AN1390: PTA 3-Wire Co-Existence (Wi-Fi®) RS9116 Application Note

Version 0.1

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PTA 3-Wire Co-Existence (Wi-Fi®) – RS9116

Silicon Labs' Packet Traffic Arbitration (PTA) supports the coordination of 2.4 GHz RF traffic of co-located 2.4 GHz radios and Silicon Labs wireless solutions (Wi-Fi, BT/BLE, THREAD, and Zigbee). This application note describes the impact of 2.4 GHz radio protocols on Wi-Fi and the PTA method to improve co-existence with the BLE protocol. This application note entails the implementation of the PTA-BLE demo for EFR32 devices for BLE and RS9116W for Wi-Fi, with both concurrently operating in overlapping frequency channels in the 2.4 GHz band while being spatially co-located. These techniques apply to the EFR32MGx family. This document assumes that the reader has a basic understanding of how Wi-Fi co-existence is implemented on EFR32 devices. For more information, see UG103.17: Wi-Fi® Co-Existence Fundamentals.

This application note focuses on the functions and configurations of the RS9116W and provides references to corresponding peer functionality on the EFR32 device.

KEY FEATURES

- PTA Main Support on RS9116W for Wi-Fi
- 2.4 GHz Channel Operation Co-Existence with EFR32 using BLE.
- Configuration Details on various modes of operation.
- Pin Connections between the RS9116W and EFR32 for PTA.

Note: This content may contain offensive terminology that is now obsolete. Silicon Labs is replacing these terms with inclusive language wherever possible. For more information, visit www.silabs.com/about-us/inclusive-lexicon-project.

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1 Introduction

Packet Transmission Arbitration (PTA) is an external co-existence mechanism that helps reduce packet collisions between coupled devices using different protocols like THREAD, Wi-Fi, and BT/BLE. For the solution provided by this document, the RS9116W device is configured as a PTA main supporting PTA 3-Wire Co-Existence for Wi-Fi only 2.4 GHz mode of operation. At the same time, the EFR32 device is configured as a PTA secondary operating in BLE mode. When two devices operate in the 2.4 GHz band with different RADIOs and are spatially co-located and operating concurrently, their channels can overlap. To avoid this, a specific synchronization is required between the EFR32 and RS9116W devices to regulate their transmission and reception so that no collisions occur between them, and they are able to perform effectively.

As stated before, the RS9116W operates as the PTA main. As such, it implements the entity that decides which of the two devices will transmit at any given time based on handshake signals exchanged over three different GPIO connections between the EFR32 and RS9116W.

The EFR32 operates as the PTA secondary. Based on the packet transfer requirements of both devices, handshake signals are triggered accordingly.

The current implementation provides a capability that allows all EFR32 transmission/reception activities to be protected by ensuring no transmission interference occurs from the side of the RS9116W for Wi-Fi. This mechanism also provides a provision to allow the Wi-Fi transmission to be protected by stopping any possible interference from the EFR32. However, the current implementation does not provide provisions to ensure the protection of Wi-Fi reception. Such support will be taken up as a future enhancement of this feature.

Radio Protocol Impact:

Worldwide, Wi-Fi (IEEE 802.11b/g/n) supports up to **14 overlapping 20/22 MHz bandwidth channels** across the 2.4 GHz ISM band with transmit power levels up to +30 dBm. Bluetooth supports 40 non-overlapping channels at 2 MHz spacing with transmit power levels up to +20 dBm (Bluetooth Core Specification v5.0).

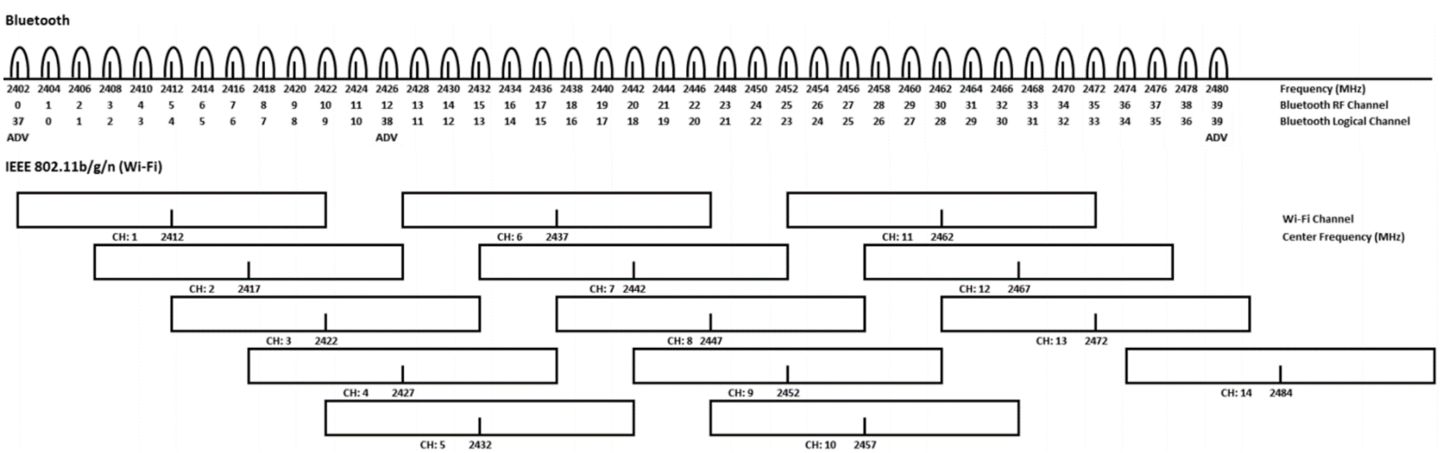


Figure 1.1 – Spectrum Access

The number of available Wi-Fi channels will vary based on the country of operation. For example, Wi-Fi channels 1 through 14 are available in Japan, while only Wi-Fi channels 1 through 11 are available in the US. Bluetooth channels 0 through 39 are available worldwide.

PTA 3-Wire Co-Ex Mechanism:

PTA (Packet Transmission Arbitration) is one of the external co-existence mechanisms that can help to reduce packet collisions between coupled devices using different protocols like THREAD, Wi-Fi, and BT/BLE. For the purpose of the described solution, the RS9116W acts as the PTA Main controlling the access to the spectrum to itself or the EFR32 based on three handshake signals.

The following three signals are implemented in the proposed 3-Wire PTA solution to establish the handshake between RS9116W and EFR32.

- REQUEST
  - Input to RS9116W and Output from EFR32
  - EFR32 requests GRANT channel access to the 2.4 GHz ISM band for Tx/Rx
- PRIORITY
  - Input to RS9116W and Output from EFR32.
  - EFR32 asserts priority to indicate priority traffic to grant access to the 2.4 GHz ISM band for Tx/Rx.
- GRANT
  - Output from RS9116W and input to EFR32.
  - RS9116W GRANT permission to access 2.4 GHz ISM Band for Tx/Rx.

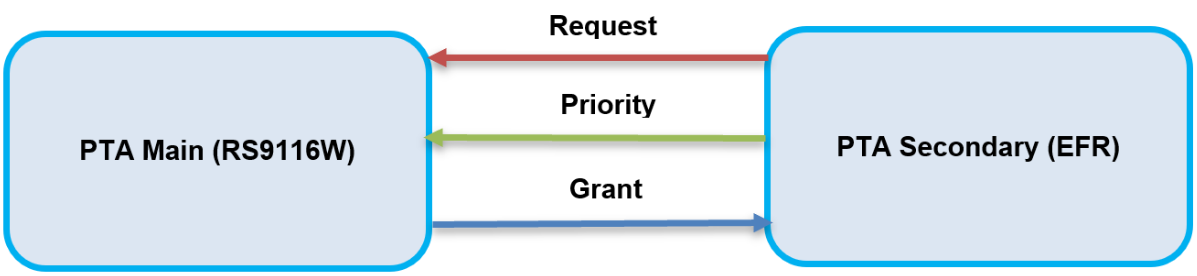


Figure 1.2 – PTA 3-Wire Co-Ex Mechanism

For spectrum access to either transmit or receive, the EFR32 device asserts the REQUEST signal. Based on the configuration (refer to Section 2. Prerequisites) chosen, the RS9116W will indicate access by asserting a GRANT signal. Based on the RS9116W configuration chosen, the GRANT might be asserted for the spectrum access only if the EFR32 asserts both REQUEST and PRIORITY signals. Refer to documents listed in Section 9. References to see how EFR32 can be configured for PTA Coexistence for various protocols.

2 Prerequisites

2.1 Hardware Requirements

- Windows PC
- PTA Main
  - RS9116W EVK
  - Either of the following host MCUs on which the application is verified:
    - EFR32 - SLWSTK6023A (EFR32xG21 Bluetooth Starter Kit)
    - STM32 - STM32F411RE MCU
  - Micro USB Cable (For RS9116W device power)
  - Interconnect board or SPI connector for SPI connection between RS9116W device and host MCU, either STM32 or EFR32
- PTA Secondary
  - EFR32 - SLWSTK6023A (EFR32xG21 Bluetooth Starter Kit)
  - BLE Smart Phone, either Android or IOS.
  - Logic analyzer (for signal monitoring)

2.2 Software Requirements

- RS9116W latest software release is available in the link below:
  - https://github.com/SiliconLabs/wiseconnect-wifi-bt-sdk
- Development Environment
  - For STM32, use licensed Keil IDE
  - For EFR32, use Simplicity studio
- EFR32 Connect App: Download and install this mobile application on android or IOS for evaluating the BLE application.
- Docklight /TeraTerm software
- EFR32 – Gecko SDK v3.2
- Python Software: version 3.9.0

NOTE:

- Refer to Update EVK Firmware to load the firmware into the RS9116W device. The firmware binary is found in the <Release_Package>/firmware folder.
- Please use the Gecko SDK suite 3.2 to validate the python BGAPI at PTA secondary device.

3 Block Diagram

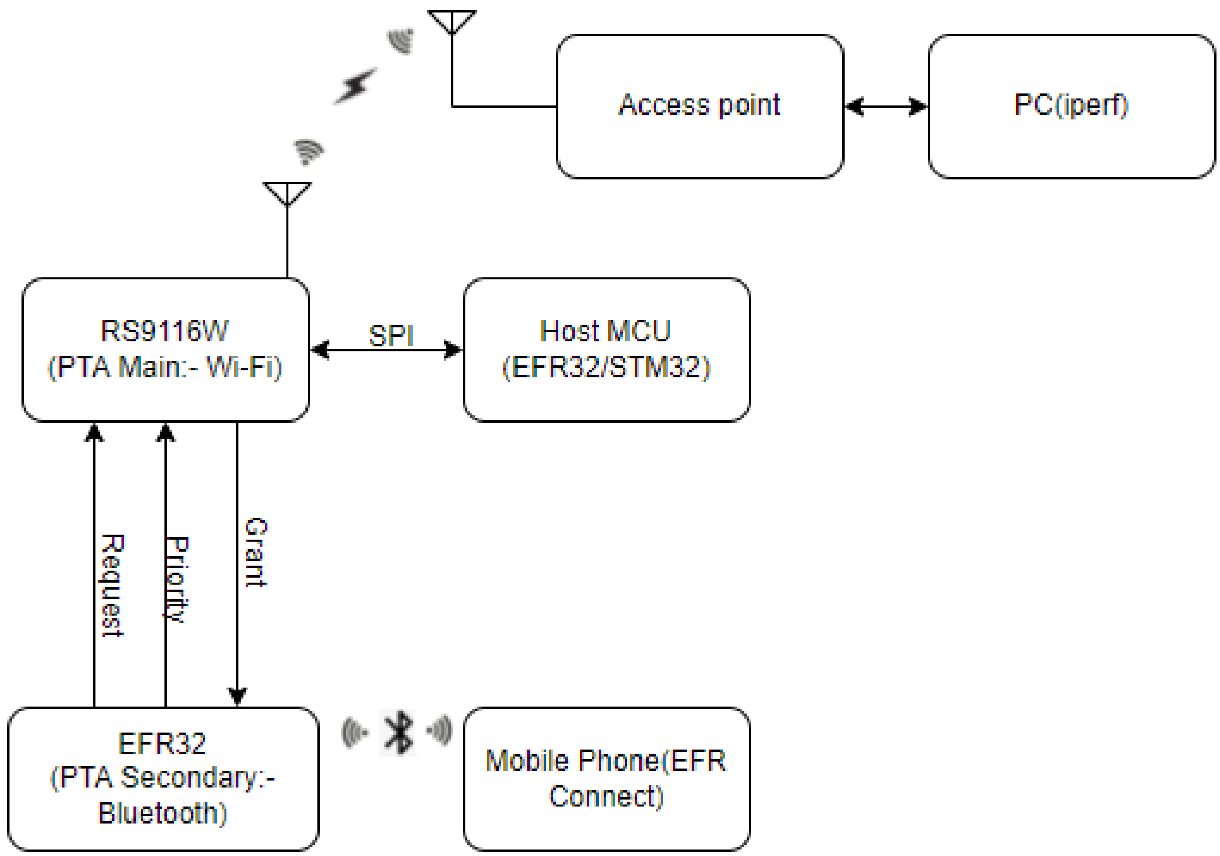


Figure 3.1 – PTA Block Diagram

As demonstrated in the image above, the following connections are required:

- The RS9116W device and the host are connected over the SPI interface, and it is connected to the Windows PC with a micro-USB cable.
- The access point is connected to the PC either with ethernet or with a Wi-Fi connection.
- A female-to-female cable is connected Request pin of the RS9116W device and the EFR32.
- A female-to-female cable is connected Priority pin of the RS9116W device and the EFR32.
- A female-to-female cable is connected Grant pin of the RS9116W device and the EFR32.
- The PTA-secondary (EFR32-BLE) is connected to the PC with a micro-USB cable.

4 Hardware Configurations

4.1 GPIO Pin Configurations

The configuration below describes the pin connections between the EFR32 and the RS9116W device that involves the GRANT, REQUEST, and PRIORITY signals and includes the EFR TX signal. The figure below shows the RS9116W Eval board connected to the EFR32 Eval board through a Peripheral card and a logic analyzer.

Pin Description	EVK GPIO Peripheral Pins	EVK Peripheral Card	EFR32 Pins	EFR32 Board
Request	ULP_GPIO_1 (BT_ACTIVE)	J2- pin8	PB00	Pin 7
Priority	ULP_GPIO_6 (BT_PRIORITY)	J2- pin 20	PD02	Pin 11
Grant	ULP_GPIO_0 (WLAN_ACTIVE)	J2- pin 6	PB01	Pin 9
EFR TX	-	-	PD03	Pin 13

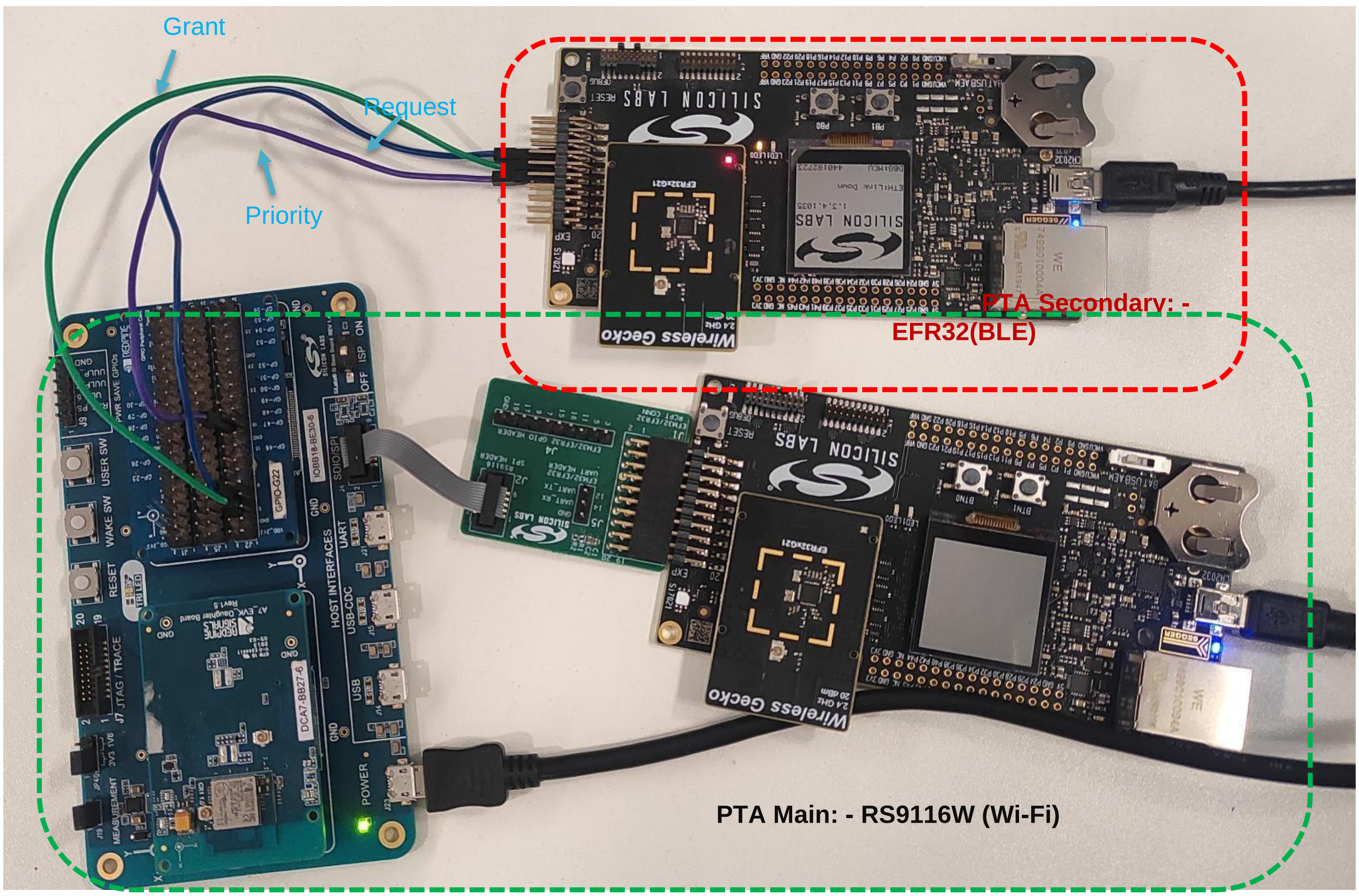


Figure 4.1 – RS9116W PTA GPIO Connections to EFR

NOTE:

As per the PTA protocol naming convention, the BT_ACTIVE, BT-PRIORITY & WLAN_ACTIVE pins are known as the REQUEST, PRIORITY & GRANT signals.

S.No.	Pin Description	RS9116 Pins	RS9116 Datasheet Pin Naming Convention
1	GRANT	ULP_GPIO_0	WLAN_ACTIVE
2	REQUEST	ULP_GPIO_1	BT_ACTIVE
3	PRIORITY	ULP_GPIO_6	BT_PRIORITY

4.2 PTA Configurations

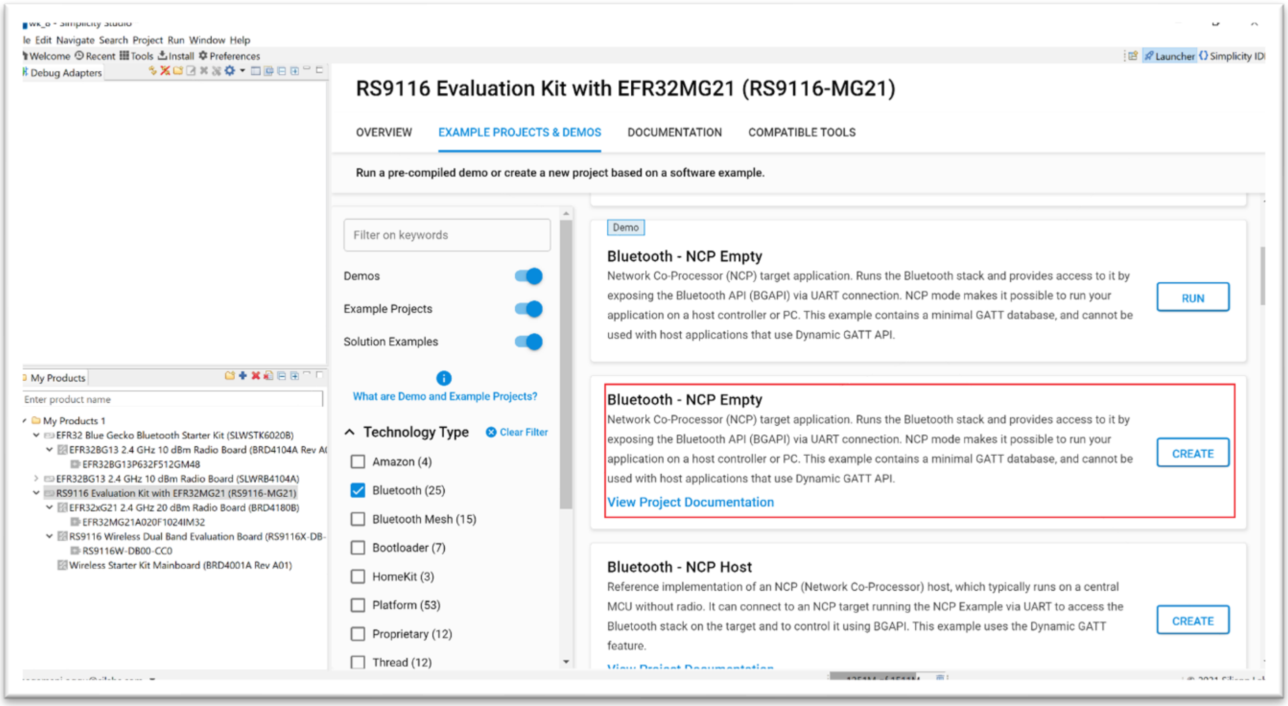
The RS9116W's PTA feature can be configured by enabling the BIT[21] of the config_feature_bitmap in the OperMode command. It has three different configurations, which can be chosen by enabling or disabling the Bit [23:22]. Each of these configurations changes the behavior of how GRANT is asserted in response to REQUEST and PRIORITY signals. The following tables define the configurations.

BIT 23	BIT 22	Configuration
0	0	Reserved
0	1	Configuration 1
1	0	Configuration 2
1	1	Configuration 3

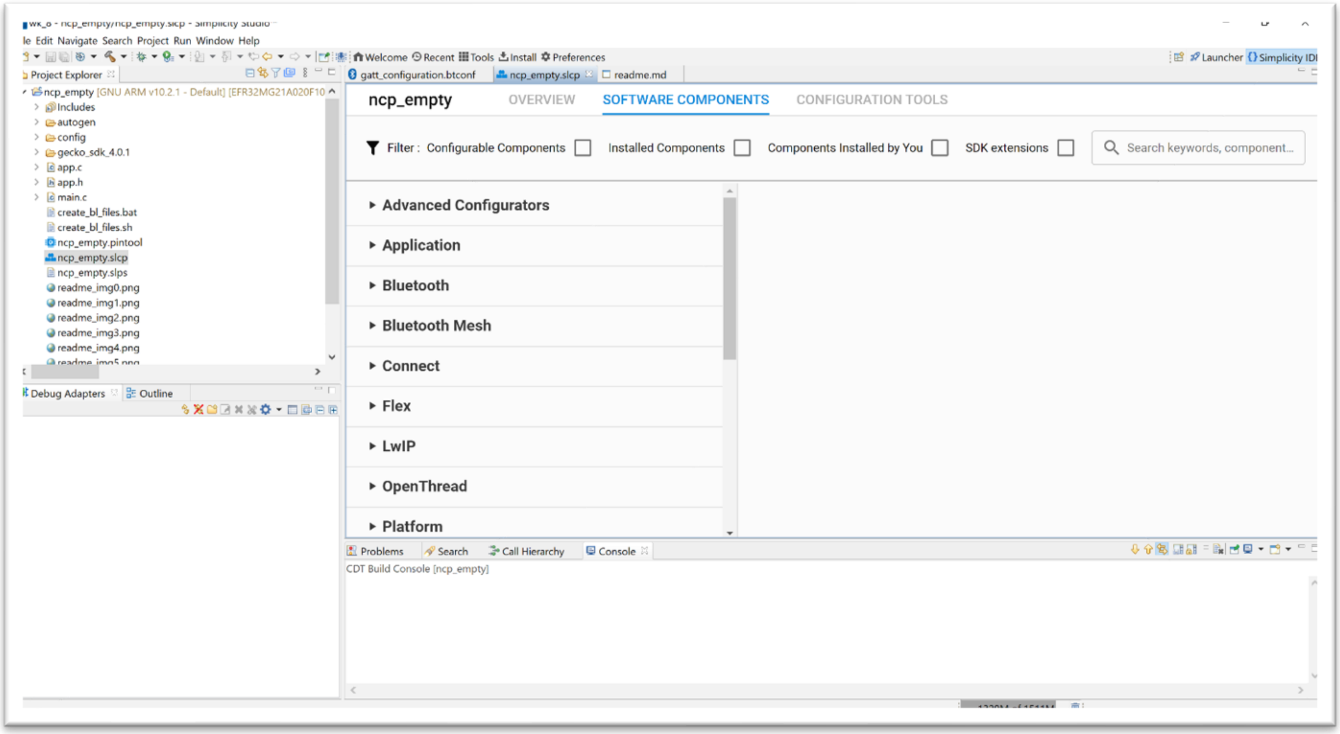
Configuration 1	The PTA Main will aggressively assert GRANT if the REQUEST is asserted irrespective of PRIORITY being asserted or not. When any ongoing Wi-Fi transmission will be halted, GRANT will be provided to the PTA secondary.
Configuration 2	The PTA Main asserts the GRANT if the REQUEST is asserted in the response without consideration of the PRIORITY signal, with only one exception of an ongoing ACK/Block ACK Transmission in response to a Wi-Fi reception. If there is an ongoing ACK/Block ACK transmission in response to a Wi-Fi Reception, PTA MAIN will GRANT the spectrum access only if PRIORITY is asserted along with REQUEST.
Configuration 3	When the PTA secondary needs the spectrum, it sends both REQUEST and PRIORITY signals. PTA Main will assert GRANT, and the Wi-Fi will hold any ongoing transmission, including ACK/BLOCK transmission.

5 PTA Secondary – EFR32 Configurations

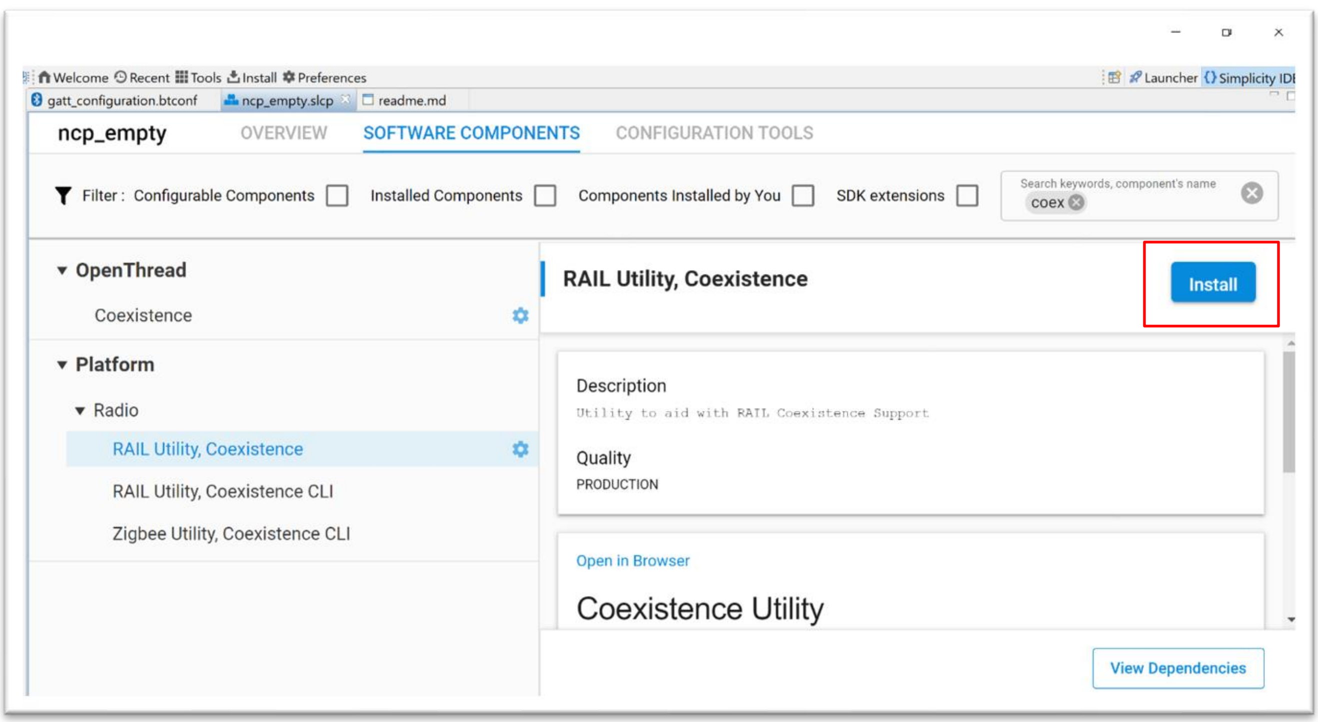
1. For EFR32 project creation, refer to the Getting Started Guide.
2. Navigate to the default examples of the EFR32 and create the Bluetooth NCP-empty project as per the EFR32 board configurations.



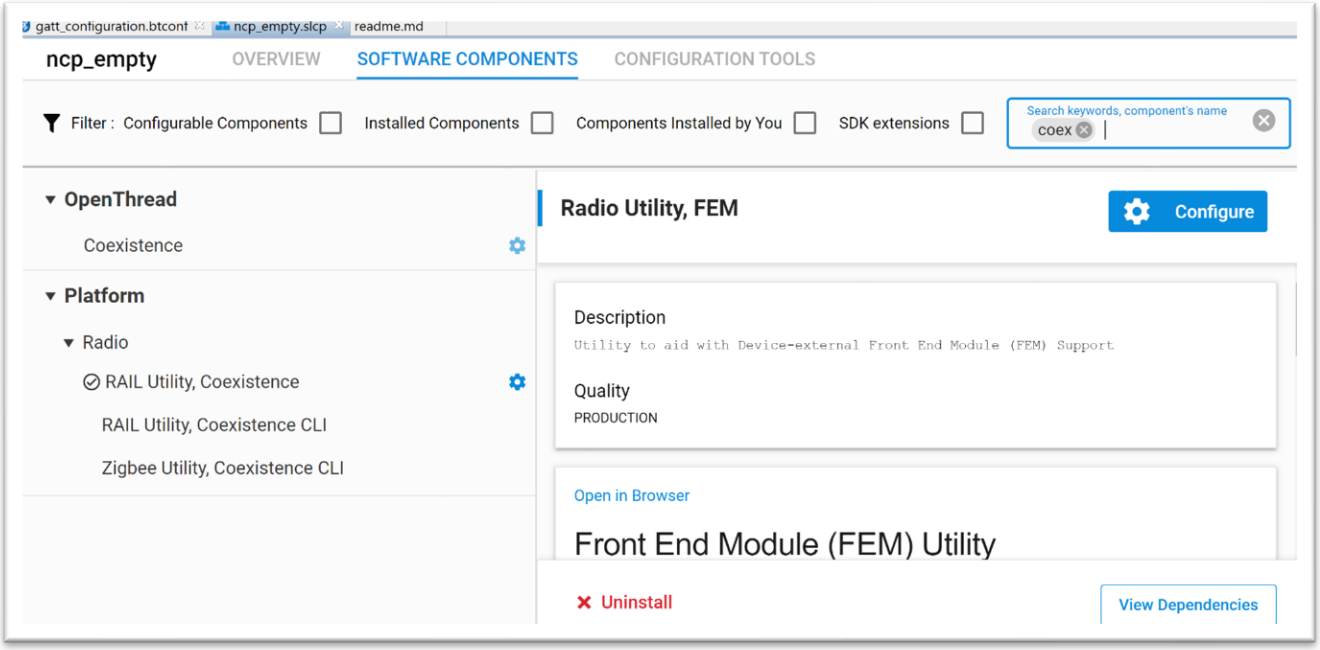
3. Click on the "project.slcp" and navigate to the software components as shown in the image below.



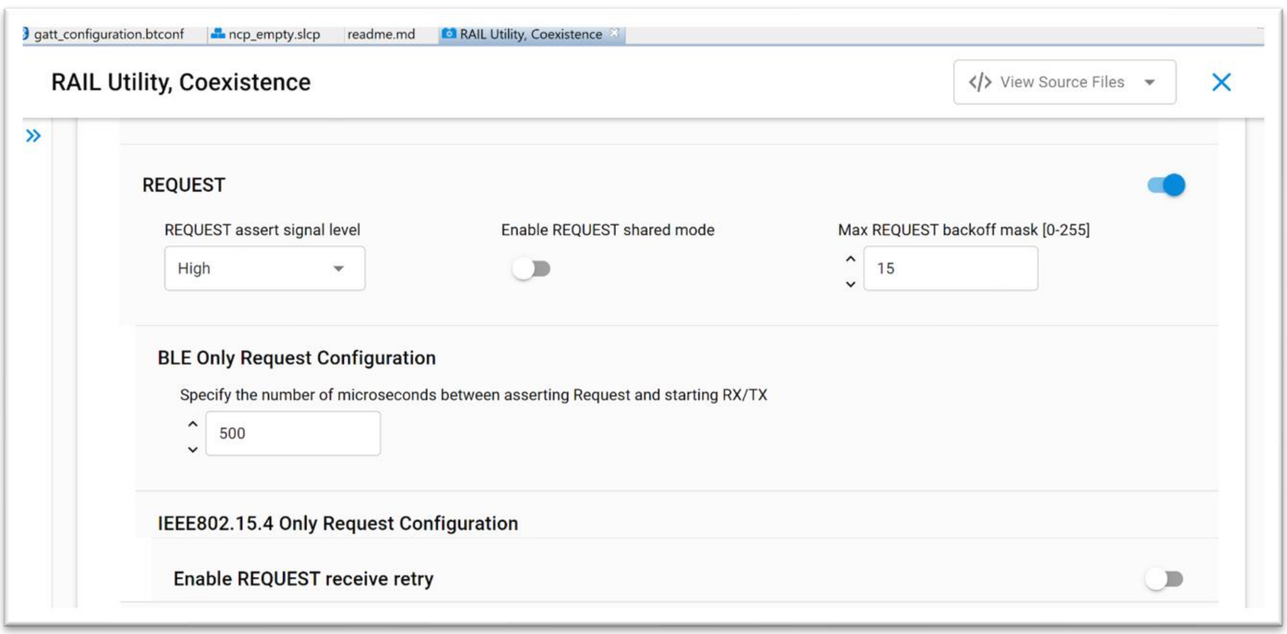
4. The "Rail” tool needs to be installed by clicking the button below to select the PTA co-existence.

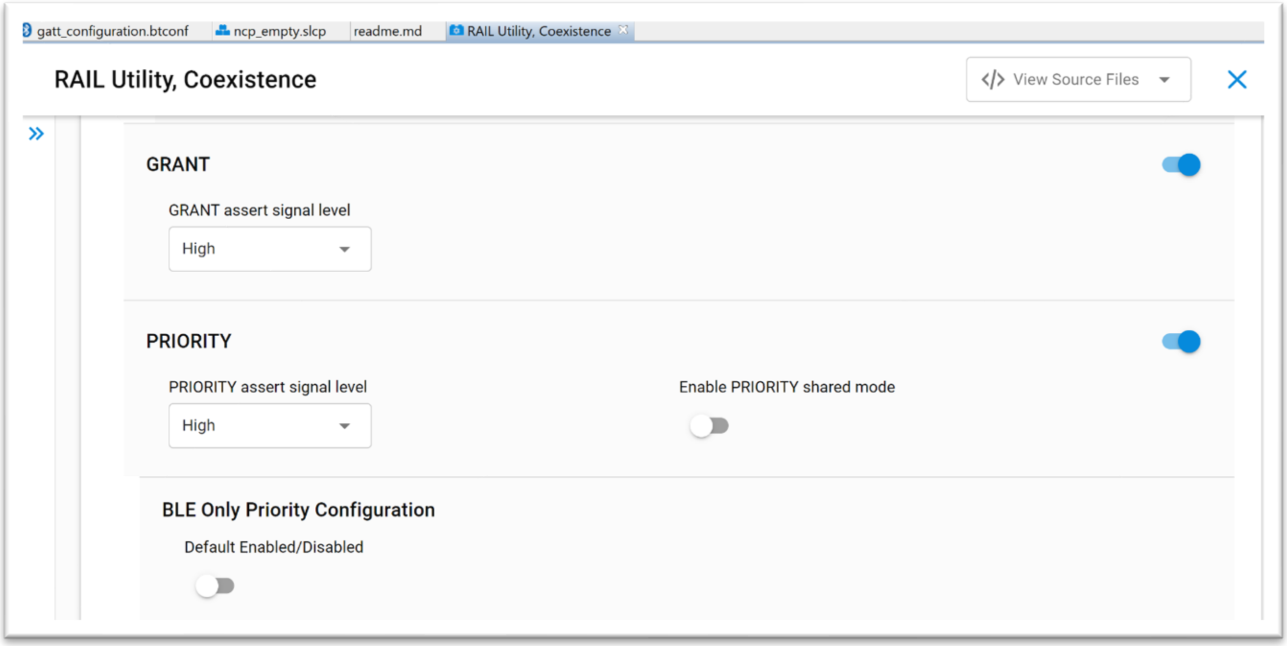


5. Once the "Rail" tool is installed, click on the "configure" button to configure the EFR32 pins.

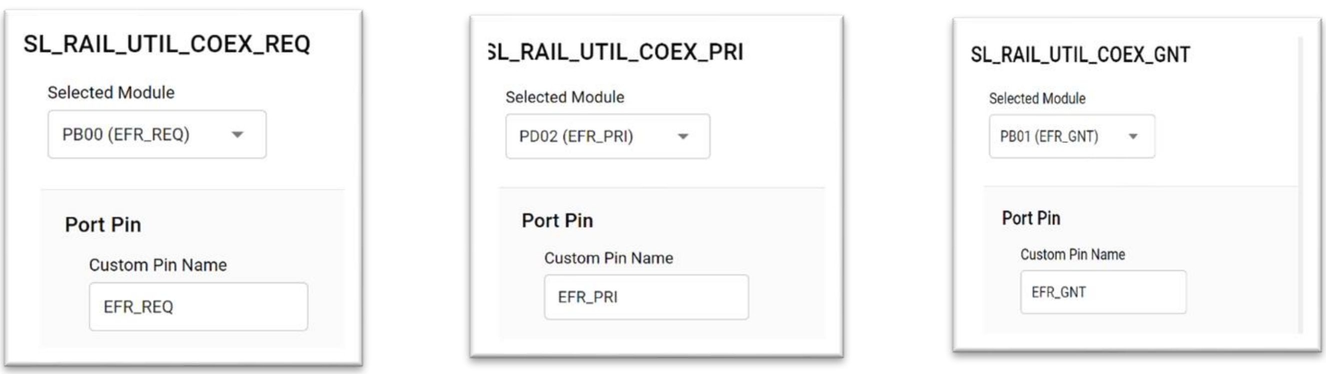


6. Enable the Request, Priority, and Grant signals in the "Rail Utility, co-existence" tool.

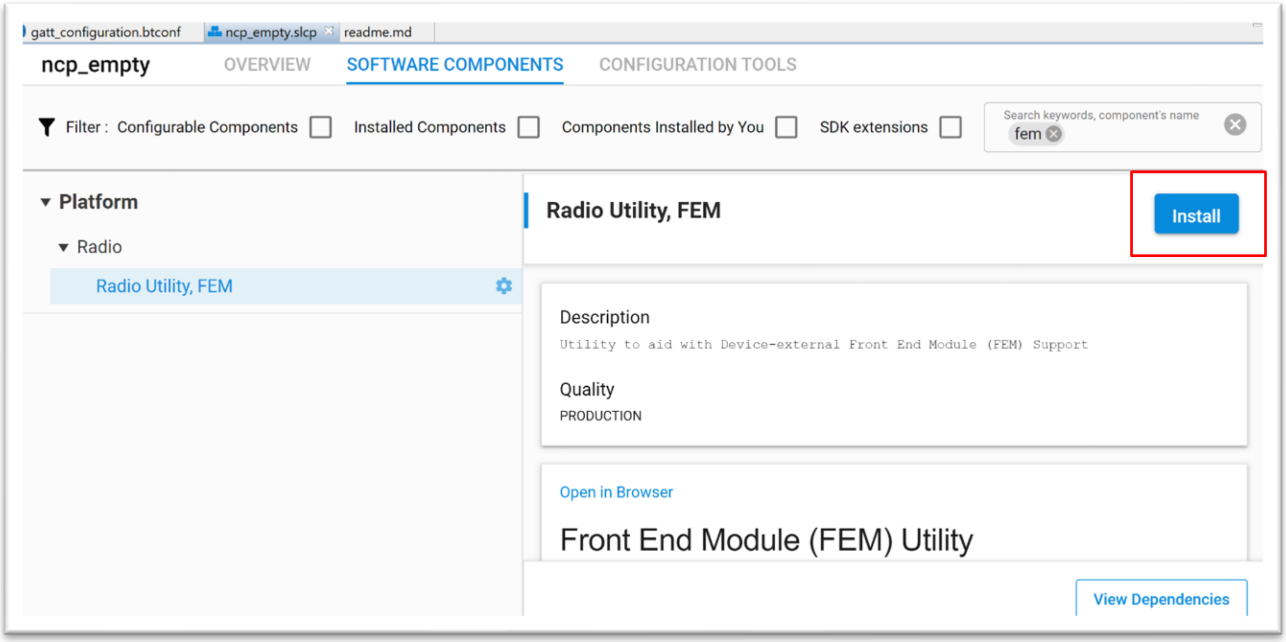




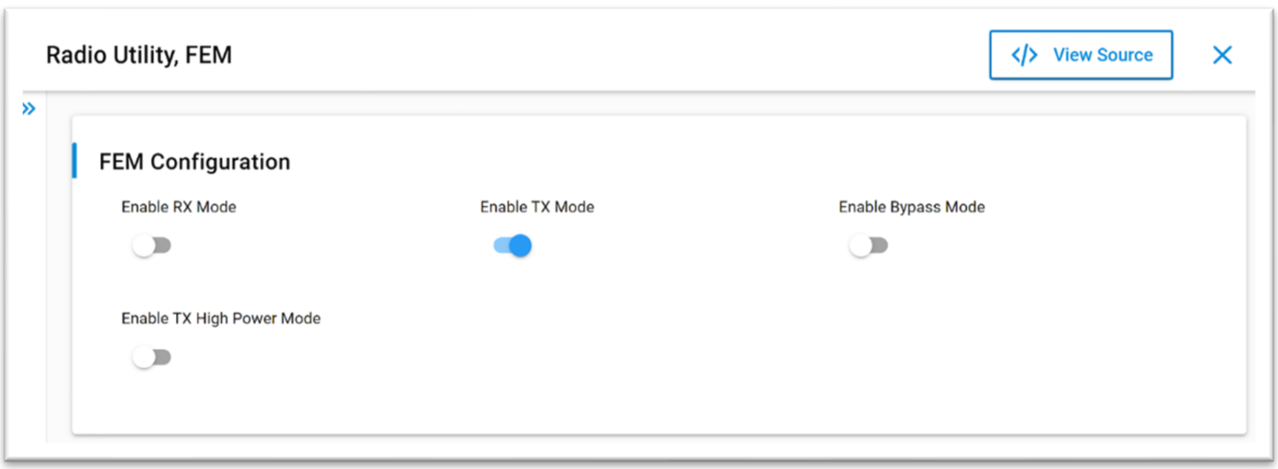
7. As described in the image below, configure the following pins:
   - "PB00" pin as a "REQUEST" signal
   - "PD02" pin as a "PRIORITY" signal
   - "PB01" pin as a "GRANT" signal



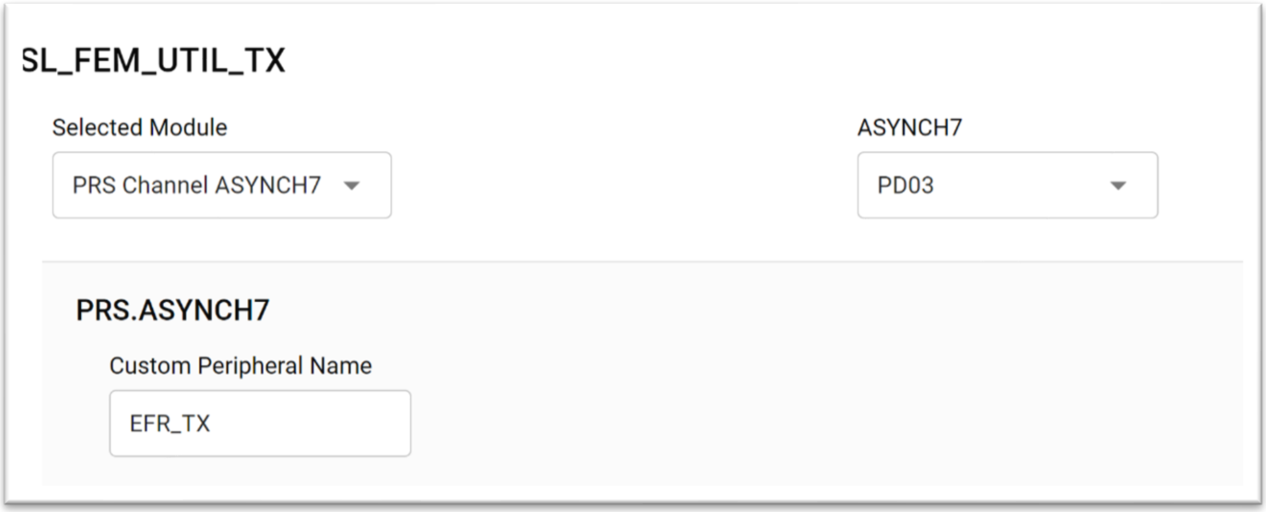
8. To watch the EFR32 TX transmission, install the "FEM" tool as shown below:



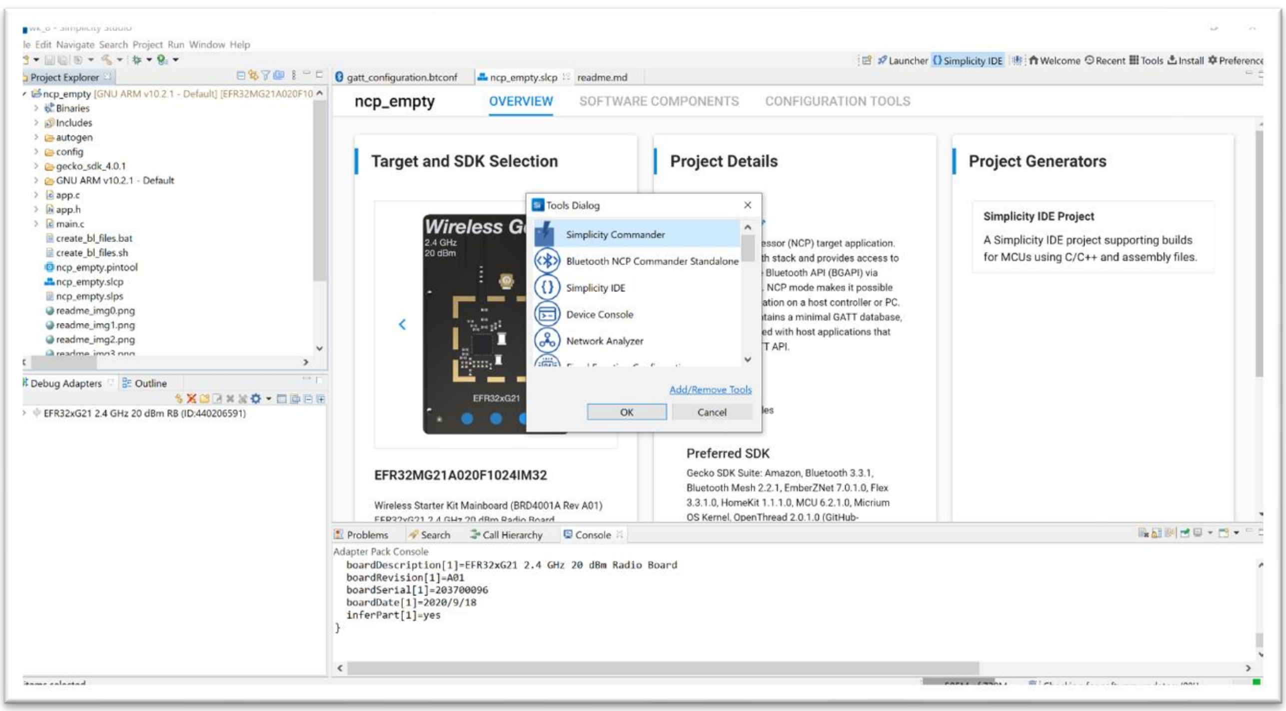
9. Enable the "Enable TX Mode" for enabling the TX signal monitoring.



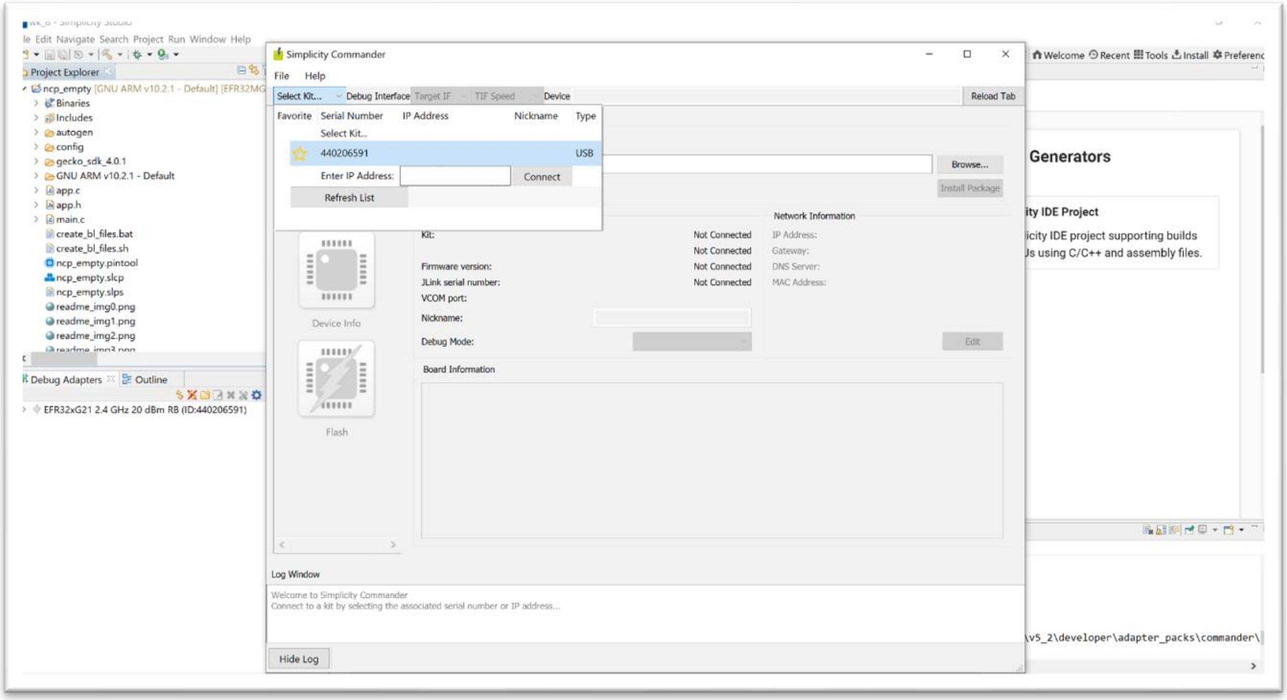
10. As described in the image below, configure the "PD03" pin as "EFR_TX."

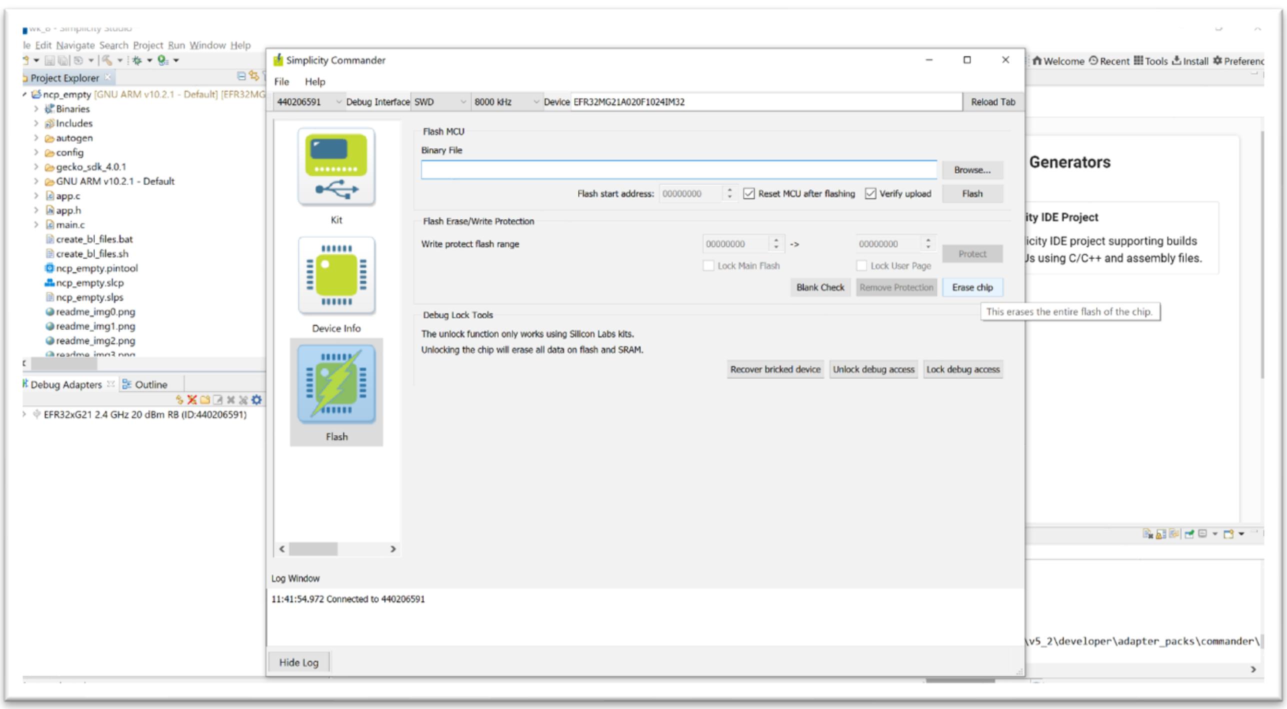


11. Clean and build the project.
12. As shown in the image below, navigate to the "Tools" -> "Simplicity Commander."

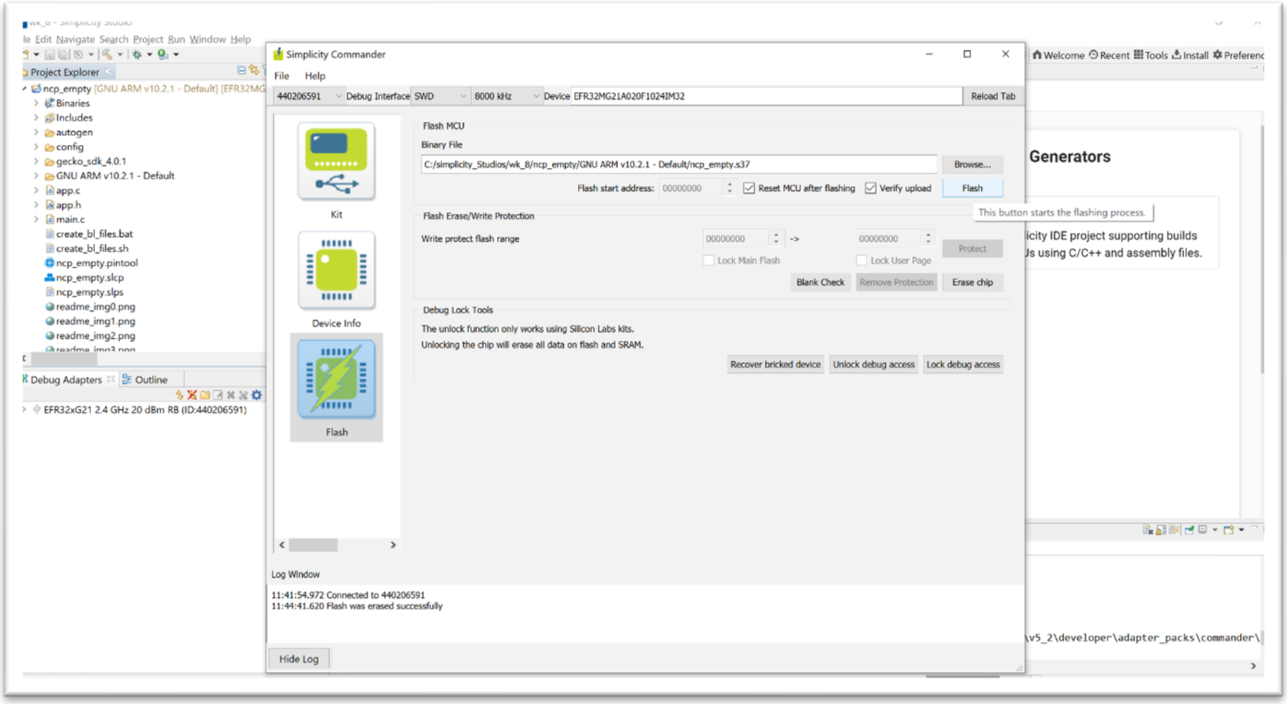


13. Select the connected EFR32 board and erase the full chip.



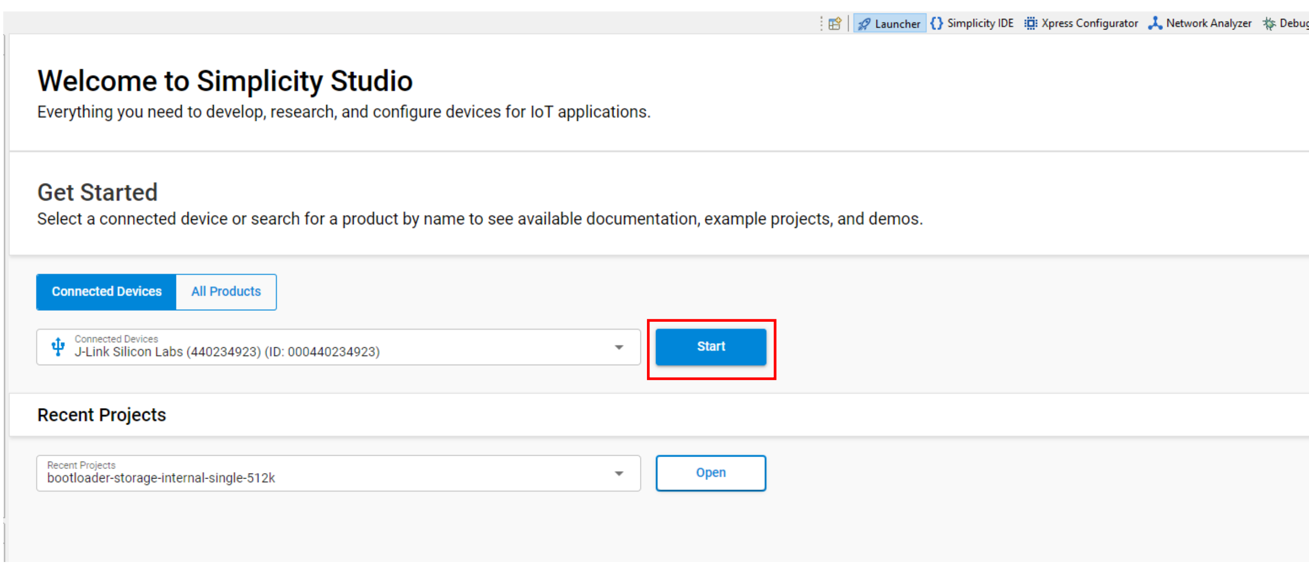


14. Flash the "bootloader" and then "project.s37". For details on the bootloader, refer to Section 5.1. Bootloader Generation Process.

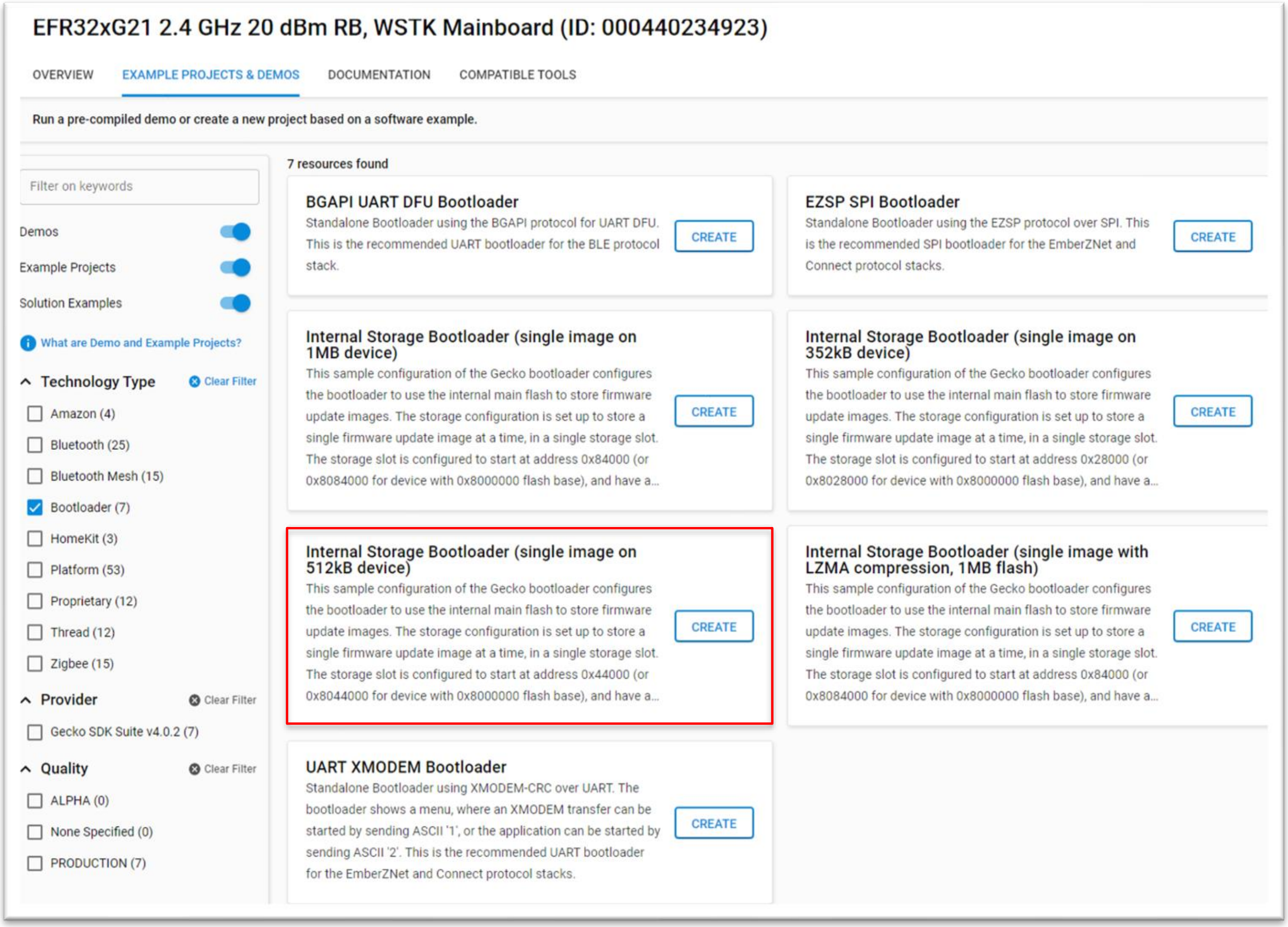


5.1 Bootloader Generation Process

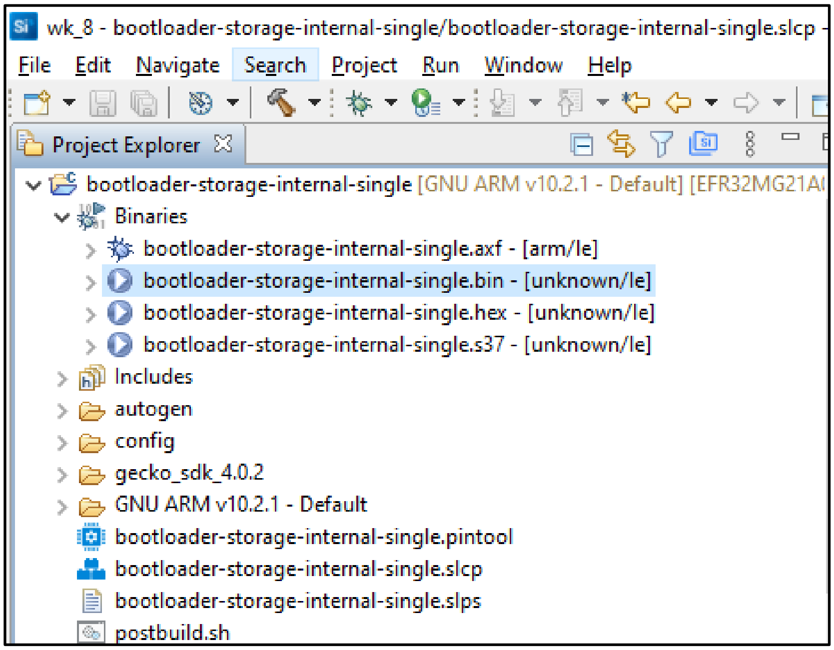
1. Connect the EFR32 device and then click on the start button as shown below:



2. Clicking the start button will automatically redirect to the EFR32 WSTK page. Navigate to the "Example Projects & demos" and select the "Bootloader," as shown below:



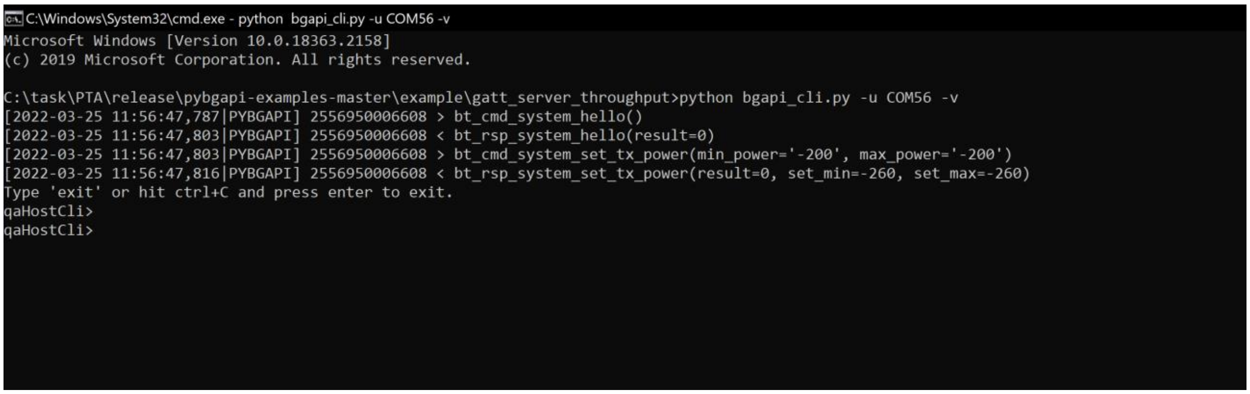
3. Click the “CREATE” button of the "Internal storage Bootloader (single image on 512kB device)" project.
4. When the project is generated successfully, build the project.
5. Once the project is built, the bootloader file will be generated successfully, as shown below. Please use the ".bin" file for the bootloader flashing.


wk_8 - bootloader-storage-internal-single/bootloader-storage-internal-single.slcp -
File Edit Navigate Search Project Run Window Help
Project Explorer
bootloader-storage-internal-single [GNU ARM v10.2.1 - Default] [EFR32MG21A
Binaries
bootloader-storage-internal-single.axf - [arm/le]
bootloader-storage-internal-single.bin - [unknown/le]
bootloader-storage-internal-single.hex - [unknown/le]
bootloader-storage-internal-single.s37 - [unknown/le]
Includes
autogen
config
gecko_sdk_4.0.2
GNU ARM v10.2.1 - Default
bootloader-storage-internal-single.pintool
bootloader-storage-internal-single.slcp
bootloader-storage-internal-single.slps
postbuild.sh

6 Application Configuration

6.1 PTA Secondary Application Configuration

- The EFR32 uses Python BGAPI commands which require the bgapi_cli.py script.
- Once the script is downloaded, navigate to the script's location, and use the below command to execute the script. It would be best to use the "COM" port, which is detected as a "Jlink" port.



- PTA secondary can be configured as a BLE peripheral or a BLE central device
- The following commands are used to make the EFR32 a peripheral device. Refer to the BGAPI documentation for more details.
  - advertiser_create_set
  - advertiser_set_timing $0 $0xA0 $0xA0 $0 $0
  - advertiser_start $0 $0x2 $0x2
  - advertiser_stop $0
- The following commands are used to setup the EFR32 as a BLE central device. Refer the BGAPI documentation for more details.
  - scanner_set_timing $5 $0xA0 $0x50
  - scanner_set_mode $5 $1
  - scanner_start $5 $0x2
  - scanner_stop

  The PTA Main allows the spectrum to the PTA Secondary based on the configuration.

6.2 PTA Main Application Configuration

- The RS9116W needs to use the throughput application. Refer to the throughput application for more details.
- The BIT(21) of RSI_CONFIG_FEATUERE_BITMAP is used to enable the PTA feature. The BIT(22) and BIT(23) are used to select the required PTA configuration. This bitmap selection is available in the "rsi_wlan_config.h" file. The RSI_CONFIG_FEATUERE_BITMAP gets enabled when BIT(31) is set to '1' in both RSI_TCP_IP_FEATURE_BIT_MAP and RSI_EXT_TCPIP_FEATURE_BITMAP.
- Below is the reference to enable and configure the PTA with CONFIGURATION 1 mode.

```
#define RSI_CONFIG_FEATURE_BITMAP (BIT(21) | BIT(22))
```

- Below is the reference to enable and configure the PTA with the CONFIGURATION 2 mode.

```
#define RSI_CONFIG_FEATURE_BITMAP (BIT(21) | BIT(23))
```

- Below is the reference to enable and configure the PTA with the CONFIGURATION 3 mode.

```
#define RSI_CONFIG_FEATURE_BITMAP (BIT(21) | BIT(22) | BIT(23))
```

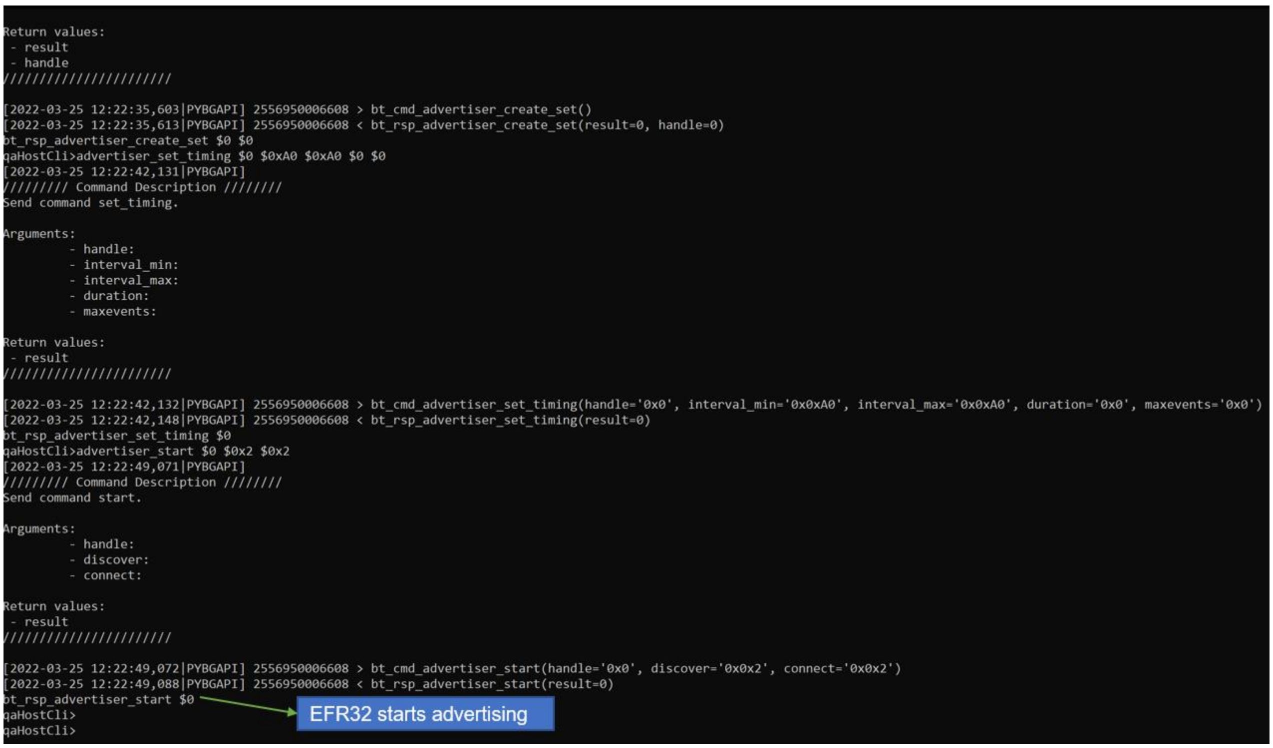
7 PTA Execution

7.1 Configuration1

- Configuration1 is the “Aggressive GRANT”. The PTA Main will aggressively assert GRANT if the REQUEST is asserted irrespective of the PRIORITY being asserted or not. When any ongoing transmission on Wi-Fi will be halted, GRANT will be provided to the PTA secondary.

Peripheral configuration:

- The EFR32 is configured as a BLE Peripheral device, and the RS9116W is configured in the Configuration1 mode.

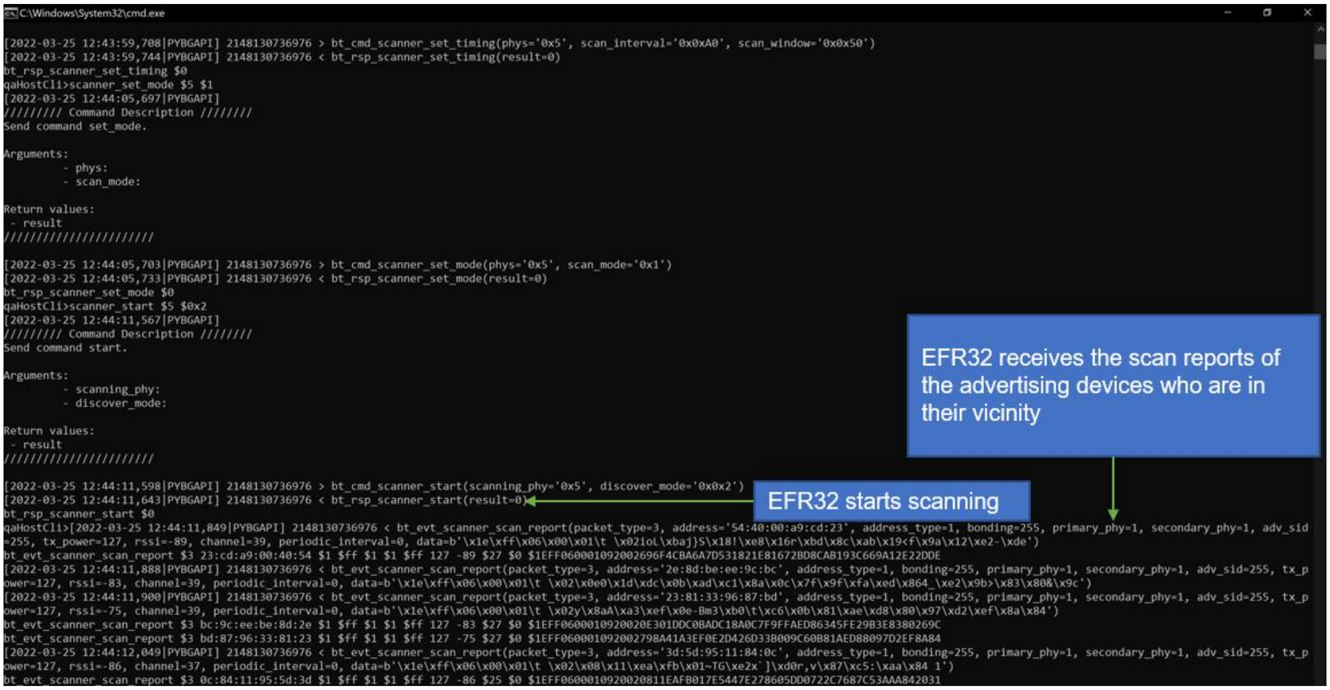


- The EFR32 sends the advertising packets for every 100 msec as per the commands provided. The RS9116W device asserts the GRANT at once whenever it receives the REQUEST from the PTA secondary.

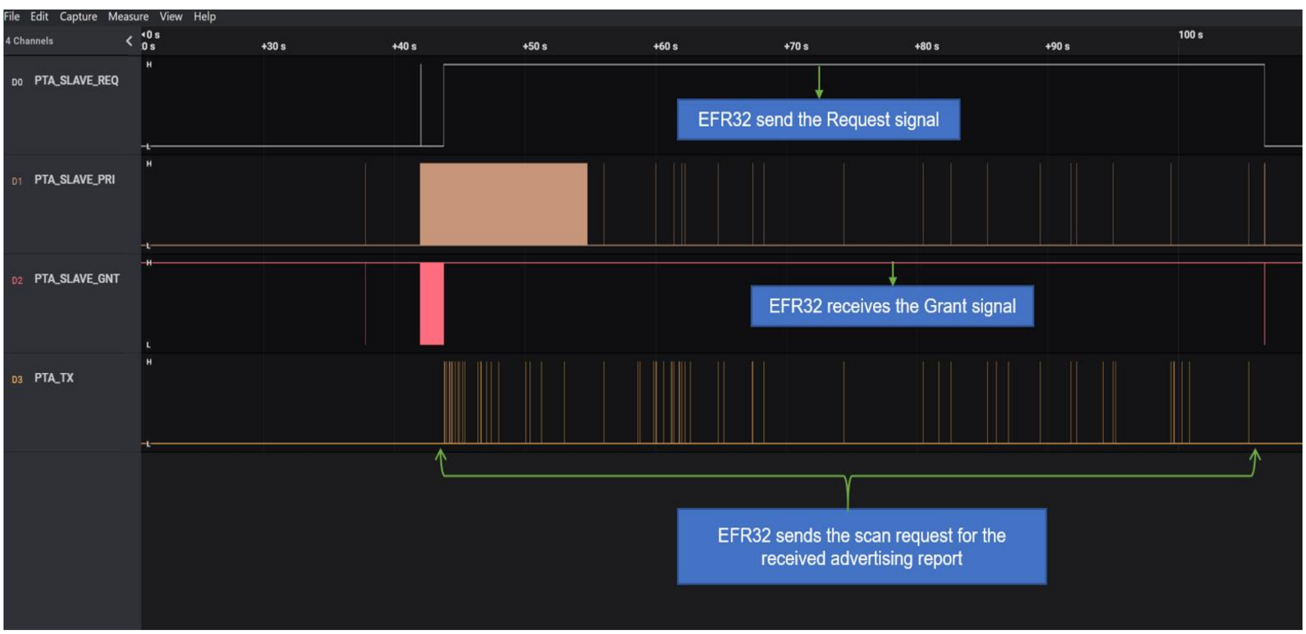
- When the EFR32 receives the GRANT, the EFR device sends the advertising packet in 3 advertising channels.

Central Configuration:

- The EFR32 is configured as a BLE Central device, and the RS9116W is configured in the Configuration1 mode.



- Once the "scan_start" command is issued from the BGAPI script, then the EFR32 will keep the "REQUEST" signal high until the EFR32 receives the "scan_stop" command. As the RS9116W device asserts the GRANT at once whenever it receives the REQUEST from the PTA secondary; hence both the "REQUEST" and "GRANT" lines are high until the "scan_stops" command.



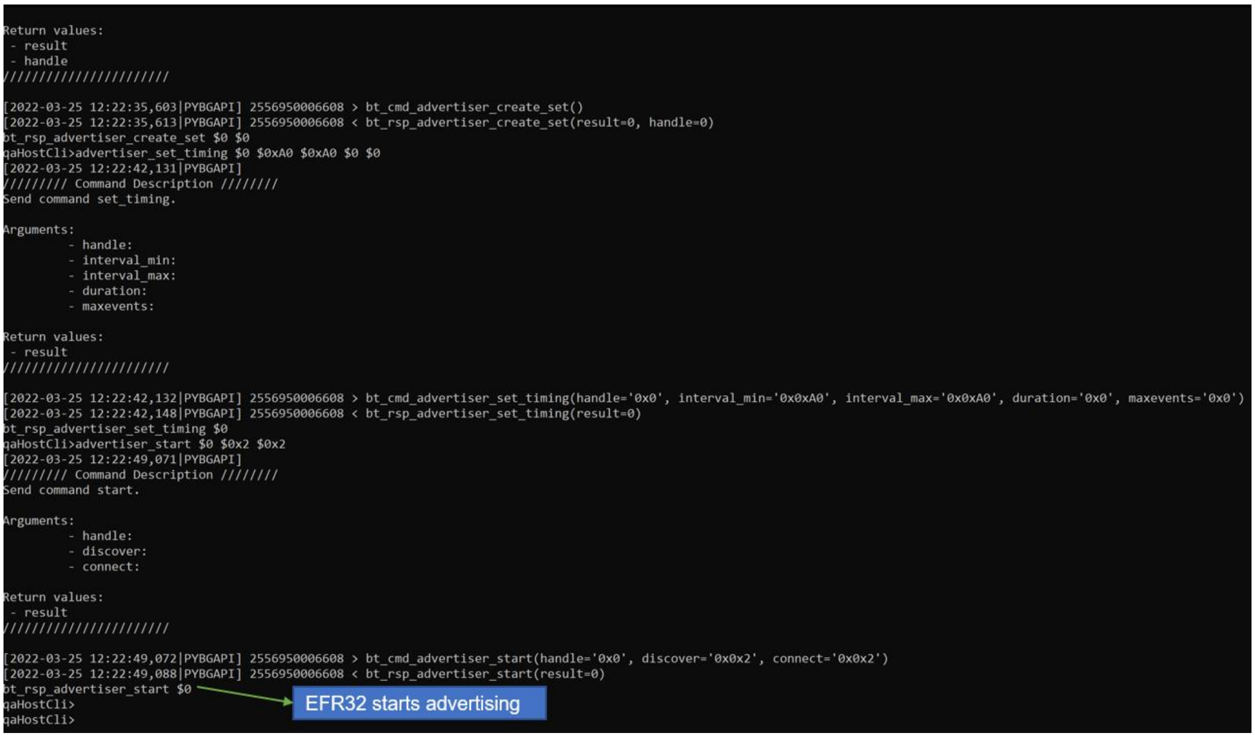
7.2 Configuration2

- Configuration 2 is “Protect Response Tx”. The PTA Main asserts the GRANT if the REQUEST is asserted in the response without consideration of the PRIORITY signal, with only one exception of an ongoing ACK/Block ACK

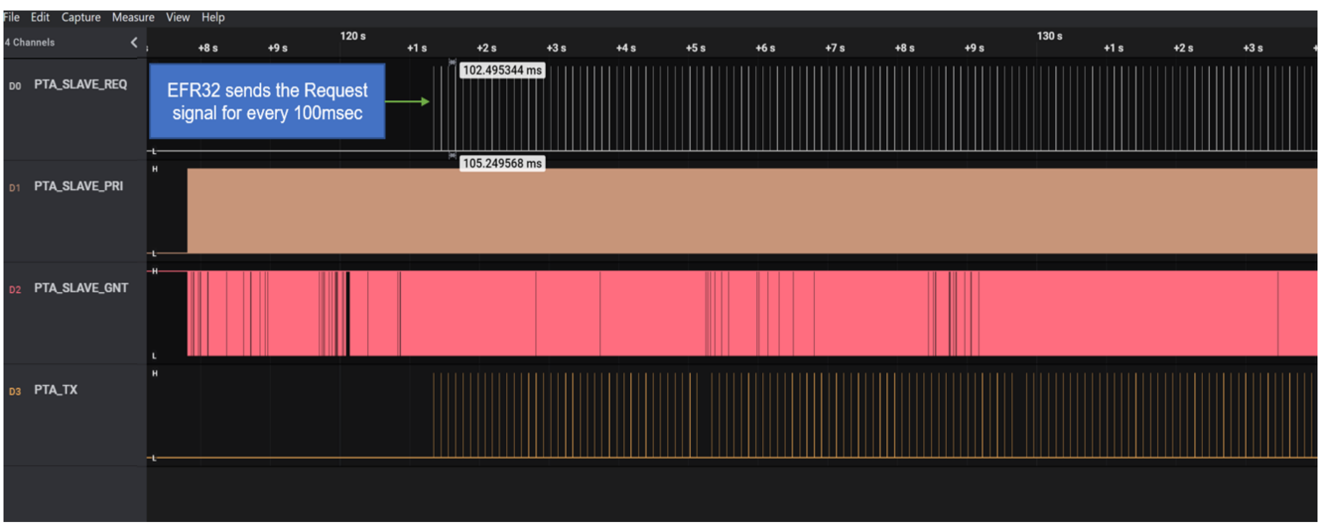
Transmission in response to a Wi-Fi reception. If there is any ongoing ACK/Block ACK transmission in response to a Wi-Fi Reception, PTA MAIN will GRANT the spectrum access only if PRIORITY is asserted along with REQUEST.

Peripheral Configuration:

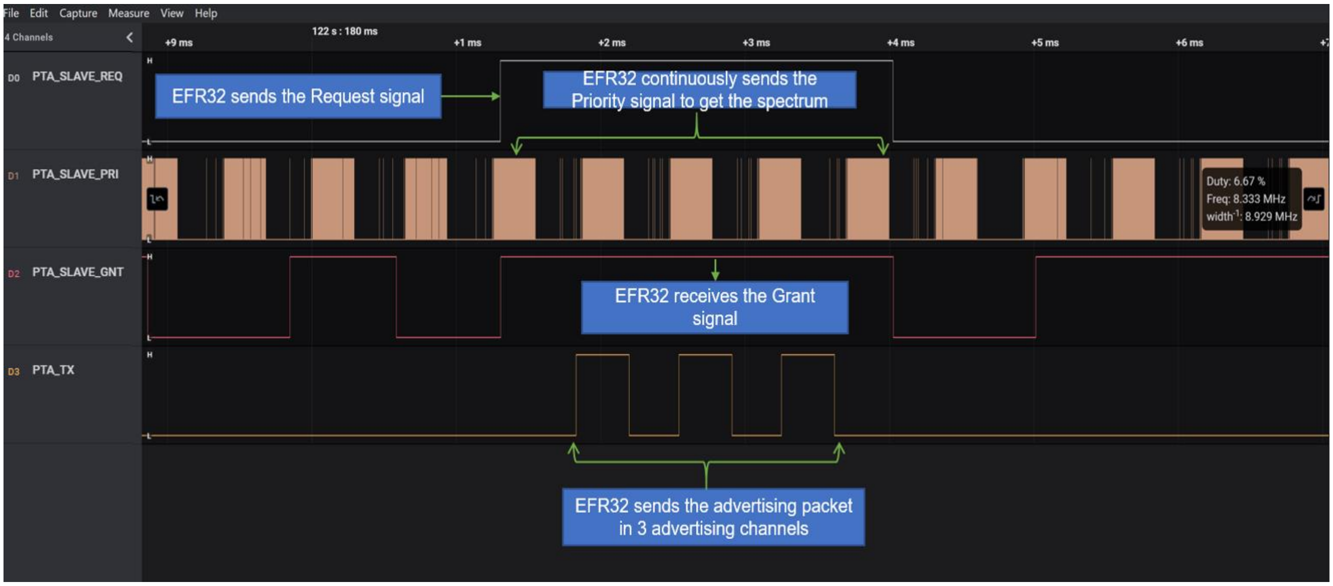
- The EFR32 is configured as a BLE Peripheral device, and the RS9116W is configured in the Configuration2 mode.



- The EFR32 sends the advertising packets for every 100 msec as per the commands provided. When the PTA secondary needs spectrum access, then it sends the "REQUEST" and the "PRIORITY" signals if the RS9116W device Will assert the "GRANT" signal if it doesn't have any Wi-Fi ACK/Block ACK transmissions.

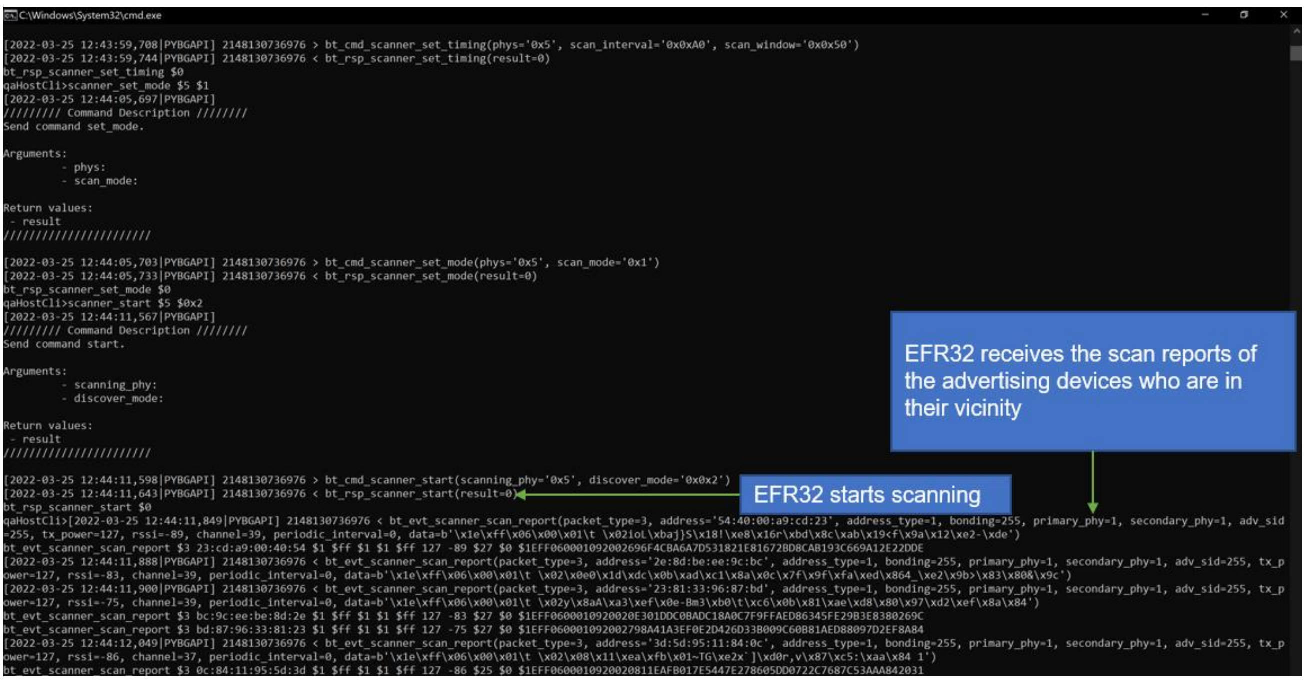


- When the EFR32 receives the GRANT, the EFR device sends the advertising packet to all three advertising channels.



Central Configuration:

- The EFR32 is configured as a BLE Central device, and the RS9116W is configured in the Configuration2 mode.



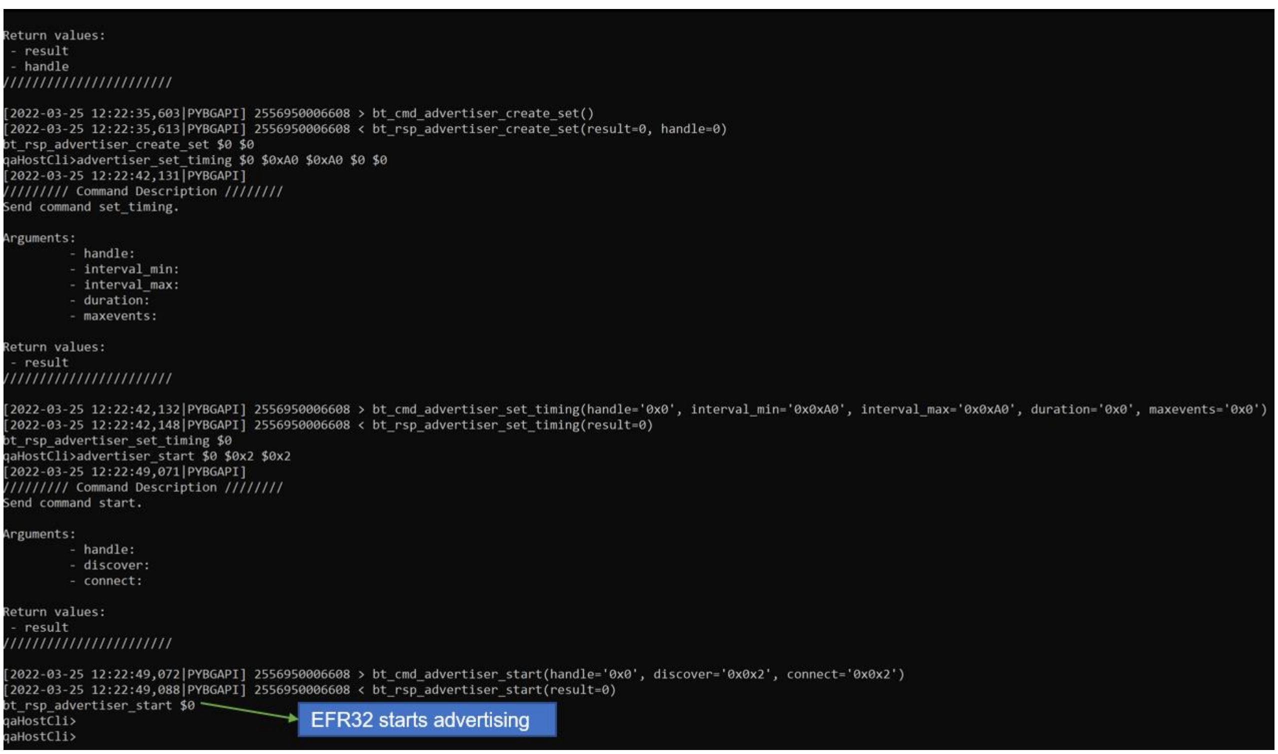
- Once the "scan_start" command is issued from the BGAPI script, then the EFR32 will keep the "REQUEST" signal high until the EFR32 receives the "scan_stop" command. And the EFR32 continuously sends the "PRIORITY" signals for the spectrum access if the RS9116W device Will assert the "GRANT" signal if it doesn't have any Wi-Fi ACK/Block ACK transmissions.

7.3 Configuration3

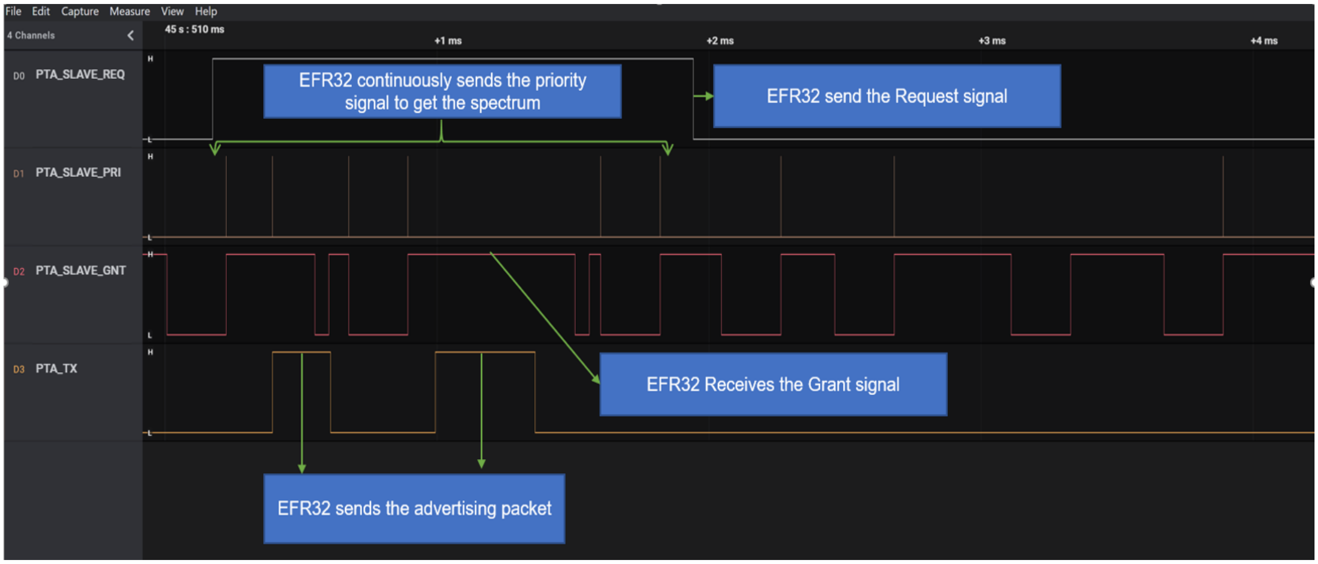
- Configuration 3 is “Protect both Tx and Response TX”. When the PTA secondary needs the spectrum, it sends both REQUEST and PRIORITY signals. PTA Main will assert GRANT, and the Wi-Fi will hold any ongoing transmission, including ACK/BLOCK transmission.

Peripheral Configuration:

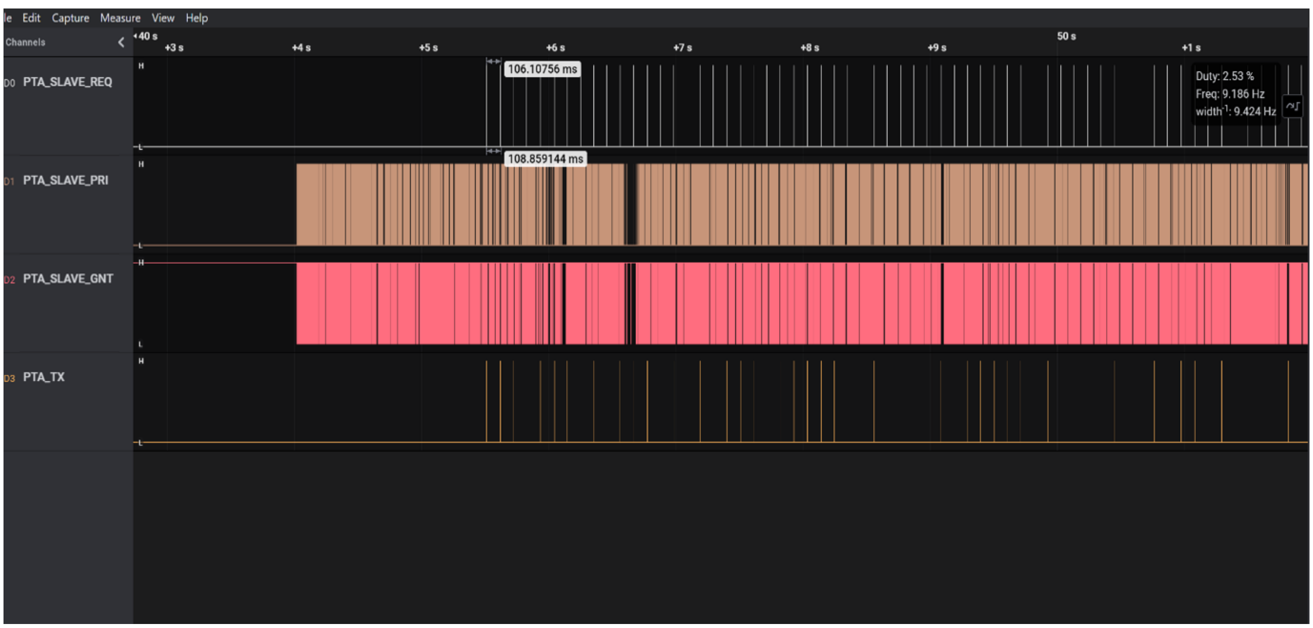
- The EFR32 is configured as a BLE Peripheral device, and the RS9116W is configured in the Configuration3 mode.



- As per the commands provided, the EFR32 sends the advertising packets for every 100msec. When the PTA secondary needs spectrum access, then it sends the "REQUEST" and the "PRIORITY" signals if the RS9116W device Will assert the "GRANT" signal if it doesn't have any ongoing Wi-Fi transmission.

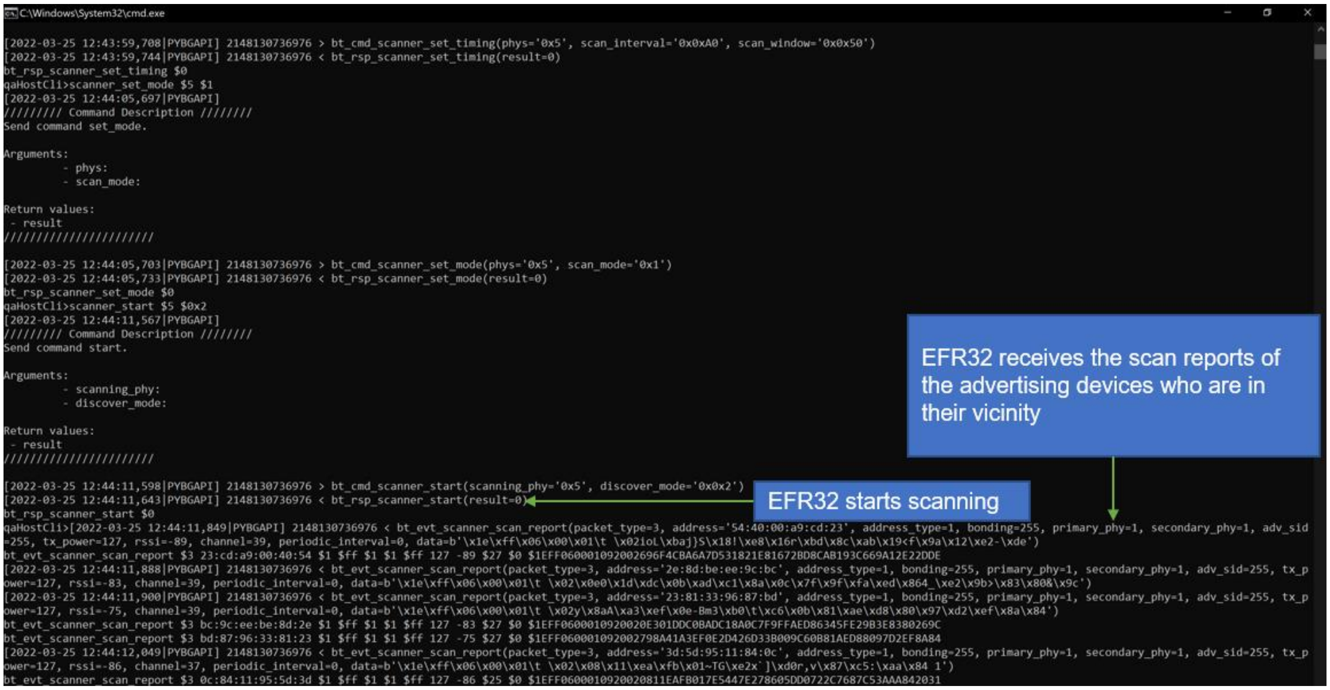


- When the EFR32 receives the GRANT signal, based on the GRANT signal duration and advertising configuration, the EFR32 tries to send the advertising packet to all the three advertising channels. Still, sometimes it sends the advertising packet in one or two channels only depending on the received GRANT signal duration.

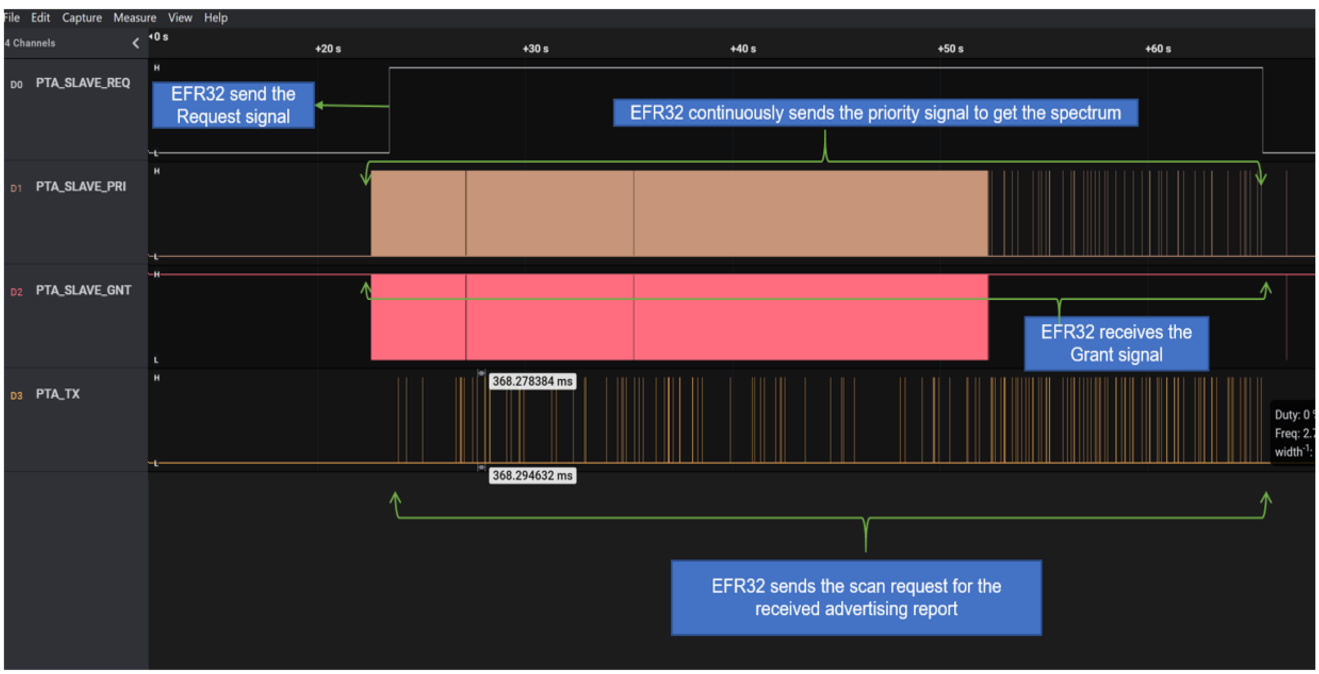


Central Configuration:

- The EFR32 is configured as a BLE Central device, and the RS9116W is configured in the Configuration3 mode.



- Once the "scan_start" command is issued from the BGAPI script, then the EFR32 will continuously send both "REQUEST" and "PRIORITY" signals for spectrum access. When the RS9116W device Will assert the "GRANT" signal if it doesn't have any ongoing Wi-Fi transmission.



8 Use Case Scenario

The current implementation of PTA will work for the following scenarios listed below.

- Low Wi-Fi usage and low Wi-Fi throughput use case. And where occasional Wi-Fi disconnects can be accepted. However, test results don't exhibit any Wi-Fi disconnection unless the REQUEST/Priority Frequency goes high. All the above three configurations can be used for this use case
- Moderate traffic on the EFR32 (i.e., BT Classic/BLE, Zigbee, THREAD) and certain transmit throughput requirements on the Wi-Fi side, Configuration3 can be used.
- Moderate Traffic on both EFR32 and Wi-Fi

The current implementation has the following limitations:

- Heavy interference on Wi-Fi reception on the same channel might result in Wi-Fi disconnects as reception is not protected on Wi-Fi
- If there are strict throughput requirements on both protocols, the mechanism is not sophisticated enough to guarantee that.
- PTA functionality will not work with WLAN power save enabled.

NOTE:

Refer to the implementation on the EFR32 side as listed in Section 9. References. There are various configuration options available on the EFR32 side, use a case-based selection of configuration options on the EFR32 side will result in the best performance.

9 References

- RS9116W API documentation: https://docs.silabs.com/rs9116-wiseconnect/latest/wifibt-wc-sapi-reference/
- ZigBee & Open Thread Co-Existence with Wi-Fi: https://www.silabs.com/documents/public/application-notes/an1017-coexistence-with-wifi.pdf
- Bluetooth Co-Existence with Wi-Fi: https://www.silabs.com/documents/public/application-notes/an1128-bluetooth-coexistence-with-wifi.pdf

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