRToolbox, to debug GR533x Bluetooth LE applications. GRToolbox features the following:

- General Bluetooth LE scanning and connecting; characteristics read/write

- Demos for standard profiles, including Heart Rate and Blood Pressure
- Goodix-customized applications

Tip:

You can obtain the GRToolbox installation file from Goodix official website or download it from the application store.

---

5 Glossary

Table 5-1 Glossary

Name	Description
API	Application Programming Interface
ATT	Attribute Protocol
Bluetooth LE	Bluetooth Low Energy
DFU	Device Firmware Update
DTM	Direct Test Mode
DUT	Device Under Test
GAP	Generic Access Profile
GATT	Generic Attribute Profile
GFSK	Gaussian Frequency Shift Keying
HAL	Hardware Abstract Layer
HCI	Host Controller Interface
HPA	High Power Amplifier
IoT	Internet of Things
L2CAP	Logical Link Control and Adaptation Protocol
LL	Link Layer
NVDS	Non-volatile Data Storage
OTA	Over The Air
PMU	Power Management Unit
PHY	Physical Layer
RF	Radio Frequency
SCA	System Configuration Area
SDK	Software Development Kit
SM	Security Manager
SoC	System-on-Chip
SPA	Small Power Amplifier
UART	Universal Asynchronous Receiver/Transmitter
UPA	Ultra-low Power Amplifier
XIP	Execute in Place