# User Manual

## SmartBond™ WiRa™ Wireless Ranging SDK

### UM-B-137


### Abstract

*This document provides basic information to help developers get familiar with the DA1469x Wireless Ranging application and modify or create a new Wireless Ranging application based on it.*

# Contents



## Figures



# 1 Terms and Definitions

| | |
|---|---|
| ADC | Analog-to-Digital Converter |
| AGC | Automatic Gain Control |
| API | Application Programming Interface |
| BLE | Bluetooth® Low Energy |
| CLI | Command-Line Interface |
| CMAC | Configurable Medium Access Controller |
| DK | Development Kit |
| DTE | Dialog Tone Exchange |
| GAP | Generic Access Profile |
| GATT | Generic Attribute Profile |
| GPIO | General purpose Input Output |
| IFFT | Inverse Fast Fourier Transform |
| IQ | In-Phase and Quadrature |
| ISM | Industrial, Scientific, and Medical (radio band) |
| LCD | Liquid-Crystal Display |
| LE | Low Energy |
| Msps | Mega samples per second |
| MTU | Maximum Transmission Unit |
| NVM | Non-Volatile Memory |
| PDU | Protocol Data Unit |
| RSSI | Receive Signal Strength Indication |
| SDK | Software Development Kit |
| UART | Universal Asynchronous Receiver-Transmitter |
| USB | Universal Serial Bus |
| UUID | Universally Unique Identifier |

# 2 References

[1] DA1469x, Datasheet, Renesas Electronics.

[2] UM-B-057, SmartSnippets™ Studio User Guide, User Manual, Renesas Electronics.

[3] UM-B-092, DA1469x Software Platform Reference, User Manual, Renesas Electronics.

[4] UM-B-093, DA1469x PRO Development Kit, User Manual, Renesas Electronics.

[5] UM-B-103, DA14695 USB Kit, User Manual, Renesas Electronics.

# 3 Introduction

The estimation of range, or distancing between two (or more) objects by the use of radio waves is not new. In fact, the use of RF signal strength measurement, RSSI (Receive Signal Strength Indication) has been in use for decades. While in a noise-free, “free space” environment with clear line-of-sight this technique can yield quite accurate results while only consuming nominal power, in more typical environments, such as indoors and especially when in a product being worn or moved around, multipath (reflected version of the “direct path” signal, bouncing off walls/floors/and so on) as well as attenuation of the direct path signal (blocked by hands, arms, bodies, furniture, and so on) presents a real challenge to RSSI, which intrinsically relies on the RF signal’s amplitude to estimate distance.

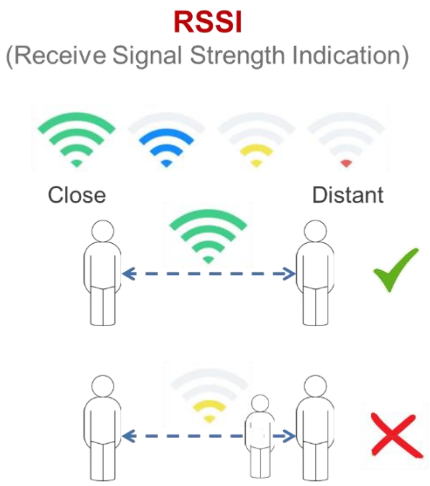



**Figure 1: Use of RSSI in a Noise-Free Environment**

An alternative approach to the use of RF signal amplitude (RSSI) estimating has been developed and made available by Renesas. This technique has been trademarked WiRa™ (Wireless Ranging) and instead of relying on amplitude measurements, it utilizes phase-based ranging. In this alternative approach, the phase difference between adjacent ISM band channels is measured and since the two channels are at different (known) frequencies, this phase difference will change over distance in direct proportion to the distance traveled.

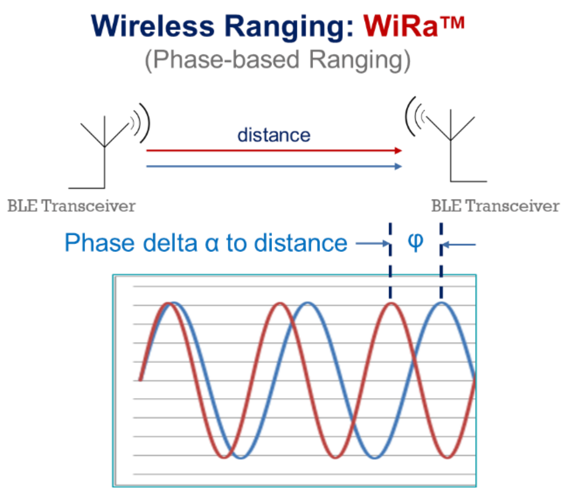



**Figure 2: Wireless Ranging (WiRa) Technique**

Whilst WiRa ranging can be far more tolerant to the direct path’s signal attenuation, on its own this technique is still vulnerable to multipath signal noise. Renesas has therefore developed advanced algorithms to help address this issue.

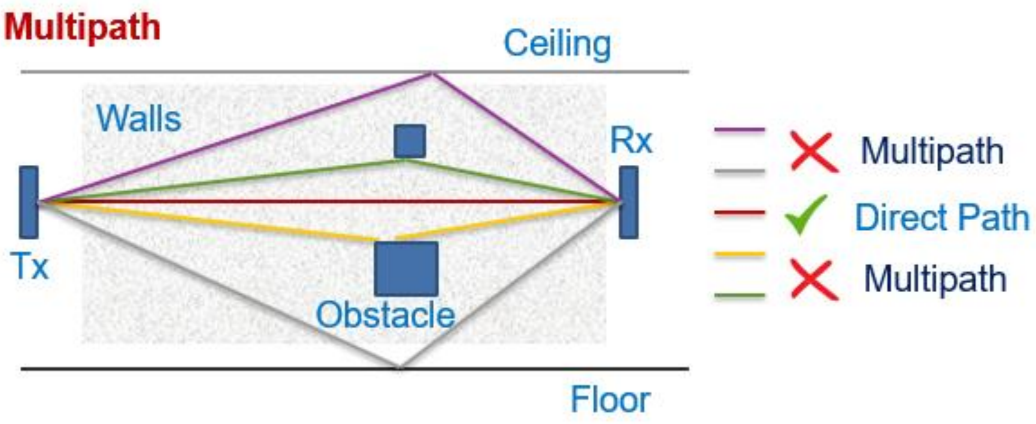



**Figure 3: Multipath in a Typical Indoor Environment**

WiRa operates in the unlicensed 2.4 GHz ISM (Industrial, Scientific, Medical) band and therefore has to tolerate noise sources from other ISM band constituents (for example, Bluetooth® LE, Wi-Fi, and so on) and the WiRa SDK includes an interference filtering solution that can tolerate strong noise presence in multiple channels.

Renesas delivers the WiRa™ SDK today, without licensing fees or royalties and you are invited to test, field trial, and deploy what we have developed. WiRa™ SDK runs on the DA1469x family of Bluetooth® LE SoCs.

# 4 WiRa Measurement Technology

## 4.1 Dialog Tone Exchange (DTE)

The distance between two devices is calculated by measuring the phase difference of continuous wave signals at various frequencies that travel from one device to the other. Knowing this phase difference one can calculate the distance between the two devices.

To achieve this, both devices exchange continuous wave signals (tones) on a pre-defined set of frequencies at pre-defined points in time. This procedure is called Dialog Tone Exchange (DTE). The device that initiates this procedure is called the Initiator and the other device is called the Responder.

The Initiator transmits a tone at a specific frequency. The Responder receives this tone and captures the In-phase and Quadrature (IQ) data of the tone. Then roles are exchanged. The Responder transmits a tone and the Initiator receives the tone and captures the IQ data. The above procedure is called an atom and is repeated for all frequencies in the pre-defined set of frequencies.

The following parameters of DTE can be configured for each device:

- The role, either Initiator or Responder
- The set of frequencies used in the tone exchange. The set is defined by setting the starting frequency, the frequency step, and the number of frequencies to use. The maximum number is 40 frequencies
- The duration of each tone. The default value is 56 µs
- The *Radio* transmit power during DTE. The default value is the maximum power (+6 dBm)

The devices must be synchronized to accurately calculate the phase difference of arrival (PDoA) between sequential tones of different frequencies.

The signal magnitude A and phase angle Ø of each tone exchanged are calculated as:

$$A^2 = I^2 + Q^2 \qquad (1)$$

$$\emptyset = arc\tan\left(\frac{Q}{I}\right) \qquad (2)$$

Both devices calculate the phase and amplitude data of the received tones. The Responder then sends the results to the Initiator. The Initiator uses all results to calculate the distance.

A BLE connection is used for both the DTE synchronization and the exchange of the phase and amplitude results using a custom BLE DTE Data service.

The tone exchange synchronization is based on the TX and RX timestamps related to the last packet transmission of the BLE connection event. The tone exchange starts at a pre-defined time offset after the last BLE packet transmission.

This exchange takes place in specific connection events. To achieve event synchronization, the BLE connection event counter is used. In a BLE connection, the role of the Initiator device is assigned to the central node and the Responder is assigned to the peripheral. The Initiator transmits to the Responder a “start request” control packet that contains an event counter value for a connection event instance in the future. At the end of the event that matches that counter, the tone exchange takes place, assuming that the Responder has enough time to receive this information and prepare for the tone exchange before that instance passes.

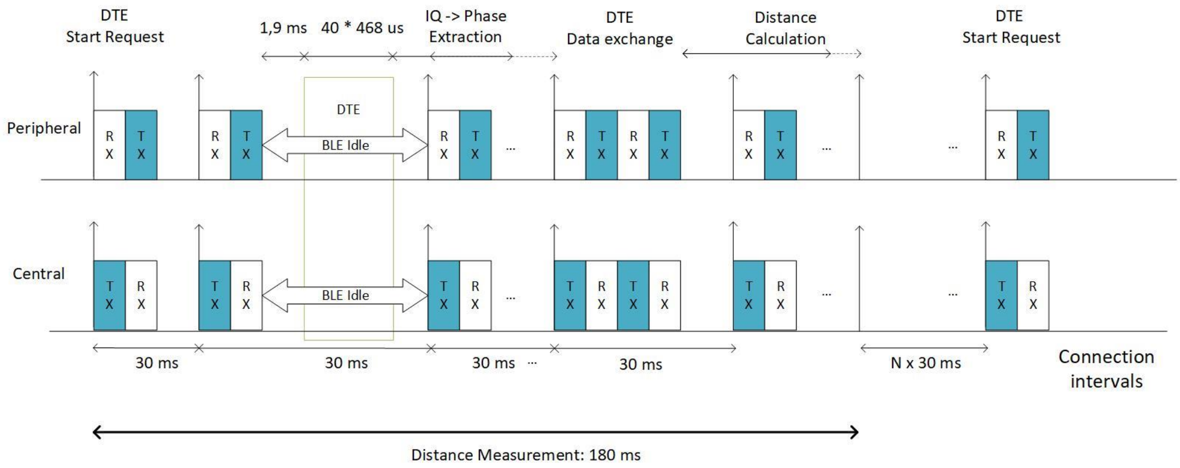



**Figure 3: Distance Measurement Timeline**

## 4.2 Data Flow

The WiRa devices work in pairs. Each pair consists of one Initiator and one Responder device. When a connection is established between the Initiator and the Responder, the distance calculation procedure starts. The following sequence is executed to calculate the distance between the two devices:

1. The Initiator sends a Link Layer DTE START measurement request with a connection event counter that refers to a future instance
2. When that instance comes, the two devices synchronize and carry out the tone exchange
3. Both devices perform the phase calculations
4. The Responder device sends the intermediate results to the Initiator
5. The Initiator device combines the local and remote results received by the Responder, calculates the distance, and optionally sends the distance measurement to the Responder

Figure 4 shows the above steps. The last step is optional and represented with dotted arrows.

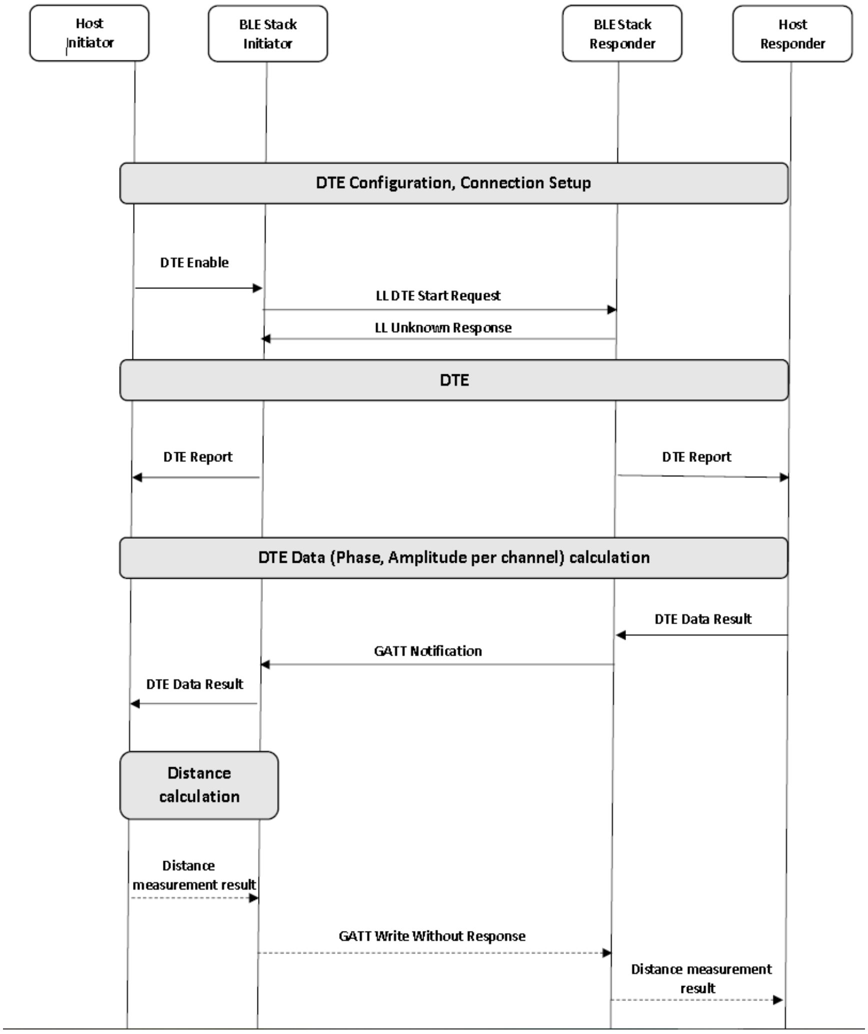



**Figure 4: Application Data Flow**

## 4.3 Implementation

### 4.3.1 IQ Data Acquisition

The radio is equipped with a hardware monitoring block (RFMON) that gets the data provided by the RF Unit, packs the data in 32-bit words, and stores them in the system memory. These data contain the 9-bit RF-ADC samples (IQ data) that are sampled at a frequency of 8 Msps.

The DTE module is responsible for the collection of IQ data for different frequencies. For each frequency, IQ data are collected through the RF monitor block to the IQ data buffer. At the end of the DTE, the data buffer contains the IQ data slices for the tones received in all frequencies.

### 4.3.2 Distance Calculation Algorithms

When the acquisition is finished, distance results are extracted from the sampled measurement data. All operations specific to distance estimation are implemented inside directory `sdk/interfaces/ble/wira/src/calc/`.

There are three algorithms available for distance calculation:

- Phase-based distance calculation (Section 4.3.2.1)
- Matrix pencil-based distance calculation (Section 4.3.2.2)
- IFFT-based distance calculation (Section 4.3.2.2)

The following steps are common to all algorithms:

1. Input data pre-conditioning:
   a. Extract IQ data from acquired test bus data samples (sampling rate of 8 Msps).
   b. Sample down by a factor of two to a sampling rate of 4 Msps. The number of samples to be processed is drastically reduced but the data samples still yield similar results.
2. Extract one representative sample per atom/measurement frequency (output data of this step is called "device-specific frequency profile" here):
   a. Compensate DC offset per atom (can be deactivated by defining `CWD_COMP_DC_OFFSET` to "false" in `sdk/ble/wira/src/calc/cw_distance_internal.h`).
   b. Go from the IQ domain into a polar domain (extract phases and magnitudes).
   c. Mix phases down by the intermediate frequency `f_if`.
   d. Apply a linear fit on the phase data of each atom to get one frequency offset and one phase value per atom.
   e. Average magnitude values to get one magnitude per atom.
3. Average frequency offset for all atoms.
4. Send the frequency profile of the Responder to the Initiator.

#### 4.3.2.1 Phase-Based Distance Calculation

If neither `WIRA_USE_MATRIX_PENCIL_DIST_CALC` nor `WIRA_USE_IFFT_DIST_CALC` are defined in the demo application's `wira_config.h`, then the phase-based distance calculation algorithm is used. The distance is determined as follows:

1. Retrieve the sum phase data of both devices per atom to get a Channel Frequency Profile.
2. Estimate the slope of the Channel Frequency Profile (phases).
   a. Build phase differences between subsequent phase values.
   b. Average phase differences.
3. Map the estimated phase difference to a distance and take that as the estimated result.

The underlying relation between distance $D$, phase difference $\Delta\varphi$, frequency difference $\Delta f$, and speed of light $c$ is:

$$D = \frac{c}{4\pi} \times \frac{-1 \times \sum_{N-1} \Delta\varphi_n}{(N - 1) \times \Delta f} \quad (3)$$

where:

- $D$ is the distance in m
- $c$ is the speed of light in m/s
- $\Delta\varphi$ is the phase difference in radians
- $\Delta f$ is the frequency difference in Hz
- $N$ is the number of atoms

#### 4.3.2.2 Matrix Pencil or IFFT-Based Distance Calculation

The following steps are common regardless of the algorithm used for final distance calculation:

1. Combine device-specific frequency profiles into measurement-specific time offset function (`phase_minus`).
   a. Subtract Responder phases from Initiator phases.
2. Calculate offsets:
   a. Differentiate `phase_minus`.
   b. Determine the quadratic component (`c_quad`) of `phase_minus`.
   c. Correct quadratic component of `phase_minus`.

   d. Determine linear component (`c_lin`) of `phase_minus`.
3. Remove offsets:
   a. Create correction function `offsets`.
   b. Correct Initiator and Responder phases and calculate the corresponding channel transfer functions `phase_init_corr` and `phase_refl_corr`.
4. Fuse Initiator and Responder channel transfer functions:
   a. Combine `phase_init_corr` and `phase_refl_corr` into `com_IQ_fused`.

Matrix pencil-based distance calculation algorithm is used, if `WIRA_USE_MATRIX_PENCIL_DIST_CALC` is defined and `WIRA_USE_IFFT_DIST_CALC` is undefined. Then the distance is determined by feeding the fused channel frequency response to Matrix Pencil processing block:

1. Estimate the path delay for each atom.
2. Find the shortest path delay and map its value to a distance.

IFFT-based distance calculation algorithm is used, if `WIRA_USE_IFFT_DIST_CALC` is defined and `WIRA_USE_MATRIX_PENCIL_DIST_CALC` is undefined.Then the distance is determined as follows:

1. Go to the time domain via iFFT to get fused one-way channel impulse response.
2. Detect the most reasonable peak of the fused one-way channel impulse response:
   a. Detect as many maxima of the Channel Impulse Response as frequencies have been used during the measurement (default: 40).
   b. Remove all peaks below a configurable threshold to filter the peak list.
   c. Calculate the corresponding distance to each peak above the threshold.
   d. Find the peak with the shortest distance and take that as the estimated result.

### 4.3.3 Distance Filtering

Two filters can be optionally applied to the raw distance measurements:

- **Sliding average filter:** The sample window size is controlled by the compile time switch `DIST_MA_WINDOW`
- **Kalman filter**: An algorithm that uses a series of measurements observed over time, containing statistical noise and other inaccuracies, is applied to produce estimates of unknown variables that tend to be more accurate than those based on a single measurement, by estimating a joint probability distribution over the variables for each timeframe. There is a tradeoff between responsiveness and smoothing of the output of the Kalman filter, that can be controlled by variance process noise (q) and variance measurement noise (S) parameters. Visualization of the impact of S and q parameters are shown in Figure 5 and Figure 6.

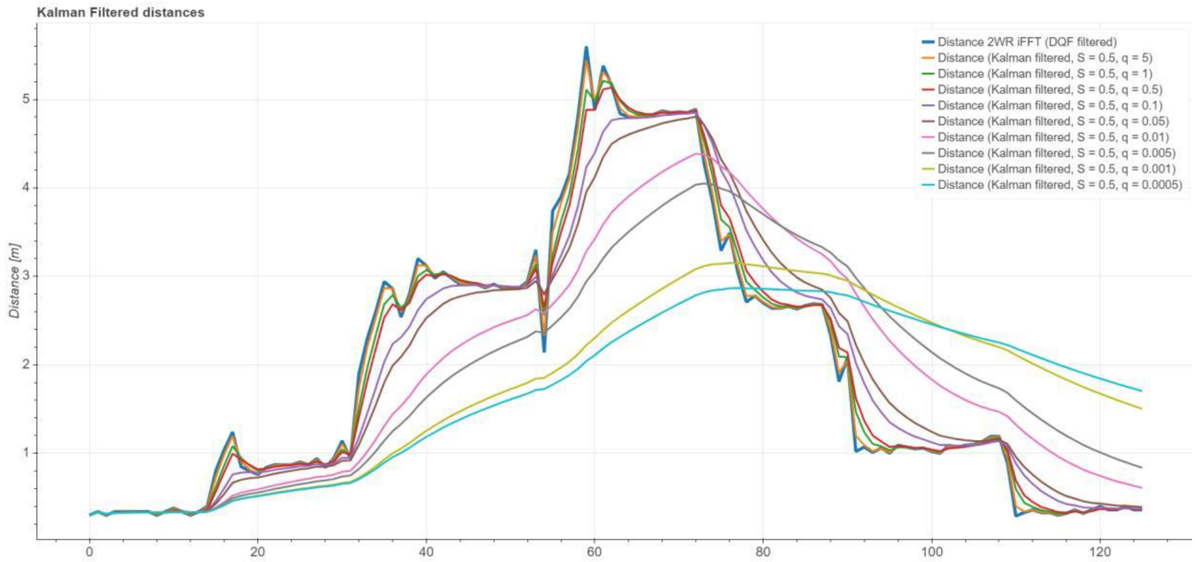



**Figure 5: Influence of Process Noise Variance in Kalman's Filter Responsiveness**

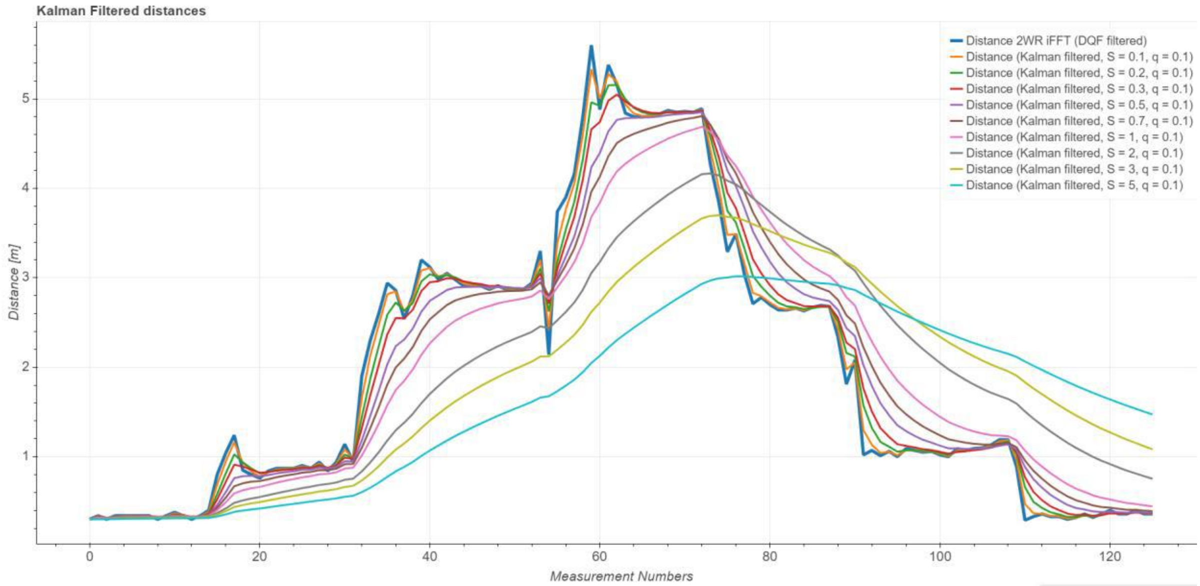



**Figure 6: Influence of Measurement Noise Variance in Kalman's Filter Responsiveness**

The default value for variance process noise (q) is 0.1 and for variance measurement noise it is 0.5.

## 4.4 Software Architecture

Figure 7 presents different software blocks of the WiRa application. Each rectangle indicates a module. The dashed blocks represent optional features that can be enabled for specific demo applications at compile time.

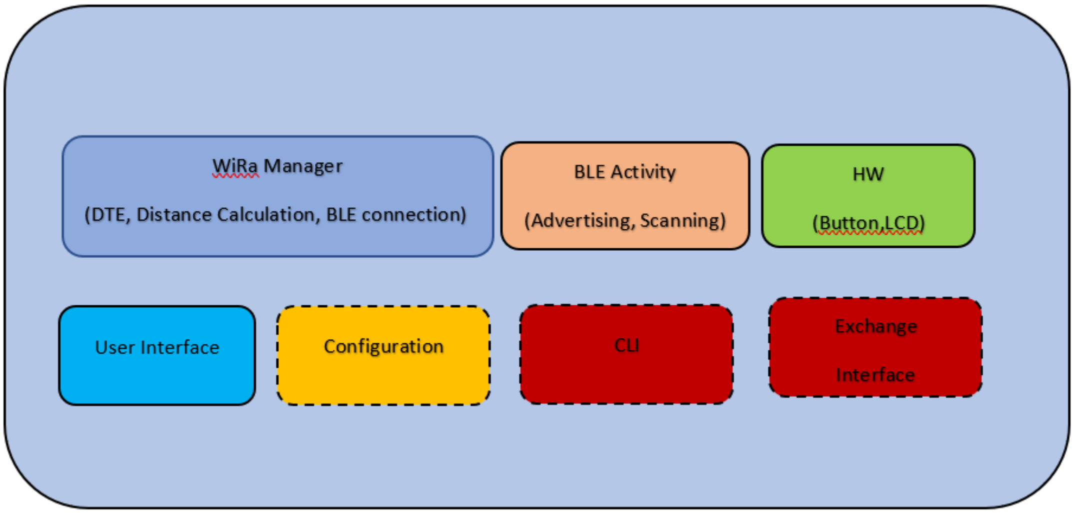



**Figure 7: WiRa Application Software Modules**

WiRa manager is responsible for the DTE configuration, the initialization of the Initiator and the Responder, the connection between them, and for starting a WiRa measurement. A detailed description can be found in Section 4.5.

The BLE activity module set a Responder to the advertising state to be detected from an Initiator which is set to the scanning state.

The hardware module consists of an LCD and buttons to make WiRa applications user-friendly.

The high-level interface function `wira_lcd_init()` initializes the display and the function `wira_lcd_draw_measurement_string()` draws a string with the RSSI and the distance measurement value in a display.

The K1 button press is detected by checking the level of the GPIO which is connected to the button.

For the available WiRa applications, a button press either sets the device in configuration mode or prints WiRa statistics depending on the duration of the button press.

The User interface module contains different font implementations and basic graphic functions for text drawing in an LCD. If `CONFIG_USE_WIRA_KIT` is defined, the LCD configuration is also enabled.

Using the Configuration module the user can change some non-volatile parameters, such as the role, the set ID, the offset, parameters for the Kalman filter, and so on. The configuration is done through the command line by keeping the K1 button pressed during reset (Section 5.1.6). For the wira_basic_demo and wira_tracking_demo, the configuration is done through an Android application (Appendix E).

The CLI is a special mode only for the Initiator device to scan for Responders and connect to them manually. It is supported only in wira_eval_demo and a detailed description is in Section 5.1.7.

The Exchange interface is an external interface module that supports communication with an external host through RAM using the Segger J-Link interface. Only the wira_eval_demo supports this interface which is described in detail in Section 5.1.8.

## 4.5 WiRa Manager

### 4.5.1 Introduction

WiRa manager is a software module that provides a simple Application Programming Interface (API) that can be used in an application to establish a connection between an Initiator and a Responder and perform distance measurements.

A configuration file named `wira_config.h` can be used to set various built-time configuration parameters. If such a file is not included in the application code, then the default configuration file located in folder `\sdk\ble\wira\include` is used.

### 4.5.2 WiRa BLE Manager API

#### 4.5.2.1 Initialization and Configuration Functions

***void wira_mgr_init(*****wira_cbs_t *cbs, gap_dte_params_t *dte_params*****)***

This function is used to initialize the WiRa manager. Callback functions can be configured using parameter cbs which points to a structure of the following type:

```
typedef struct {
        wira_status_cb_t     status_cb;
        wira_iq_data_cb_t    iq_data_cb;
        wira_phase_data_cb_t phase_data_cb;
} wira_cbs_t;
```

The function assigned to `status_cb` is called from the WiRa manager to notify the application that the status of the manager has changed and to provide the WiRa measurement results.

The function assigned to `iq_data_cb` is called when new IQ data have been captured.

The function assigned to `phase_data_cb` is called when new phase and magnitude data have been calculated.

DTE configuration is defined using the parameter `dte_params` which points to a structure of the following type:

```
typedef struct {
        bool is_initiator;
        uint8_t nb_atoms;
        uint16_t meas_length_us;
        uint16_t f_start_mhz;
        uint8_t f_step_mhz;
        uint8_t agc_freeze_lvl;
        bool agc_freeze_auto;
        uint8_t tx_power;
} gap_dte_params_t;
```

Default values as defined in `wira_config.h` are used if `dte_params` is NULL.

The configuration parameters are the following:

- is_initiator: set to true to configure the device as Initiator, false to configure it as Responder
- f_start_mhz: The frequency of the first atom. The default value is 2402 MHz
- f_step_mhz: The frequency difference between two consecutive atoms. The default value is 2 MHz

- nb_atoms: The total number of atoms. The default value is 40
- meas_length_us: The length of the data section to be copied from each atom. The default value is 56 µs
- agc_freeze_lvl: Set Radio AGC gain to the specified level. If `agc_freeze_auto` is set to true, this value is ignored
- agc_freeze_auto: Set to true to enable automatic gain control
- tx_power: Set the Radio transmit power. The default value is +6 dBm

#### void wira_mgr_periph_init(wira_validate_connection_func_t func)

This function is used to initialize the WiRa Responder (in a peripheral role). Parameter `func` can be set to point to a function that is used for validating an incoming connection. If this function returns `WIRA_VALID_OK` the WiRa connection is established. If it returns `WIRA_VALID_LOW_BAT` then a low battery indication is sent to the Initiator to terminate the connection. If it returns `WIRA_VALID_NO_WIRA_PEER` then WiRa is not enabled.

#### void wira_mgr_periph_data_service_init(void)

This function is used to initialize the custom WiRa Data Service.

#### void wira_mgr_periph_enable(bool enable)

This function enables or disables the WiRa Responder. If WiRa Responder is disabled, it is not responding to `LL_DTE_START` requests.

#### void wira_mgr_periph_set_id(wira_id_t id)

This function sets the ID of the Responder.

#### void wira_mgr_central_init(void)

This function is used to initialize the WiRa Initiator (in the central role).

#### void wira_mgr_central_set_id(wira_id_t id)

This function sets the ID of the Initiator.

### 4.5.2.2 Event handlers

#### bool wira_mgr_ble_handler(ble_evt_hdr_t *hdr)

This function must be called from the BLE task of the application to handle BLE events needed for the operation of the WiRa manager.

#### void wira_mgr_notif_handler(uint32_t notif)

This function must be called from the BLE task of the application to handle notification events needed for the operation of the WiRa manager.

### 4.5.2.3 Connection and Measurement Functions

#### void wira_mgr_central_connect(bd_address_t *addr, const gap_ext_conn_params_t *conn_params, bool disconnect_after_measurement)

This function can be used to establish a connection with a Responder having the BD address assigned to the `addr` parameter. Custom connection parameters can be set using the `conn_params` parameter. If set to NULL, the default connection parameters defined in `wira_config.h` are used. If `disconnect_after_measurement` is set to true, the connection is dropped immediately after the WiRa measurement. When a connection is established, the status callback defined in `wira_mgr_init()` is called to provide the connection context to the application.

#### void wira_mgr_central_start_measurement(conn_context_t *ctx)

This function can be used to start a WiRa measurement after a connection has been established with the Responder. Parameter `ctx` must point to the connection context provided when the status callback was called. If set to NULL, WiRa measurement will be performed with the last Responder with which a connection was established.

#### void wira_mgr_central_connect_and_start_measurement(bd_address_t *addr, bool disconnect_after_measurement)

This function is a combination of `wira_mgr_central_connect()` and `wira_mgr_central_start_measurement()`. If a connection is already established, then WiRa measurement starts immediately.

### 4.5.2.4 Errors and Statistics

The following error codes (as defined in enumeration `dte_error_t`) are reported and logged:

- DTE_NO_ERROR: The measurement sequence has finished without any error
- DTE_ERROR_INSTANT_PASSED: Failed to start measurement because the requested connection event counter has passed
- DTE_ERROR_SYNC_FAILED: Failed to synchronize with the partner device
- DTE_ERROR_RESULTS_TO: Failed to receive either the report with the acquisition data from the RF Unit or the intermediate results from the remote device
- DTE_ERROR_DISCONNECTED: Failed because the peer has been disconnected

Every device maintains a table with measurement statistics for each DTE capable connection which can be printed to the debug console by calling the function wira_mgr_print_statistics_report().

# 5 Demo Applications

## 5.1 WiRa Evaluation Demo Application

### 5.1.1 Introduction

This application demonstrates how Bluetooth® LE and Dialog Tone Exchange (DTE) are used to get distance measurements between two devices, one Initiator and one Responder. This demo application is the default demo in the development kits. It supports a configuration mode to change parameters easily through the terminal. It provides also a CLI special mode only for the Initiator, where a user can perform a set of commands on demand.

### 5.1.2 Description

A Bluetooth® LE connection is used for both the DTE synchronization and the exchange of the intermediate DTE Data. There are two configuration parameters related to the Bluetooth® LE connection: the role and the set number.

A device is configured to have the role of an Initiator (Section 5.1.2.1) or the role of a Responder (Section 5.1.2.2).

The set number is used to distinguish two different WiRa sets that are simultaneously operated in each other's vicinity (within the BLE reception range).

Both devices, Initiator and Responder go through a sequence of states before the measurement cycle can start.

Initially, the Responder starts advertising with a custom DTE Data service UUID and the set number in the advertising data. The Initiator starts scanning, looking for the DTE Data service UUID and a matching set number in the advertising reports it receives. If both the UUID and the set number match, the two devices get connected.

#### 5.1.2.1 Initiator Role

The sequence of states for the Initiator is the following:

- **Scanning state**: The device starts scanning, looking for the WiRa Data service's UUID and a matching set number in the received advertising reports. If both the UUID and the set number match, the device attempts to connect with the remote device
- **Connected State**: The connection attempt is successful
- **Maximum Transmission Unit (MTU) Exchange State**: The Initiator requests the maximum allowed MTU to increase the results throughput. Data packet length extension is by default enabled on the DA1469x devices, so the PDU Payload Length in the Maximum Transmit Data Channel is 251 octets
- **Discovery State**: The device discovers BLE services and related attributes

After the discovery is completed, the device starts the measurement cycle.

In CLI mode the scanning is bypassed, and the device enters a Connecting State in which an attempt is made to connect to a remote device with a specific Bluetooth® address that is a parameter of the connect command.

#### 5.1.2.2 Responder Role

The sequence of states for the Responder is the following:

1. **Advertising State**: The device starts advertising with the WiRa Data service's UUID and the device set number in the advertising data. Then the Responder waits for connection requests from the Initiator device.
2. **Connected State**: After the two devices connect, the Responder replies to the discovery and MTU requests and waits for a START request to start the measurement sequence.

### 5.1.3 Configuration Options

The functionality and the performance of the demo can be customized by modifying various build-time or run-time configuration parameters.

#### 5.1.3.1 Build-Time Configuration Parameters

The build-time configuration parameters are defined in configuration files located at `projects/dk_apps/wira/wira_eval_demo/config/` folder. There are configuration parameters related to WiRa, parameters related to the specific demo, and global parameters.

Configuration parameters related to WiRa are defined in `wira_config.h`. These parameters define the behavior of the WiRa manager.

- **wira_config.h**:
  - WIRA_RESPONDER_ROLE and WIRA_INITIATOR_ROLE are both defined and the development kit starts as an Initiator, as it is defined by the DEFAULT_DTE_ROLE in `wira_eval_demo_config.h`
  - WIRA_MAX_DISTANCE_CM: WiRa calculated distance greater than the max distance is rejected

    WIRA_MIN_RSSI_THRESHOLD: If the RSSI is lower than this minimum threshold, the measurement will be rejected
  - WIRA_CW_OFFSET_CM: A constant offset that is deducted from the WiRa measurements
  - WIRA_USE_IFFT_DIST_CALC and WIRA_USE_MATRIX_PENCIL_DIST_CALC: These are the two methods for distance calculation. Only one can be defined. Matrix pencil distance calculation is used by default. If none of them is defined, then phase-based distance calculation is used to calculate the distance (Section 4.3.2)
  - WIRA_MULTILINK_SUPPORT: If it is defined WiRa manager can handle multiple connections
  - WIRA_SEND_RESULT_TO_RESPONDER: If it is defined, the Initiator sends the result to the Responder by writing the value to the WiRa data R result characteristic
  - WIRA_MEASUREMENT_TO_MS: Time within which a WiRa measurement should be performed. If it is not then the measurement is considered invalid
  - WIRA_ENABLE_DTE_STATISTICS: If it is defined DTE statistics are enabled.
  - WIRA_DEBUG_MEASUREMENTS: If it is defined, WiRa log messages are enabled to get raw measurements and additional details about WiRa

  Configuration parameters related to the demo application are defined in `wira_eval_demo_config.h`
- **wira_eval_demo_config.h**:
  - EXCHANGE_MODE: If it is set to 1, the application exchanges data with an external Python application (Section 5.1.8). It is set to 0 by default

    DEFAULT_DTE_ROLE: Configures the default role of a device. For the wira_eval_demo application, the role is set to Initiator by default
  - The connection parameters are defined by the symbols:
    - BLE_CONN_INTERVAL_MIN
    - BLE_CONN_INTERVAL_MAX
    - BLE_CONN_SLAVE_LATENCY
    - BLE_CONN_SUPERVISION_TO
  - The scan parameters for the Initiator are defined by the symbols:
    - BLE_SCAN_INTERVAL
    - BLE_SCAN_WINDOW
  - The advertisement parameters for the Responder are defined by the symbols:
    - BLE_ADV_INTERVAL_MIN

  - BLE_ADV_INTERVAL_MAX
- PRINT_DTE_RSSI: If it is set to 1, the RSSI is printed on the console
- LCD_DTE_RSSI: If it is set to 1, the RSSI is printed on the LCD
- PRINT_WIRA_COMPACT: If it is set to 1, a compact print of the raw result is performed
- DIST_MA_WINDOW: Defines a 2^N sized sliding window filter to apply on raw values for average distance reporting
- HOST_PM_MODE_ACTIVE: If it is set to 1, active power management mode is configured instead of extended sleep

Global project configuration parameters are defined in `custom_config_qspi.h`.

- **custom_config_qspi.h**:
  - Enable UART logging: If the symbol `CONFIG_RETARGET` is defined, then the application log messages are sent to the UART interface. The UART configuration settings are the following:
    - Baud rate: 115200
    - Data bits: 8
    - Parity: None
    - Stop bits: 1

### 5.1.4 Running the Demo after Unboxing the Development Kits

After plugging each Smartbond Wireless Ranging USB Development Kit into a USB port, the WiRa Evaluation Demo Application will run. There are one Initiator and one Responder in the box. During the startup, the user can see on the display "**Initiator connecting"/"Responder connecting**", which is an indication that the devices are not connected yet, but they scan/advertise respectively.

After a connection is established between the two devices, the user can read the distance (in the unit of meters) between the two devices from both displays.

Open for each device a UART terminal with the following configuration to get the logs:

- Baudrate: 115200
- Bits: 8
- Parity: None
- Stop bits: 1

On the Initiator's console, you will see something like in Figure 8.

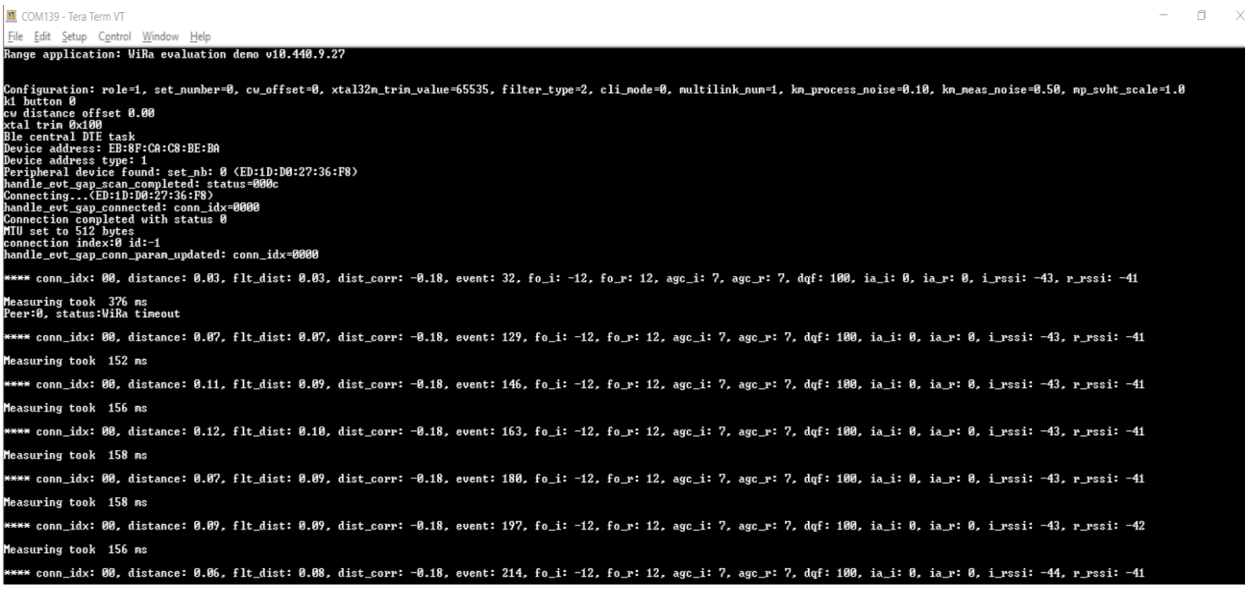



**Figure 8: Logging Information of Initiator**

At the beginning of the logging board's configuration is printed. Afterward when a peripheral is scanned the connection procedure started and in the log, the Responder's BD address, the MTU, and the connection index will be printed. The output log contains the following information:

- **conn_idx**: is the BLE connection that provides the anchor times for the ranging information related radio measurements
- **distance**: is the actual distance measured in meters after the **cw_offset** is applied
- **flt_dist**: if distance filtering is enabled, this is the output of a filter applied to the valid distance measurements (with dqf:100). Three filter options are available:
  - no-filtering
  - moving average configurable sample window
  - Kalman filter
- **dist_corr**: is a correction factor automatically applied to the calculated distance to compensate for the influence of the offset between the 32-MHz clock crystals (up to +/-50 ppm) on the Initiator and Responder. Therefore, crystals and crystal trimming fulfilling regular Bluetooth® specification suffice for WiRa use as well
- **event**: is the connection event at which a radio measurement has taken place
- **fo_i**: is the frequency offset in kHz for the Initiator
- **fo_r**: is the frequency offset in kHz for the Responder
- **argc_i**: is the AGC gain value of the Initiator used during the data acquisition
- **argc_r**: is the AGC gain value of the Responder used during the data acquisition
- **dqf**: is a distance quality factor based on the frequency offset values of both sides. It should be 100 for a good measurement
- **ia_i and ia_r**: are the numbers of Tone Exchange steps with invalid IQ data as identified during the IQ data acquisition phase. Currently, if there are any such steps, the whole measurement is dropped (dqf = 0)
- **i_rssi and r_rssi**: are the RSSI values of the last BLE reception of the Initiator and the Responder respectively
- Finally, the measuring time is printed. It is the time from sending the start command until the measurement is stopped

In Figure 9, there is the Responder's logging information. As you can see less information is printed than in the Initiator's log.

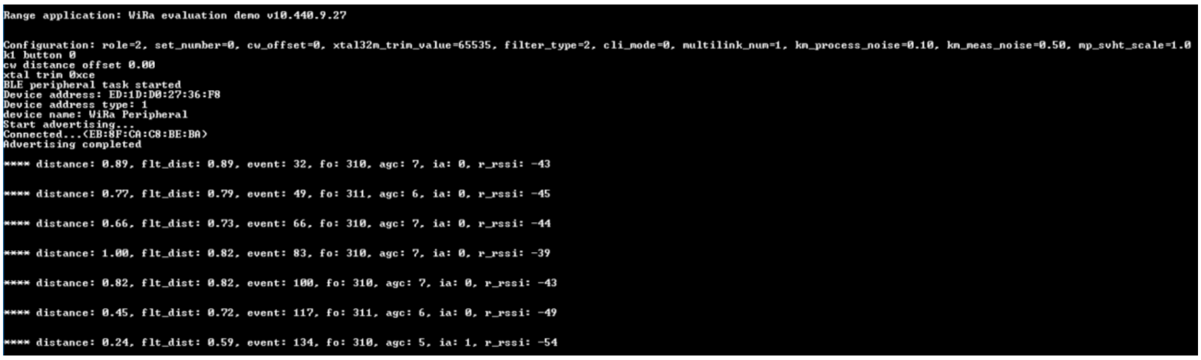



**Figure 9: Logging Information of Responder**

### 5.1.5 Downloading and Running the Demo

The following steps are required to run the wira_eval_demo in case another firmware is already programmed to the board:

1. Configure the device as described in Appendix A.
2. Power up the first device.

3. Download the firmware to the device:
   a. If the device is already programmed with firmware that supports SUOTA then the firmware can be updated over the air as described in Appendix C. The SUOTA images for the supported boards (DA1469x PRO DK, USB Kit, and WiRa Kit) are provided in folder **/binaries/wira/wira_eval_demo/suota_images/**.
   b. If the device does not support SUOTA, then:
      i. Use the SmartSnippets Toolbox to erase the data of the whole Flash area, as described in Appendix B in step 8. This is required to delete the old partition table.
      ii. Use the SmartSnippets Toolbox to program the device as described in Appendix B. The binary files for the supported boards (DA1469x PRO DK, USB Kit, and WiRa Kit) are provided in folder **/binaries/wira/wira_eval_demo/binaries/**.

### 5.1.6 Configuration Mode

This demo supports a configuration mode and the user can change some non-volatile parameters, such as the role, the set ID, the offset, enable the cli mode, parameters for the Kalman filter, and so on. The device enters configuration mode by holding the K1 button pressed during RESET. A RESET is invoked by pressing the K2 button. The configuration menu is as in Figure 10.

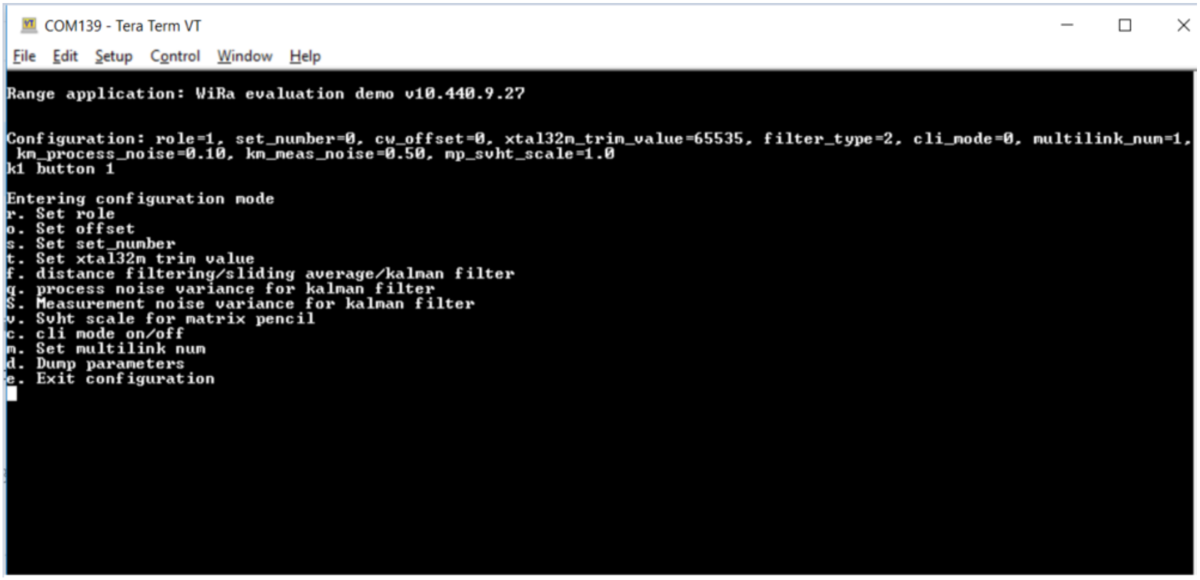



**Figure 10: Configuration Mode Options**

A detailed description of the available options is below:

- **r**: Configure the role which is related to the acquisition TX/Rx sequence. Two roles are defined, the Initiator and the Responder
- **o**: Set the offset in centimeters. This offset adjusts the distance measurement so that the correct distance result is reported. Initially, calibration of the distance measurements at fixed distances is needed to calculate the initial offset value
- **s**: Set the set ID. It is a number less or equal to 254. It is used at normal operation to uniquely identify an Initiator/Responder set. The Initiator device uses this number to identify the Responder to which it will connect. It is not meaningful if CLI mode is enabled
- **t**: Set the XTAL frequency trimming register. This value may change if auto trimming is enabled
- **f**: If it is set to zero no filtering is applied and all measurements are reported raw to the output. If it is set to a value other than zero then the user can select between two possible filters that can be applied to the distance measurements:
  - **sliding average filter (1)**: a 2^N sliding window filter to apply to the raw values. The sample window size is controlled by the compile time switch DIST_MA_WINDOW

- ○ **Kalman filter (2)**: is an algorithm that uses a series of measurements observed over time, containing statistical noise and other inaccuracies, and produces estimates of unknown variables that tend to be more accurate than those based on a single measurement alone, by estimating a joint probability distribution over the variables for each timeframe

  **q and S**: There is a tradeoff between responsiveness and smoothing of Kalman's filter output, which can be controlled by the tuning parameters of **km_variance_process_noise_q** and **km_variance_measurement_noise_S**

- **v**: Set the SVHT scale for matrix pencil.
- **c**: If cli_mode is set, the Initiator will operate in manual mode leveraging a cli for assisted user setup. The cli_mode is described in detail in Section 5.1.7. This setting does not apply to Responder and is therefore ignored.
- **m**: Set the max number of connections. The Initiator continues to scan for more connections after a connection is established until multilink_num is reached. At this time the DTE range measurement is triggered for every connection in a Round-Robin fashion. The value of multilink_num is ignored if the device is:
  - ○ a Responder or
  - ○ an Initiator that operates in CLI mode
- **d**: Print the parameters
- **e**: The device exits from configuration mode, it resets with the new parameters applied

### 5.1.7 CLI Mode

The CLI is a special mode for the Initiator, which may be enabled in the configuration mode, as described in Section 5.1.6 above, where the setting for cli mode is set to on. When operating in CLI mode, the initiator waits for the user to issue any of the available cli commands (Figure 11) whose detailed description and functionality are given in Section 5.1.7.1.

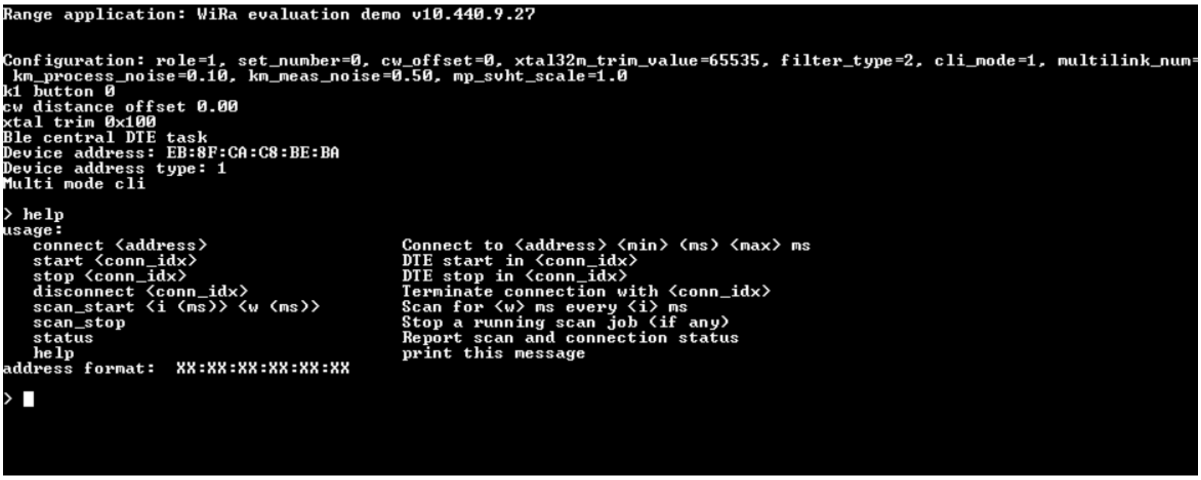



**Figure 11: CLI Mode for Initiator**

The CLI functionality is implemented in file `projects/dk_apps/wira/wira_eval_demo/src/cli.c`. The function `cli_init()` initializes the CLI task. This task receives input strings and notifies the waiting BLE central task that a string has been read from the CLI. Function `cli_get_clistr()` returns the current input string that has been read from the CLI. Function `readline()` reads a line from the CLI and `parseline()` parses the line to get a command.

#### 5.1.7.1 CLI Commands

The following CLI commands are available:

- **connect <address> <min> <max>**: This command takes one mandatory and two optional input arguments. The first argument must be the address of the remote device to try to connect to and must be in the form <xx:xx:xx:xx:xx:xx>. Additionally, up to two input arguments may be used to specify the minimum and maximum values for the connection interval. If any of the optional arguments are not given, the default value of 30 ms is used.

| NOTE |
| --- |
| Any user-scheduled scan needs to be stopped before attempting to make a connection. See command **scan_stop** for more details. |

- **start <conn_idx>**: With this command, the Initiator is instructed to trigger the DTE range measurement for the specified connection index.
- **stop <conn_idx>**: The device will stop triggering any further DTE range measurements for this connection index.
- **disconnect <conn_idx>**: If a valid connection index is provided as an input argument, the Initiator will try to terminate the corresponding connection.
- **scan_start <interval> <window>**: The Initiator will try to schedule a scan job of <window> milliseconds every <interval> milliseconds. The scan interval needs to be greater than the scan window otherwise the command will fail. The **status** command described below can be used to check whether the user has a scan job already scheduled in the background or not. Currently, the command provides no console output and its usage is intended for testing purposes only.
- **scan_stop**: The device will try to remove any scan job the user has scheduled.
- **status**: Helper command to display information about the available connections. Upon execution, entries of the format **<conn_idx> <address> <DTE status>** will be printed on the console output. DTE status indicates whether the range measurement for this connection is unsupported, disabled, or enabled. If DTE ranging is supported, then the start and stop commands described earlier can be used to enable or disable it. Besides the list, the command output also provides information regarding the number of connections, active scan jobs, and ongoing advertising.

### 5.1.8 Exchange Interface

The Exchange interface is an external interface module that supports communication with an external host through RAM using the SEGGER J-Link. Only the **wira_eval_demo** supports this interface. To enable the external interface functionality, set the define `EXCHANGE_MODE` to 1 in file `projects/dk_apps/wira/wira_eval_demo/config/wira_eval_demo_config.h`.

This mode supports Python interaction through SEGGER J-Link using PyMon. PyMon is a python package that enables the control of a Bluetooth® SoC through a SEGGER J-Link debugger probe.

The header file `projects/dk_apps/wira/wira_eval_demo/include/exchange_mem.h` describes a sample set of parameters for data exchange between the application and Python. There are three different types of parameters:

- Bidirectional flags used for a handshake between the DTE application and Python scripts
- Configuration parameters set from Python
- Data parameters sent to Python

These parameters are stored in a special "`.exchange_section`" so that they can be located at a fixed predefined address that Python scripts can access. For this reason, the original `sections.ld.h` SDK file has been modified and the "`.exchange_section`" has been added.

There are four main functions for the exchange mode support:

- `exchange_mem_init()` for handshake parameters initialization from the application side
- `exchange_mem_params_exchange()` for setting the `is_initiator`, `f_start_mhz`, `f_step_mhz`, `nb_atoms` DTE configuration parameters from Python
- `exchange_mem_iq_data_set()` and `exchange_mem_phase_data_set()` for sending IQ data and phase/magnitude information to Python

The exchange functions implement a blocking handshake where they set a ready flag and then wait for Python code to set parameters/copy information and then clear the flag.

There is an initial handshake between the application and python in the function `exchange_mem_params_exchange()`.

Then at every measurement, there are two handshakes, one for IQ data `exchange_mem_iq_data_set()` and one for phase and magnitude data exchange `exchange_mem_phase_data_set()`.

A python script **dte_iq_data_analyzer.py** to test the IQ data and phase exchange and the PyMon module is available in `projects/host_apps/python_iqdata_tools`.

The script can be tested with the Spyder python environment that is included in Anaconda, the Python Data Science Platform.

To show the plots in Spyder in their own interactive window, go to **Tools** > **Preferences** > **Ipython console** > **Graphics tab** > **Graphics backend** > **Backend** and set it to **Automatic**.

## 5.2 WiRa Basic Application Demo

### 5.2.1 Introduction

This application demonstrates the use of WiRa technology to estimate the distance between two devices, one acting as an Initiator and one as a Responder.

Each device is assigned a set ID. The Initiator connects to the Responder with the same set ID to measure the distance.

Bursts of multiple WiRa events are executed. The data of all WiRa events are evaluated, filtered, and processed to calculate the distance estimation. The procedure is repeated with a predefined period.

The device enters hibernation mode when the device remains inactive for a while.

The set ID, number of WiRa events per measurement, measurement period, and inactivity period can be configured using the WiRa Android application (See Appendix E).

Device logs including WiRa event data and distance estimation are sent to the UART or USB CDC interface. The information is also transmitted in beacon advertising packets by the Initiator that is monitored using the WiRa Android application (See Appendix E).

The application can run in DA1469x PRO DK, USB kit, or WiRa Kit boards. Pre-built binaries and SUOTA images are included in `/wira/wira_basic_app_demo/binaries` and `binaries/wira/wira_basic_app_demo/suota_images` folders respectively.

### 5.2.2 Configuration Options

The functionality and the performance of the demo can be customized by modifying various build-time or run-time configuration parameters.

#### 5.2.2.1 Build-Time Configuration Parameters

The build-time configuration parameters are defined in configuration files located in the `projects/dk_apps/wira/wira_basic_app_demo/config` folder.

**WiRa Configuration Parameters Defined in wira_config.h**

The configuration parameters in this file define the behavior of the WiRa manager:

- **WiRa device role**: Either Initiator or Responder. The initiator role is enabled when the symbol WIRA_INITIATOR_ROLE is defined. The responder role is enabled when the symbol WIRA_RESPONDER_ROLE is defined. At least one role must be defined. Both roles can be defined. The default role is defined by the symbol DEFAULT_WIRA_ROLE in file `custom_config_qspi.h` and can be changed at run time using the WiRa configuration BLE service.
- **WiRa connection parameters**: The connection parameters are defined using symbols WIRA_CONN_INTERVAL_MIN, WIRA_CONN_INTERVAL_MAX, WIRA_CONN_SLAVE_LATENCY, and WIRA_CONN_SUPERVISION_TO. A short connection interval must be defined to minimize the duration of the WiRa measurement event.
- **Keep-alive connection parameters**: If the time between WiRa measurements is long then the system can be configured to change the connection parameters between measurements to optimize the power consumption by defining the symbol WIRA_USE_KEEPALIVE_CON_PARAMS. Keep-alive connection parameters are applied after the WiRa measurement event. WiRa connection parameters are applied before performing the next WiRa measurement. The keep-alive connections parameters are defined using symbols WIRA_CONN_KEEPALIVE_INTERVAL_MIN, WIRA_CONN_KEEPALIVE_INTERVAL_MAX, WIRA_CONN_KEEPALIVE_SLAVE_LATENCY, and WIRA_CONN_KEEPALIVE_SUPERVISION_TO.
- **Service discovery bypass**: If WIRA_USE_FIXED_CHAR_HANDLES, then the Initiator bypasses the service discovery when a connection to a Responder is established. The handles of the characteristics of the WiRa service are considered fixed and known. This reduces the time for

the first WiRa measurement after the connection establishment. The handles are defined using symbols WIRA_I_RESULT_VAL_HANDLER, WIRA_R_RESULT_VAL_HANDLER, and WIRA_R_RESULT_CCC_HANDLER.

- **WiRa manager logging**: Logging can be enabled by defining macro LOG_WIRA.

#### Demo Configuration Parameters Defined in demo_config.h

The configuration parameters in this file define the behavior of the demo application:

- **Drop the connection after WiRa measurement**: if the symbol WIRA_DISCONNECT_AFTER_MEASUREMENT is defined the Initiator will drop the connection after the WiRa measurement. The Initiator will reconnect to the device after the WiRa measurement period. If WIRA_DISCONNECT_AFTER_MEASUREMENT is not defined the Initiator remains connected to the Responder.
- **Inactivity timeout**: If the symbol ENABLE_INACTIVITY_TIMEOUT is defined the device is powered off after an inactivity timeout is defined by the symbol DEFAULT_WIRA_INACTIVITY_TIMEOUT in file `custom_config_qspi.h`. It can be configured using the WiRa configuration service.
- **WiRa result beaconing**: If INITIATOR_BEACON_WIRA_RESULTS is defined then the Initiator beacons the WiRa measurement results using non-connectable advertising packets. The data in the advertising packets are described in the file `wira_beacon_readme.md` located in the `/dk_apps/wira/common/utils` project folder. The advertising interval is defined using symbols BLE_BEACON_INTERVAL_MIN_MS and BLE_BEACON_INTERVAL_MAX_MS in milliseconds.
- **Initiator scanning parameters**: The scanning parameters for the Initiator (central) role are defined using symbols BLE_SCAN_INTERVAL_MS and BLE_SCAN_WINDOW_MS in milliseconds.
- **Responder advertising parameters**: The advertising parameters for the Responder (peripheral) role are defined using symbols BLE_ADV_INTERVAL_MIN_MS and BLE_ADV_INTERVAL_MAX_MS in milliseconds.

#### Global Project Configuration Parameters Defined in File custom_config_qspi.h

- **Enable UART logging**: If the symbol `CONFIG_RETARGET` is defined then application log messages are sent to the UART interface. The UART configuration settings are the following:
  - Baud rate: 115200
  - Data bits: 8
  - Parity: None
  - Stop bits: 1
- **Enable USB CDC logging**: If the symbol `CONFIG_RETARGET_USB_CDC` is defined then application log messages are sent to the USB CDC interface.
- **Enable colorful logging**: If the symbol `USE_COLORS_IN_LOGS` is defined colors are used to improve the readability of the log messages. This symbol must not be defined if the terminal application is not able of displaying colors.

### 5.2.2.2 Run-Time Configuration Parameters

If the WiRa configuration service is enabled in file `custom_config_qspi.h` then the WiRa Android application can be used to change the following parameters at run-time as described in Appendix E. The description of these parameters is also provided in this Appendix. The default values are defined in file `custom_config_qspi.h`.

- **WiRa role**: Either Initiator or Responder. The default role is defined by the symbol DEFAULT_WIRA_ROLE. The device is configured as Responder by default. This parameter has no effect if only one role has been enabled in `wira_config.h` when building the project.
- **Inactivity timeout**: The default value is 10 minutes and it is defined by the symbol DEFAULT_WIRA_INACTIVITY_TIMEOUT.

- **WiRa set number**: The default value is zero and it is defined by the symbol DEFAULT_WIRA_SET_NUM.
- **Number of WiRa events per WiRa measurement**: The default value is four and it is defined by the symbol DEFAULT_WIRA_NUM_OF_EVT.
- **WiRa measurement period**: The default value is 10 and it is defined by the symbol DEFAULT_WIRA_PERIOD_SEC.
- **SVHT scale**: The default value is 60% and it is defined by the symbol DEFAULT_WIRA_MATPEN_SVHT_SCALE.
- **Distance offset**: The default value is zero and it is defined by the symbol DEFAULT_WIRA_DISTANCE_OFFSET_CM. The distance offset is subtracted from all WiRa distance measurements.
- **Filter type**: The default value is none and it is defined by the symbol DEFAULT_WIRA_FILTER_TYPE. Sliding average or Kalman filter can be selected.
- **Kalman filter process noise:** The default value is 10% and it is defined by the symbol DEFAULT_WIRA_KALMAN_PROCESS_NOISE.
- **Kalman filter measurement noise:** The default value is 50% and it is defined by the symbol DEFAULT_WIRA_KALMAN_MEASUREMENT_NOISE.
- **RSSI threshold**: The default value is -85dBm and it is defined by the symbol DEFAULT_WIRA_RSSI_LOW_THRESHOLD. WiRa measurements, having RSSI lower than this value, are ignored.
- **Maximum WiRa distance threshold**: The default value is 100dm (10m) and it is defined by the symbol DEFAULT_WIRA_DISTANCE_HIGH_THRESHOLD. WiRa measurements, with a distance longer than this value, are ignored.

### 5.2.3 Running the Demo

1. Configure the device as described in Appendix A.
2. Power up the first device.
3. Download the firmware to the device:
   - If the device is already programmed with firmware that supports SUOTA then the firmware can be updated over the air as described in Appendix C. The SUOTA images for the supported boards (DA1469x PRO DK, USB Kit, and WiRa Kit) are provided in folder **/binaries/wira/wira_basic_app_demo/suota_images**.
   - If the device does not support SUOTA then:
     - Use the SmartSnippets Toolbox to erase the data of the whole Flash area, as described in Appendix B. This is required to delete the old partition table. A new partition table with SUOTA support will be created when the demo firmware is executed for the first time.
     - Use the SmartSnippets Toolbox to program the device as described in Appendix B. The binary files for the supported boards (DA1469x PRO DK, USB Kit, and WiRa Kit) are provided in folder **/binaries/wira/wira_basic_app_demo/binaries**.
4. (Optional) Connect the device to the USB port of a computer and use a terminal program to get the debugging logs from the device. Configure the terminal with the following settings:
   - Baud rate: 115200
   - Data bits: 8
   - Parity: None
   - Stop bits: 1

   If the device is upgraded successfully with **wira_basic_app_demo**, at the first RESET the output log in the terminal is as in Figure 12.

```
WiRa basic application demo, v10.440.9.29
Cannot open NVMS_GENERIC_PART, using default parameters
Device connected to USB host. Power-off timeout disabled.
generating random BD address
Device address: E4:35:62:93:E2:83
Device address type: 1
device name: WiRa device
WiRa responder enabled
Start advertising as responder
```

**Figure 12: The Output Log at the First Reset**

5. Repeat the above procedure for the second device.
6. Configure the first device:
   a. Long press the user button (K1) of the first device to enter configuration mode.

```
Start advertising as responder
          no_error: 0
    instant_passed: 0
       sync_failed: 0
        results_to: 0
      disconnected: 0
   mem_capa_exceed: 0
    cmd_disallowed: 0
   instant_delayed: 0
transaction_failed: 0
       cmd_pending: 0
    rfmon_overflow: 0
      dcdc_enabled: 0
Responder: Start advertising for configuration
Role switched from ROLE_RESPONDER to ROLE_RESPONDER_CONFIG
```

**Figure 13: Configuration Mode**

   b. The device remains in configuration for 10 seconds to allow the Android app to connect and configure the device as described in Appendix E. WiRa set number, inactivity timeout, a number of WiRa events, and WiRa measurement period can be configured.

      If the user does not connect to the device using the app within 10 seconds, then the device resumes normal operation and the following message is logged to the console:

```
Role switched from ROLE_RESPONDER_CONFIG to ROLE_RESPONDER
Start advertising as responder
WiRa responder enabled
```

**Figure 14: Output Log when Switching from Configuration to Normal Mode**

   c. Disconnect the Android app from the device.
7. Repeat the previous step to configure the second device as Initiator. The set ID of the Initiator must match the set ID of the Responder.
8. When both devices are disconnected from the Android app the Initiator connects to the Responder with the same set ID and distance measurement is started.
9. Results are reported to the debugging console:

```
Configuration:
    role:Initiator, set number:0
    Number of WiRa events:4, WiRa period: 1sec, WiRa SVHT scale:60
    RSSI threshold:-85dBm, Distance threshold:1000cm
    poweroff timeout: 10min
Device address: E9:4A:BD:B3:0F:5A
Device address type: 1
device name: WiRa device
WiRa Initiator enabled
Start scanning...
Peripheral device found. set:0 (DC:F0:84:88:2A:E1)
[WIRA MGR]: Initiator connected, con_idx: 0
[WIRA MGR]: Start WiRa measurement
[WiRa status]: connected          Peer:0 connection index:0
[CWD]: Matrix pencil: 3 Signals determined
[WiRa status]:                    Peer:0 raw distance:71cm, fo:7/-7, agc gain:8/7, rssi:-37/-40
[CWD]: Matrix pencil: 3 Signals determined
[WiRa status]:                    Peer:0 raw distance:68cm, fo:7/-7, agc gain:8/7, rssi:-37/-40
[CWD]: Matrix pencil: 3 Signals determined
[WiRa status]:                    Peer:0 raw distance:69cm, fo:7/-7, agc gain:8/7, rssi:-37/-40
[WiRa status]: OK                 Peer:0 valid:3/3, Distance:69cm, filtered distance:69cm
[WIRA MGR]: Start WiRa measurement
[CWD]: Matrix pencil: 3 Signals determined
[WiRa status]:                    Peer:0 raw distance:80cm, fo:7/-7, agc gain:8/8, rssi:-34/-37
[CWD]: Matrix pencil: 3 Signals determined
[WiRa status]:                    Peer:0 raw distance:86cm, fo:7/-7, agc gain:8/8, rssi:-33/-36
[CWD]: Matrix pencil: 2 Signals determined
[WiRa status]:                    Peer:0 raw distance:92cm, fo:7/-7, agc gain:8/8, rssi:-33/-36
[WiRa status]: OK                 Peer:0 valid:3/3, Distance:86cm, filtered distance:86cm
```

**Figure 15: Output Log of wira_basic_demo**

- WiRa manager logs are printed in purple color
- WiRa distance results are logged in blue color
- Distance estimations using the individual WiRa distance results are logged in green color

Results are also beaconed by the Initiator and can be monitored using the Android application as described in Appendix E.

## 5.3 WiRa Tracking Demo

### 5.3.1 Introduction

The goal of this demo is to combine RSSI and WiRa measurement data to decide if a device is close enough to another device to take a decision (for example, turn on/off a LED, open/close a door). The RSSI is used to get a rough estimation of the distance between the devices and WiRa measurements are performed to improve the distance estimation.

There are two possible implementations:

- Initiators are placed at a fixed point (for example, at a door) and the Responders simulate the users. Initiators are scanning continuously for users and start WiRa when it is required.
- Responders are placed at a fixed point (for example, at a door) and the Initiators simulate the users. Initiators are scanning continuously for doors and start WiRa when required.

The wira_tracking_demo is compatible with DA1469x PRO DK, USB Kit, and WiRa Kit boards. The hardware boards are described in Appendix A.

### 5.3.2 Configuration Options

- Under the **projects/dk_apps/wira/wira_tracking_demo/config** folder there are three configuration files: `custom_config_qspi.h`, `demo_config.h` and `wira_config.h`. In case the user wants to change one of the defines or parameters in these files, the application should be rebuilt and the development kit upgraded with the new image. To build an application, see Appendix D. To upgrade a device, see Appendix B (using SmartSnippets Toolbox), Appendix C (upgrade over SUOTA). **custom_config_qspi.h:**
    - Enable UART logging: If the symbol `CONFIG_RETARGET` is defined then application log messages are sent to the UART interface. The UART configuration settings are the following:
        - Baud rate: 115200
        - Data bits: 8
        - Parity: None
        - Stop bits: 1
    - Enable USB CDC logging: If the symbol `CONFIG_RETARGET_USB_CDC` is defined then application log messages are sent to the USB CDC interface.
    - WIRA_USE_CONFIGURATION_SERVICE: If it is defined, WiRa configuration service is enabled. Then the WiRa Android application can be used to change the following parameters at run-time as described in Appendix E. There is also a description of these parameters in Appendix E. The default values for these parameters are defined also in this file:
    - DEFAULT_WIRA_ROLE: The WiRa role can be either Initiator or Responder. The default value is set to WIRA_ROLE_RESPONDER.
    - DEFAULT_WIRA_INACTIVITY_TIMEOUT: After this time in minutes the device goes to sleep. The default value is set to 0, which means that the device remains forever active.
    - DEFAULT_WIRA_SET_NUM: An Initiator and a Responder with the same number can connect to each other. The default value is set to 0.
    - DEFAULT_WIRA_NUM_OF_EVT: Number of WiRa events executed for each WiRa measurement. The default value is set to 4.
    - DEFAULT_WIRA_PERIOD_SEC: In this period of time in seconds WiRa performs DEFAULT_WIRA_NUM_OF_EVT events.
    - DEFAULT_WIRA_MATPEN_SVHT_SCALE: Default value is set to 60.
    - DEFAULT_WIRA_DISTANCE_OFFSET_CM: An offset that is deducted from the WiRa measurement. The default value is set to 0.
    - DEFAULT_WIRA_RSSI_LOW_THRESHOLD: The default value is set to -85 dBm.
    - DEFAULT_WIRA_RSSI_HIGH_THRESHOLD: The default value is set to -38 dBm.

- DEFAULT_WIRA_DISTANCE_LOW_THRESHOLD: The default value is set to 10 dm.
- DEFAULT_WIRA_DISTANCE_HIGH_THRESHOLD: The default value is set to 100 dm.

- **demo_config.h:** The definition and configuration parameters in this file are demo specific.
  - ENABLE_INACTIVITY_TIMEOUT: If it is defined, the device goes to sleep after a time, which is defined by DEFAULT_WIRA_INACTIVITY_TIMEOUT. This timeout can be changed by the Android WiRa application at run time. The default value is set to 0 to disable inactivity timeout.
  - WIRA_ROLE_SWITCH_TIMEOUT_SEC: After a long press of Button K1 the Initiator or the Responder enters the configuration mode to change their parameters. The user can connect to the development kit through the Android WiRa application within WIRA_ROLE_SWITCH_TIMEOUT_SEC seconds.
  - INITIATOR_BEACON_WIRA_RESULTS: If it is defined, the WiRa measurement results will be included in Initiator's beacon. The advertising parameters used in the Initiator for beaconing the WiRa measurements are:
    - BLE_BEACON_INTERVAL_MIN_MS
    - BLE_BEACON_INTERVAL_MAX_MS
  - INITIATOR_BEACON_WIRA_DETAILS: If it is defined, raw measurements and RSSI will be included in Initiator's beacon.
  - The scan parameters for the Initiator role are defined by the following symbols:
    - BLE_SCAN_INTERVAL_MS, set to 220 ms
    - BLE_SCAN_WINDOW_MS, set to 220 ms

    Both parameters are set to a low value to optimize the time that an Initiator needs to find and process a Responder.
  - The advertising parameters for the Responder are defined by the following symbols:
    - BLE_ADV_INTERVAL_MIN_MS, set to 50 ms
    - BLE_ADV_INTERVAL_MAX_MS, set to 70 ms

    The advertisement interval is set max to 70 ms to be detected by the Initiator which scans on each channel for 220 ms.
  - INFO_DEBUG_MESSAGES: If it is defined, info log messages are enabled for more logs and debugging reasons.
  - Enable colorful logging: If the symbol `USE_COLORS_IN_LOGS` is defined colors are used to improve the readability of the log messages. If the terminal application can not display colors, this symbol must not be defined.
- **wira_config.h**: The configuration parameters in this file define the behavior of the WiRa manager. The available defines used by wira_tracking_demo are the following:
  - WIRA_RESPONDER_ROLE and WIRA_INITIATOR_ROLE. If both are defined, the development kit will start as a Responder, as it is defined by the DEFAULT_WIRA_ROLE as mentioned before. If only WIRA_RESPONDER_ROLE is defined, the device will start as a Responder and if only WIRA_INITIATOR_ROLE is defined it will start as an Initiator.
  - WIRA_EVT_NUM: the number of WiRa events that are needed to calculate one distance result.
  - WIRA_EVT_NUM_MAX: the maximum number of WiRa events to calculate one distance result.
  - WIRA_MAX_DISTANCE_CM: WiRa calculated distance greater than the max distance will be rejected.
  - WIRA_MIN_RSSI_THRESHOLD: If the RSSI is lower than this minimum threshold, the measurement will be rejected.
  - WIRA_OUTLIER_FILTER_RATIO: Ratio to filter-out outliers in %. A measured distance is considered an outlier if the distance is greater than the average by this ratio.
  - WIRA_CW_OFFSET_CM: A constant offset that is deducted from the WiRa measurement.

- WIRA_USE_CLOSEST_DISTANCE_EST: If it is defined and all measurements are considered outliers, the smallest distance from the average will be reported as the WiRa measurement. If it is not defined, the average will be used. In both cases, the measurement is considered invalid.
- WIRA_USE_IFFT_DIST_CALC and WIRA_USE_MATRIX_PENCIL_DIST_CALC: These are the two methods for distance calculation. Only one can be defined. Matrix pencil distance calculation is used by default.
- WIRA_USE_KEEPALIVE_CON_PARAMS: If it is defined, the connection parameters between WiRa measurements can be changed to reduce power consumption. The keepalive parameters are applied between WiRa measurement events. The available keepalive connection parameters are:
  - WIRA_CONN_KEEPALIVE_INTERVAL_MIN
  - WIRA_CONN_KEEPALIVE_INTERVAL_MAX
  - WIRA_CONN_KEEPALIVE_SLAVE_LATENCY
  - WIRA_CONN_KEEPALIVE_SUPERVISION_TO
- The connection parameters for establishing a connection to a Responder are:
  - WIRA_CONN_INTERVAL_MIN
  - WIRA_CONN_INTERVAL_MAX
  - WIRA_CONN_SLAVE_LATENCY
  - WIRA_CONN_SUPERVISION_TO
- The scan parameters for establishing a connection are:
  - WIRA_SCAN_INTERVAL_FOR_CONNECTION
  - WIRA_SCAN_WINDOW_FOR_CONNECTION
- WIRA_SEND_RESULT_TO_RESPONDER: If it is defined, the Initiator sends the result to the Responder by writing the value to the WiRa data R result characteristic.
- WIRA_USED_FIXED_CHAR_HANDLES: If it is defined, the Initiator skips the service discovery and uses the fixed WiRa handlers for exchanging data with the Responder device.

  The handles of the characteristics of the WiRa service are considered fixed and known. This reduces the time for the first WiRa measurement after the connection establishment. The handles are:
  - WIRA_I_RESULT_VAL_HANDLER
  - WIRA_R_RESULT_VAL_HANDLER
  - WIRA_R_RESULT_CCC_HANDLER
- WIRA_CONNECTION_TO_SEC: Time within a connection between an Initiator and a Responder should be established. If this time passed the Initiator aborts the connection.
- WIRA_DISCONNECTION_TO_SEC: Time within a WiRa measurement should be performed. If it is not performed the Initiator will drop the connection.
- WIRA_MEASUREMENT_TO_MS: Time within a WiRa measurement should be performed. If it is not performed the measurement is considered invalid.
- WIRA_ENABLE_DTE_STATISTICS: If it is defined DTE statistics are enabled.
- WIRA_DEBUG_MEASUREMENTS: If it is defined, WiRa log messages are enabled to get raw measurements and more details about WiRa.

### 5.3.3 Running the Demo

For the WiRa tracking demo, at least two devices are needed, one configured as Initiator and one as a Responder. Initially, the Responder starts advertising with a custom DTE Data service UUID and the set number in the advertising data. The Initiator starts scanning, looking for the DTE Data service UUID and a matching set number in the advertising reports it receives. If both the UUID and the set number match, the two devices get connected.

When testing with more than two devices, the user can see how a Responder interacts with more than one Initiator. A prioritization mechanism is applied to decide when and with whom a WiRa measurement should be performed.

The steps to run the demo are the following:

1. Power up the device.
2. Download the firmware to the device:
   a. If the device is already programmed with firmware that supports SUOTA then the firmware can be updated over the air as described in Appendix C. The SUOTA images for the supported boards (DA1469x PRO DK, USB Kit, and WiRa Kit) are provided in folder **/binaries/wira/wira_tracking_demo/suota_images**.
   b. If the device does not support SUOTA then:
      i. Use the SmartSnippets Toolbox to erase the data of the whole Flash area, as described in Appendix B. This is required to delete the old partition table. A new partition table with SUOTA support will be created when the demo firmware is executed for the first time.
      ii. Use the SmartSnippets Toolbox to program the device as described in Appendix B. The binary files for the supported boards (DA1469x PRO DK, USB Kit, and WiRa Kit) are provided in folder **/binaries/wira/wira_tracking_demo/binaries**.
3. (Optional) Connect the device to the USB port of a computer and use a terminal program to get the debugging logs from the device. Configure the terminal with the following settings:
   - Baud rate: 115200
   - Data bits: 8
   - Parity: None

   Stop bits: 1

   After resetting the development kit, it starts by default as a Responder. To change the device's role to Initiator the Android WiRa application should be used, following the steps below:

   a. Long press the user button (K1) of the first device to enter configuration mode.


**Figure 16: Configuration Mode**

   b. The device remains in configuration for 10 seconds to allow the Android app to connect and configure the device as described in Appendix E. WiRa set number, inactivity timeout, a number of WiRa events, and WiRa measurement period can be configured.

   If the user does not connect to the device using the app within 10 seconds, then the device resumes normal operation and the following message is logged to the console:


**Figure 17: Output Log when Switching from Configuration to Normal Mode**

   c. Disconnect the Android app from the device.

Repeat the steps for all the devices. At least one Responder should exist in the demo setup.

1. Place all the Initiators at 2 meters distance from each other. This scenario simulates the implementation in which the Initiators are placed at fixed points and the Responders simulate the users, who move around.
2. Move the Responder from one Initiator to the other and when USB Kit or DA1469x PRO DK are used, check the logs and LED's state on the Initiator's side. In case WiRa KITs are used, there is no LED indication because this LED is used by the LCD interface. In the case of WiRa Kit, check the LCD where the distance is displayed and when the devices are close enough the color of the first line on the display changes from white to red.
3. Open for each Initiator a UART terminal with the following configuration to get the logs:
    - Baudrate: 115200
    - Bits: 8
    - Parity: None
    - Stop bits: 1

The demo procedure with the default values for the thresholds is the following:

- The Responders start advertising and the Initiators start scanning for Responders. Responders with RSSI lower than the DEFAULT_WIRA_RSSI_LOW_THRESHOLD ( -85 dBm) are filtered out and not processed further because they are too far away. For the other Responders, the distance is calculated by the RSSI and a priority calculation is performed to decide about the WiRa measurement.
- Responders are prioritized according to their RSSI and WiRa distance. The following rules are applied for the priority calculation:
    - WiRa is not needed if the RSSI value is higher than the DEFAULT_WIRA_RSSI_THRESHOLD (-38 dBm). In this case, the Responder is within the 1 m radius. (DEFAULT_WIRA_DISTANCE_LOW_THRESHOLD)
    - Responders without a WiRa measurement have priority over those with a WiRa measurement. At least one WiRa measurement is needed for each Responder
    - Priority depends on the time passed since the last WiRa measurement
    - Responders with lower RSSI have higher priority
    - WiRa is performed when the calculated priority is above a threshold. In our demo, the priority threshold is set to 90

After each WiRa measurement a decision is taken:

- Either the LED on the development kit (DA1469x Pro DK, USB Kit) is turned on at the Initiator's side to indicate that a Responder is within a 1 m radius or it is turned off/remains off if the Responder is farther than 1 m from the Initiator
- For WiRa Kit the color on the LCD changes to red from white on the Initiator's display, when a Responder is within a 1 m radius

The logs in the Initiator's terminal are shown in Figure 18.

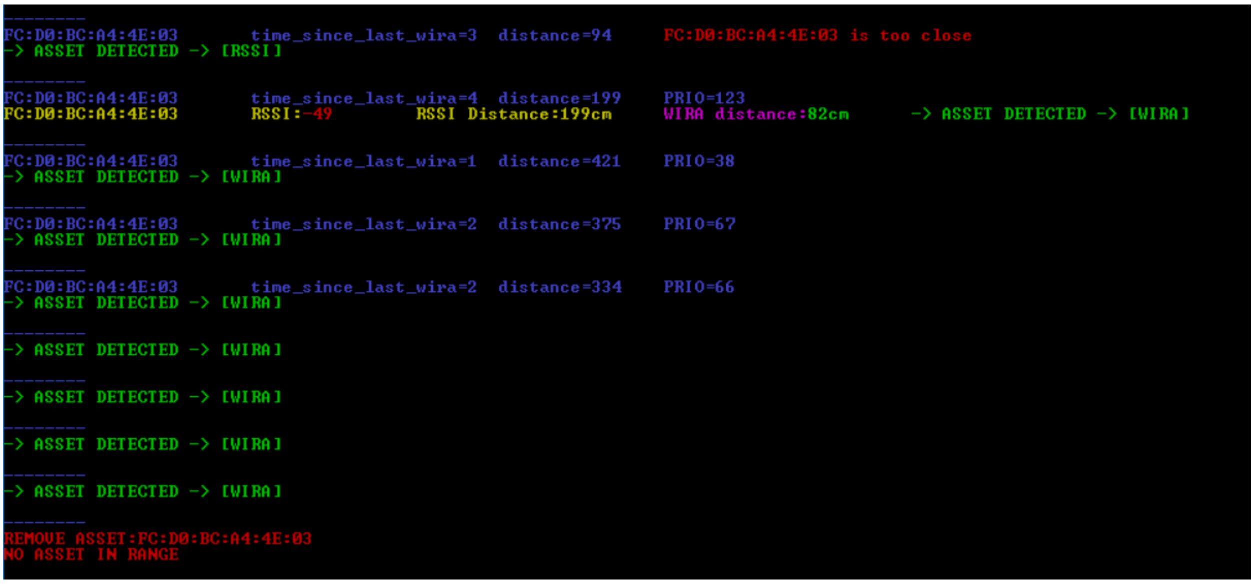



**Figure 18: Logs in the Initiator's Terminal**

After each scan completion the blue line is printed, reporting the Responder's BD address, the time in seconds since the last WiRa measurement for the specific Responder, the distance calculated by the RSSI reported in scan results, and the calculated priority. The priority calculation results combine the previous two values.

At the first line, the Responder is very close to the Initiator, which means the RSSI is higher than the predefined threshold (-38 dBm). The decision is that an asset is detected by the RSSI and no priority calculation is needed.

At the next scan, the priority is 123, greater than the predefined threshold (90), so a WiRa measurement will be performed. After WiRa completion in the next line (yellow and purple) the results are reported.

The results consist of the Responder's BD address, the RSSI, the calculated distance using the RSSI, the calculated WiRa distance, and at the end the result.

In the WiRa results line the RSSI is lower than the predefined threshold ( -38 dBm), therefore the value (-49 dBm) is printed in red color. However, the calculated WiRa distance is lower than the predefined threshold (1 m), therefore the value (82 cm) is printed in green color and the decision will be taken due to WiRa measurement (distance). The asset is detected in range and consequently, the LED on the development kit (DA1469x PRO DK, USB Kit) will be turned on or the color in the display will change to red (WiRa Kit).

At the next three scan completions, the priority is lower than 90, so no WiRa is performed. Afterward, the Responder is switched off. It is not present anymore in the scan results, therefore no blue lines are printed.

After an absence in five consecutive scan results, the Responder will be removed from the asset list and the LED on the development kit will be turned off (DA1469x PRO DK, USB Kit) or the color on the LCD will be changed to white (WiRa Kit). NO ASSET IN RANGE printout will appear.

If there are two or more Responders in the test setup, the output of the log changes is similar to Figure 20.


**Figure 19: Output Log with Two Responders**

In the above log, there are two Responders in range. After scan completion, there is one blue line for each Responder and at the next line (white color) the maximum RSSI and the last minimum calculated WiRa distance of the two Responders are printed, to show which Responder triggered the decision.

For example, at the first run, the priority of F4:1F:8B:41:D3:29 is 92, higher than 90 and a WiRa measurement is performed with this Responder. The calculated WiRa distance of F4:1F:8B:41:D3:29 is 93 cm, lower than the predefined threshold (1 m), so the asset is detected by WiRa. The LED of the development kit (DA1469x PRO DK, USB Kit) will be turned on or the color on the LCD will change to red (WiRa Kit).

The “MIN distance” (white line) remains 93 cm for the next three scans. At the third scan the priority of FC:D0:BC:A4:4E:03 is 93, so a WiRa is performed with this Responder, but the calculated distance is more than 1 meter so the LED remains on due to the distance of the other Responder.

At the next scan, a new WiRa measurement is performed with F4:1F:8B:41:D3:29 due to priority, but both Responders are not in the predefined range, so the result is NO ASSET IN RANGE and the development kit’s LED will be turned off (DA1469x PRO DK, USB Kit), display's color is changed to white (WiRa Kit).

At the last scan the RSSI of FC:D0:BC:A4:4E:03 Responder is -32 dBm, higher than the predefined threshold (-38 dBm), so the asset is detected by its RSSI, no WiRa is needed. LED will be turned on (DA1469x PRO DK, USB Kit), display's color will change to red (WiRa Kit).

### 5.3.4 Detailed Software Description

#### 5.3.4.1 Basic Structures

When the Initiator receives the BLE_EVT_GAP_ADV_REPORT or the BLE_EVT_GAP_EXT_ADV_REPORT message, the code collects the data from the advertisement report and saves them in **scan_results_t** structure.

```
typedef struct scan_results_s
{
        struct scan_results_s *next;
        scanned_dev_entry dev
} scan_results_t;
```

It is a linked list with the structure **scanned_dev_entry** as the member that contains each entry of the advertisement report.

```
typedef struct
{
    bd_address_t    addr;
    int16_t              rssi;
    uint8_t              count;
} scanned_dev_entry;
```

where:

- **addr** is the BD address of the device
- **rssi** is the reported RSSI for each device in the advertisement report
- **count** is a variable that indicates how many times a device appears in one advertisement report

When the Initiator receives the BLE_EVT_GAP_SCAN_COMPLETED or BLE_EVT_GAP_EXT_SCAN_COMPLETED message the process of the scanned devices begins. The data are processed and finally, a list with available assets is created and used to perform WiRa or not and take decisions like turn on/off a LED, open/close a door, and so on.

There is the following structure:

```
typedef struct
{
        void*               scan_list;
        void*               unique_scan_entries_list;
        void *              assets_list;
    OS_TIMER    scan_duration_tmr;
} tracking_env_t;
```

The member **scan_duration_tmr** is a timer that stops a scan after a period of 3*scan_interval milliseconds.

All the collected data from an advertisement report are saved in the **scan_list** member. Then another list is created, member **unique_scan_entries_list**, which contains a unique entry for each device that was in the scan results. This unique entry consists of the bd address of the device and the average RSSI. The creation of a list with all the candidate assets for WiRa measurement is the next step. This list is the member **assets_list**.

All the assets are saved in the following linked list:

```
typedef struct assets_s
{
   struct assets_s *next;
   tracking_info_dev_t dev;
} assets_t;
```

Where each asset/device is described by the **tracking_info_dev_t** structure which has the following members:

```
typedef struct
{
    bd_address_t          addr;
   int8_t                 rssi;
   int8_t                 rssi_vals[RSSI_CIRC_BUFF_MAX];
   uint16_t               distance_by_rssi;
   uint8_t                updated_last_scan;
  uint32_t                 t_wira_s;
  uint8_t                  num_of_wira;
   int16_t                distance;
   uint16_t               prio;
   bool                   decision;
```

```
    uint8_t                head;
    uint8_t                tail;
} tracking_info_dev_t;
```

where:

- **addr** is the BD address of the asset
- **rssi** is the average RSSI of the asset in one advertisement report
- **rssi_vals** is a circular buffer that keeps the last RSSI values of the asset. How many RSSI values will be kept is defined by **RSSI_CIRC_BUFF_MAX**
- **distance_by_rssi** is the calculated distance in cm using the rssi member. It is needed for the priority calculation **updated_last_scan** to be set to 1 when an asset was present in the last scan results
- **t_wira_s** time in seconds since the last WiRa measurement for the asset. It is needed for the priority calculation
- **num_of_wira** is the total number of performed WiRa measurements
- **distance** is the calculated distance in cm by WiRa measurement
- **prio** is the calculated priority. If a WiRa measurement will be performed, depends on the priority
- **decision** is a boolean variable which is set to false after a WiRa measurement and to true to perform a WiRa measurement

# Appendix A Development Boards

## A.1 DA1469x PRO Development Kit

### A.1.1 Description

The DA1469x PRO Development Kit hardware is described in Ref. [4].

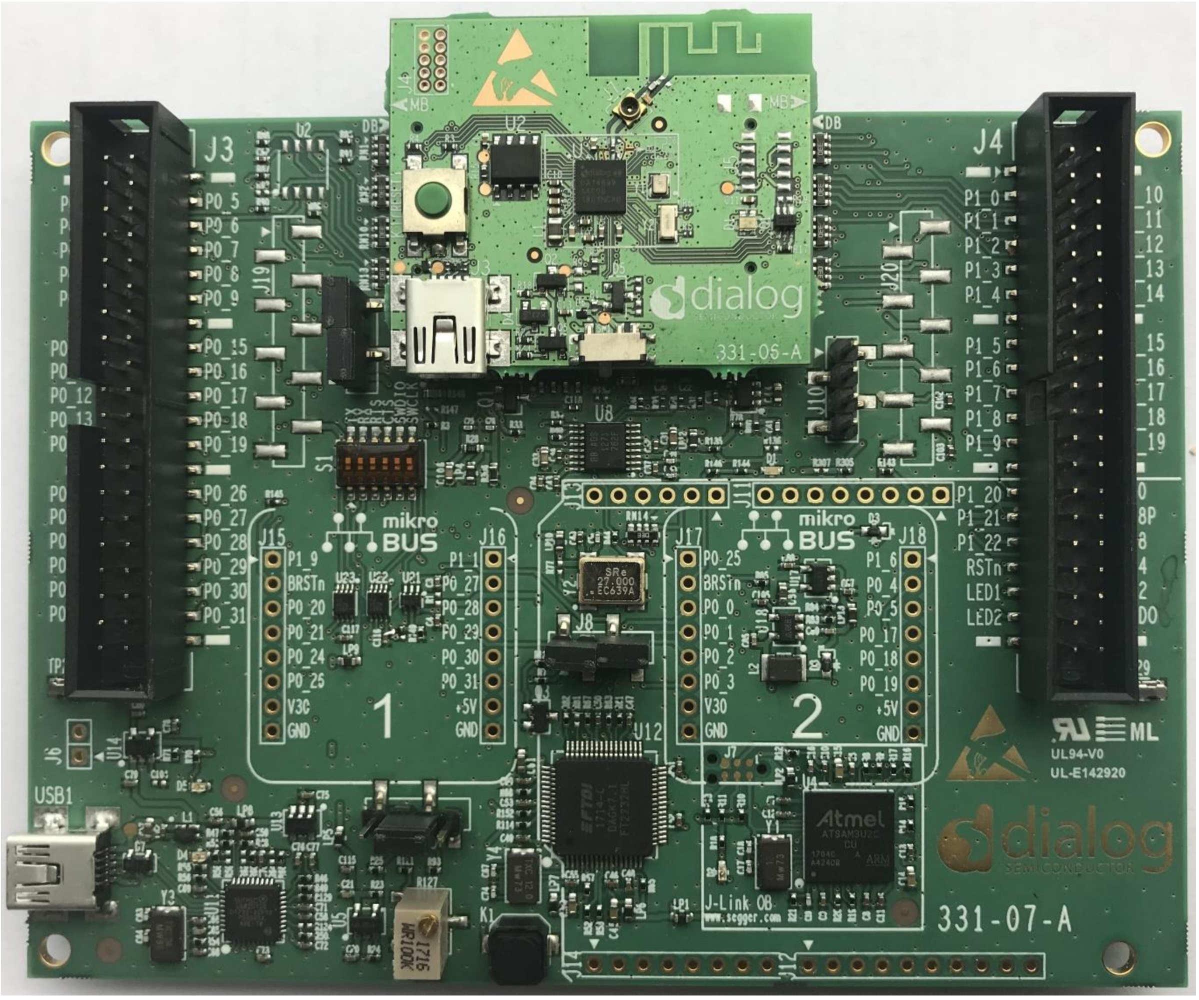



**Figure 20: DA14695 PRO DK**

### A.1.2 Buttons and Switches

The available buttons are:

- K2 (RESET): Hardware resets the DA1469x daughter board
- K1: If the button is pressed momentarily it will print WiRa statistics on the terminal (if WIRA_DEBUG_MEASUREMENTS is defined in `wira_config.h`). If the button is pressed for 2 seconds, PRO-DK enters the configuration mode either it is configured as a Responder or as an Initiator. It advertises for 10 seconds, within which the user can connect to the device using the WiRa Android application to change configuration parameters

### A.1.3 Connecting Hardware and Powering On

Do **NOT** change any of the jumper positions or remove/misalign the daughterboard.

To flash the application firmware image, follow the instructions in Appendix B (using SmartSnippets Toolbox), Appendix C (SUOTA) first. The available binaries that will be used by Toolbox for DA1469x PRO DK are located under the **binaries/wira/<project_name>/binaries** folder and their filenames end in **Pro_DK_macronix_sst.bin**. The proper images that will be used by SUOTA for DA1469x PRO DK are located under the **binaries/wira/<project_name>/suota_images** folder and their filenames end in **Pro_DK.img**. The boards are powered via USB. To power it on, use the provided USB cable to connect the DA1469x PRO DK to a laptop or desktop.

When the DA1469x PRO DK is to be connected to a power adapter or power bank, you need to solder a header on J6 and install a jumper there to bypass the enumeration with a USB host.

After power-on via USB, the DA1469x PRO board programmed with one of the three available applications will enter Scanning or Advertising mode based on the configuration of the non-volatile role parameter.

## A.2 DA1469x USB Kit

### A.2.1 Description

The DA1469x USB Kit hardware is described in Ref. [5]. In case an LCD monitor is attached to the USB kit, the device is called DA1469x WiRa Kit. Without the LCD it will be called a USB Kit. For all the demo applications there are the corresponding Build configurations for each USB Kit.

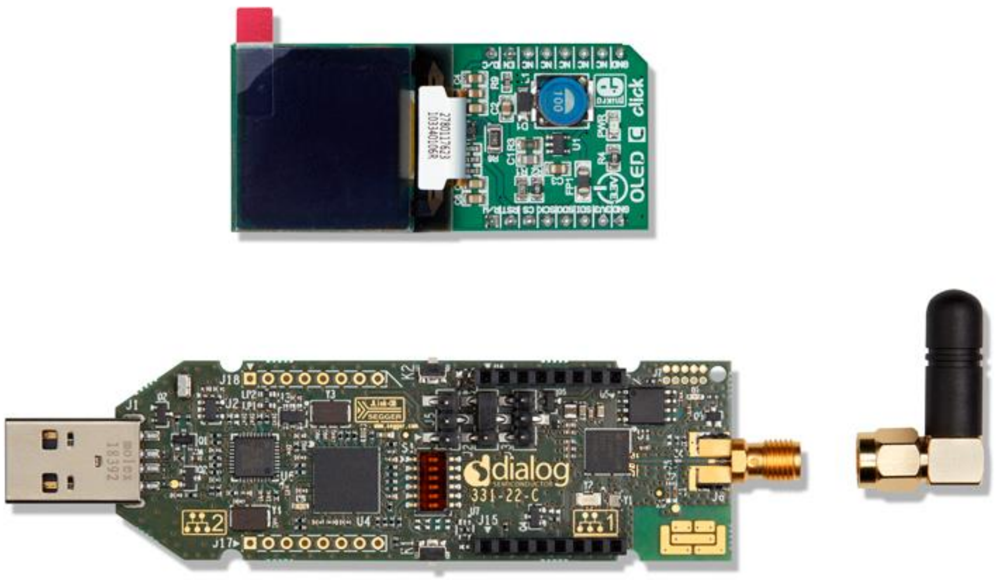



**Figure 21: DA14695 Wireless Ranging Kit (WiRa Kit) HW Components with External Antenna**

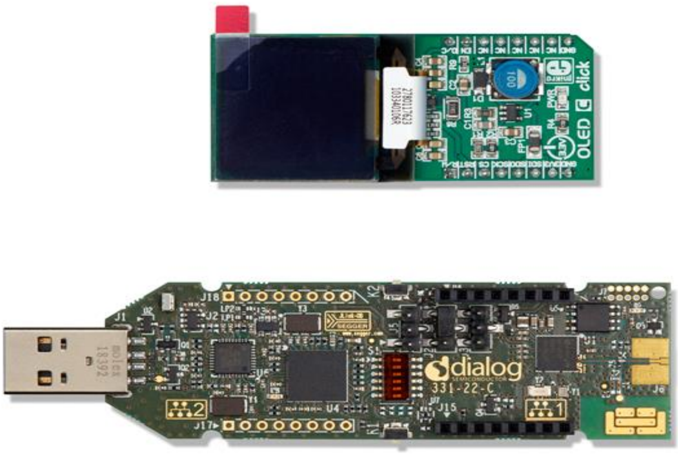


Figure 22: DA14695 Wireless Ranging Kit (WiRa Kit) HW Components with ZOR Antenna

Figure 23: DA14695 USB Kit HW Components with External Antenna

Figure 24: DA14695 USB Kit Components with ZOR Antenna

### A.2.2 Buttons and Switches

The available buttons are:

- K2: It is the reset button. Hardware resets the USB Kit
- K1: If the button is pressed momentarily it will print WiRa statistics on the terminal (if WIRA_DEBUG_MEASUREMENTS is defined in wira_config.h). If the button is pressed for 2 seconds, the USB Kit enters the configuration mode either it is configured as Responder or as an Initiator. It advertises for 10 seconds, within which the user can connect to the device through the Android application to change configuration parameters. In this configuration mode, it can also be accessed via SUOTA mobile app to perform Firmware upgrade

### A.2.3 LCD Support

USB Kit supports the OLED C click display connected to the mikroBUS socket.

The following hardware modification is required on the DA1469x USB Kit board:

- Add sockets to J17 and J18 for OLED C Click Display to be clicked on. Hardware modifications have already been applied in-house for all delivered DA1469x Wireless Ranging development kits

### A.2.4 Connecting Hardware and Powering On

Do **NOT** change any of the jumper positions or remove/misalign the daughterboard.

To flash the application FW image, follow the instructions in Appendix B (to use SmartSnippets Toolbox) or Appendix C (to use SUOTA), first. The available binaries that can be used by Toolbox for DA1469x USB Kit and WiRa Kit are located under the **binaries/wira/<project_name>/binaries** folder and their filenames end in **USB_DK_macronix_sst.bin** and **WIRA_KIT_macronix_sst.bin** respectively. The proper images that can be used by SUOTA for DA1469x USB Kit and WiRa Kit are located under the **binaries/wira/<project_name>/suota_images** folder and their filenames end in **USB_DK.img** and **WIRA_KIT.img** respectively. The boards are powered via USB. To power it on, use the provided USB cable to connect the DA1469x USB Kit to a laptop or desktop.

When the DA1469x USB Kit is to be connected to a power adapter or power bank, diode D9 near K2 must be removed.

After power-on via USB, the DA1469x USB Kit programmed with one of the three available applications will enter Scanning or Advertising mode based on the configuration of the non-volatile role parameter.

# Appendix B Upgrade Development Kits Using SmartSnippets Toolbox

The following steps should be executed to upgrade a development kit using SmartSnippets Toolbox:

1. Download and install to your PC/Laptop the latest version of SmartSnippets Toolbox (**v5.0.20 or higher**) from here: https://www.renesas.com/eu/en/software-tool/smartbond-development-tools
2. Plug the development kit into the USB port of the PC/Laptop and open the SmartSnippets Toolbox.
3. Select the device and the communication interface (JTAG or UART).
4. Open **Board** > **Device** and choose **DA1469x-00**.

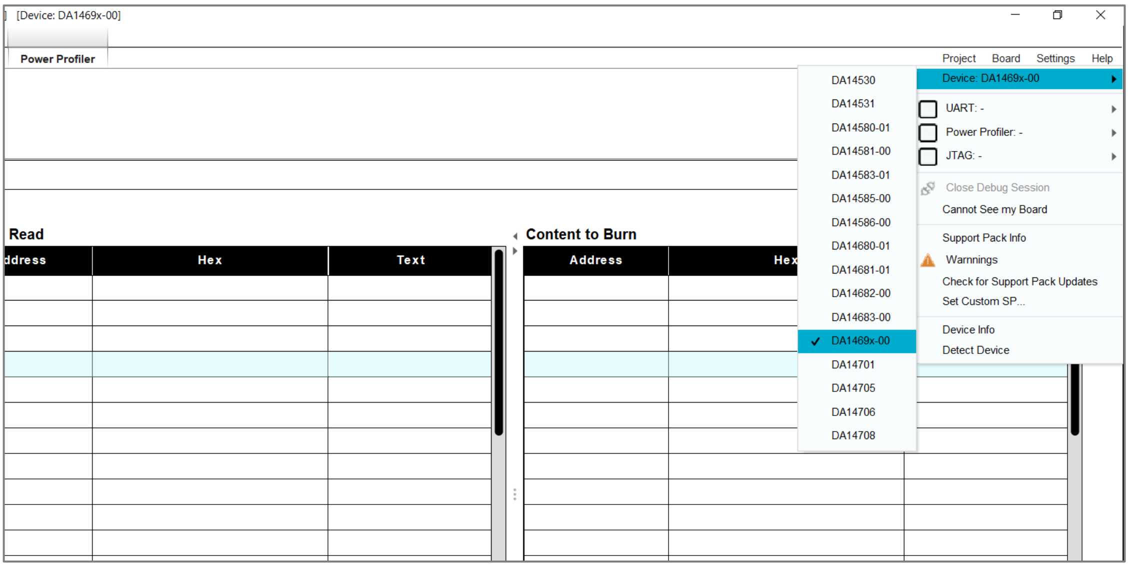



**Figure 25: Select the Hardware Device**

5. Select the **JTAG** option.

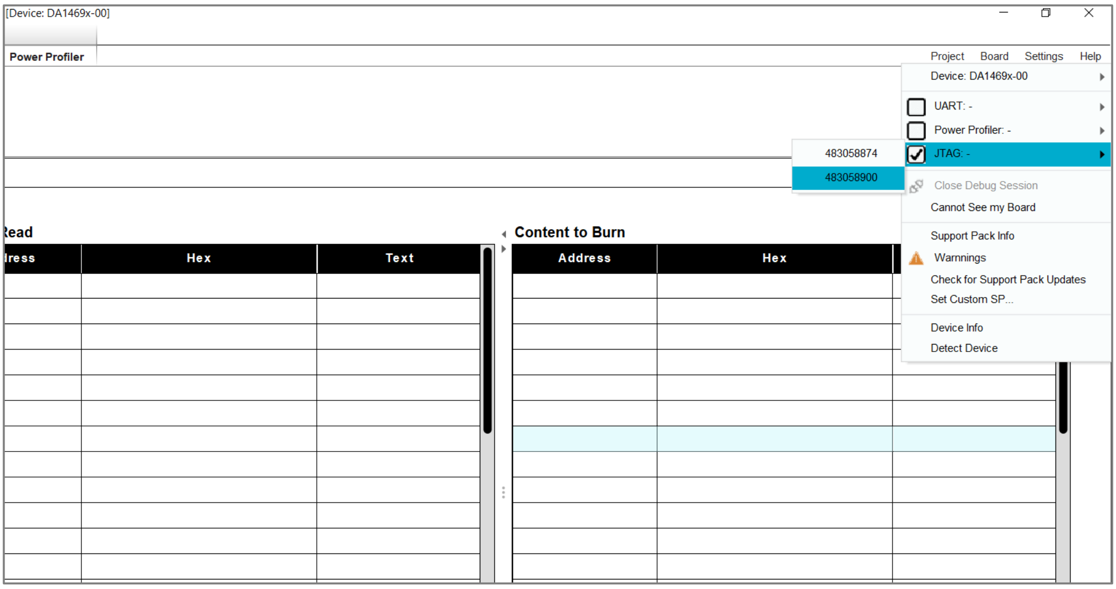



**Figure 26: Select the Communication Way**

6. Open **Programmer** > **Flash Code** to upgrade the development kit.

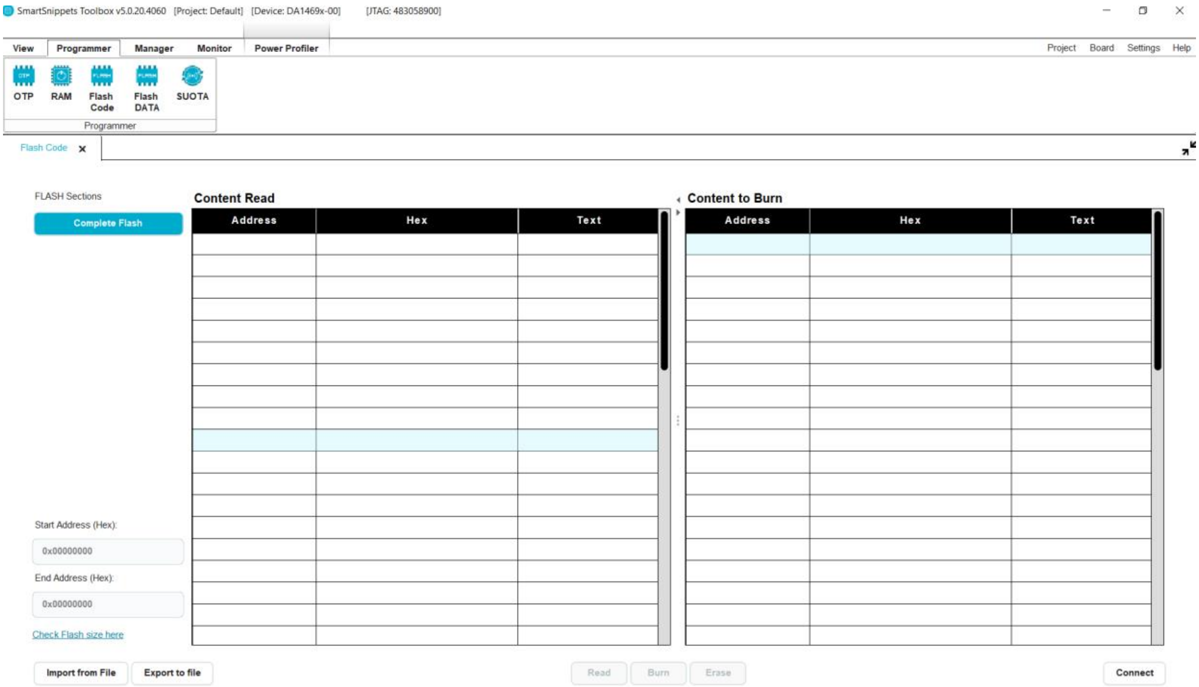



**Figure 27: Flash Code Initial Screen**

7. Click **Connect**, and wait until that Toolbox is connected successfully to the device. After a successful connection, in the Log Window the following messages will appear:

```
[INFO    @22-08-17 16:39:28] Started reading Configuration Script from Memory.
[INFO    @22-08-17 16:39:29] Configuration Script has not been found.
[INFO    @22-08-17 16:39:29] Trying to detect Product Header at address 0x00000000.
[INFO    @22-08-17 16:39:29] Valid Product Header detected at address 0x00000000.
[INFO    @22-08-17 16:39:29] Valid Backup Product Header detected at address 0x00001000.
[INFO    @22-08-17 16:39:29] Started reading Firmware Image(s) header from Memory. Please wait...
[INFO    @22-08-17 16:39:29] Found Firmware Image with size 443836 bytes starting at address 0x00002000
[INFO    Flash Code@22-08-17 16:39:29] Memory reading completed.
```

**Figure 28: Toolbox Log after Successful Connection with Hardware Board**

8. Click **Erase** to erase the flash. After completion, check the Log file to see the messages below:

```
[INFO    Flash Code@22-08-17 16:42:28] Started erasing from 0x00 to 0x8000
[INFO    Flash Code@22-08-17 16:42:28] Memory erasing completed successfully.
[INFO    Flash Code@22-08-17 16:42:28] Reading QSPI flash memory to verify its contents after erase...
[INFO    Flash Code@22-08-17 16:42:29] Verification succeeded. 32768 bytes read for verification.
[INFO    Flash Code@22-08-17 16:42:29] Reading memory to refresh table contents...
[INFO    Flash Code@22-08-17 16:42:30] Reading has finished. Read 32768 bytes.
```

**Figure 29: Toolbox Log after Successful Flash Erase**

9. If a user would like to erase the whole flash, to delete the partition table also, then the following steps are required:
   a. Check the flash size by clicking **Check Flash size here**.

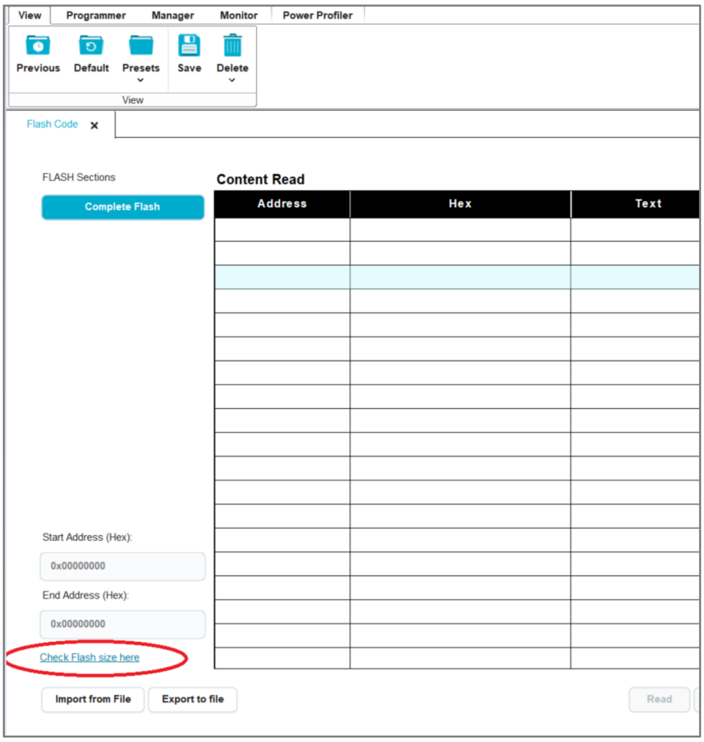



**Figure 30: Check Flash Size Option**

b. A pop-up window will appear with the flash size. In this case, the flash size is 4 MB.

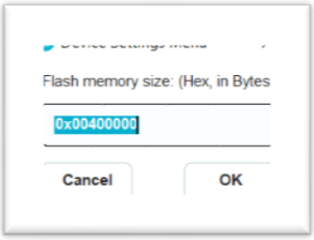



**Figure 31: Pop-up Flash Memory Size**

c. Click **OK** and the End Address will be filled automatically with the flash size. Then click **Erase**. The erase procedure takes a few seconds.

d. In the **Log** window, the following messages will appear:

```
[INFO    Flash Code@22-08-17 16:46:41] Started erasing from 0x00 to 0x400000
[INFO    Flash Code@22-08-17 16:47:15] Memory erasing completed successfully.
[INFO    Flash Code@22-08-17 16:47:15] Reading QSPI flash memory to verify its contents after erase...
[INFO    Flash Code@22-08-17 16:47:23] Verification succeeded. 524287 bytes read for verification.
[INFO    Flash Code@22-08-17 16:47:23] Reading memory to refresh table contents...
[INFO    Flash Code@22-08-17 16:47:23] Reading has finished. Read 32768 bytes.
[INFO    @22-08-17 16:47:23] Started reading Configuration Script from Memory.
[INFO    @22-08-17 16:47:24] Configuration Script has not been found.
[INFO    @22-08-17 16:47:24] Trying to detect Product Header at address 0x00000000.
[INFO    @22-08-17 16:47:24] Started reading Firmware Image(s) header from Memory. Please wait...
[INFO    @22-08-17 16:47:24] Flash Programmed indication could not be detected. Cannot find active/upgrade FW Image address.
[INFO    Flash Code@22-08-17 16:47:24] Memory reading completed.
```

**Figure 32: Toolbox Log after Erasing Successfully Whole Flash Memory**

10. To burn the desired image to flash, click **Import from file**, and a pop-up window will appear. Select the location where the desired file is saved by clicking **Browse**.

    All the images are located under the **binaries/wira/<demo_name>/binaries** folder.

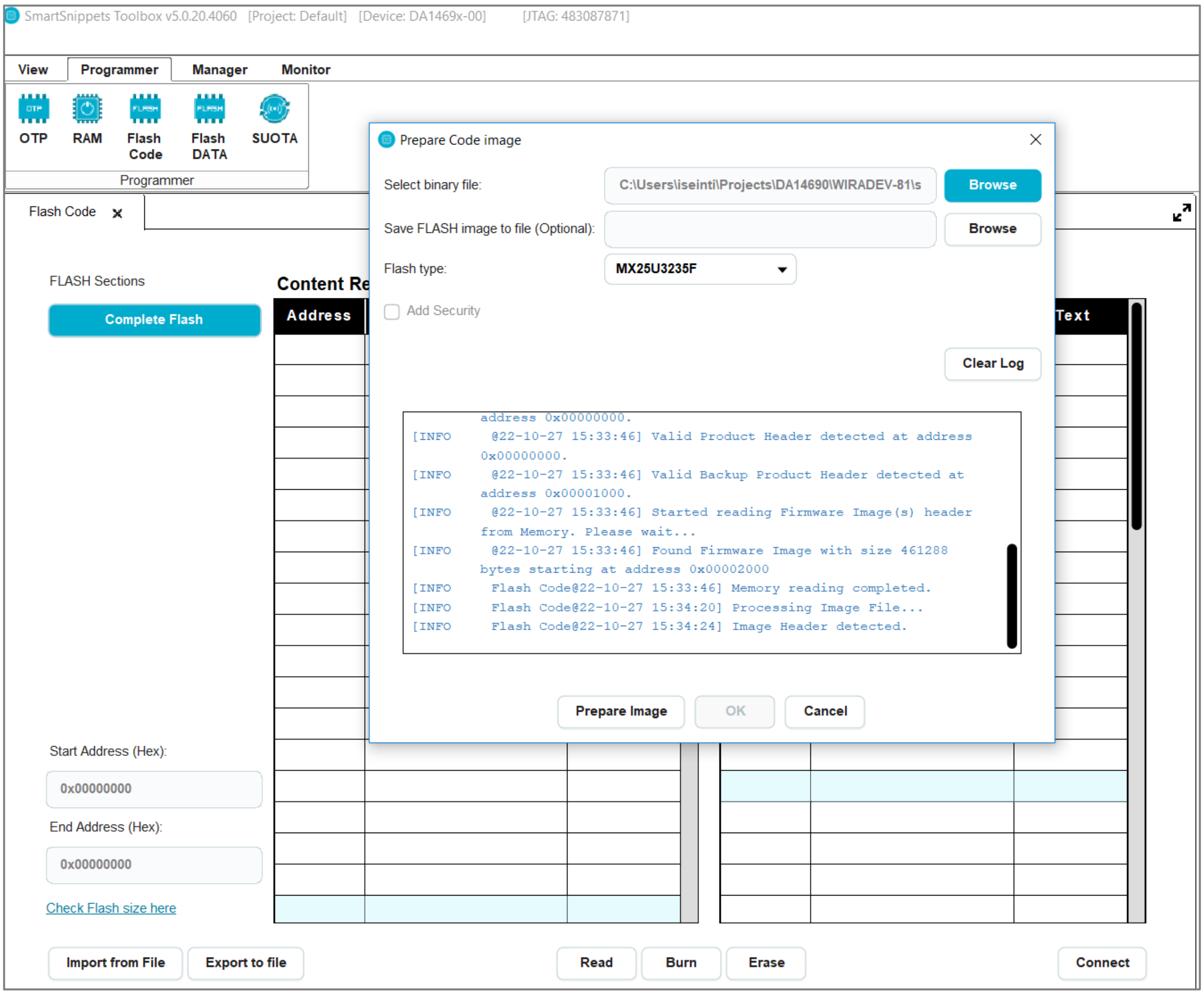



Figure 33: Pop-up to Choose Binary to Burn the Flash Memory

11. Click **OK** and then click **Burn**.
12. In the Log window, check for the following messages:

```
[INFO    Flash Code@22-08-17 16:51:21] Memory burning completed successfully.
[INFO    Flash Code@22-08-17 16:51:21] Reading memory to refresh table contents....
[INFO    Flash Code@22-08-17 16:51:28] Reading has finished. Read 453052 bytes.
[INFO    @22-08-17 16:51:28] Started reading Configuration Script from Memory.
[INFO    @22-08-17 16:51:28] Configuration Script has not been found.
[INFO    @22-08-17 16:51:28] Trying to detect Product Header at address 0x00000000.
[INFO    @22-08-17 16:51:28] Valid Product Header detected at address 0x00000000.
[INFO    @22-08-17 16:51:28] Valid Backup Product Header detected at address 0x00001000.
[INFO    @22-08-17 16:51:28] Started reading Firmware Image(s) header from Memory. Please wait...
[INFO    @22-08-17 16:51:29] Found Firmware Image with size 443836 bytes starting at address 0x00002000
[INFO    Flash Code@22-08-17 16:51:29] Memory reading completed.
```

Figure 34: Toolbox Log after Successful Flash Burning

13. Press the **Reset** button (K2 button) on the device. The device will start with the upgraded image.

# Appendix C Upgrade Development Kits over SUOTA

To upgrade a device using SUOTA, the current flashed image should support SUOTA.

**wira_eval_demo DOES NOT** support SUOTA. To change from wira_eval_demo to another demo, the procedure described in Appendix B **MUST** be followed.

The following steps should be executed to upgrade a development kit using the SUOTA service:

1. Download from Play Store the **Renesas SUOTA** (a.k.a.**Dialog SUOTA)** app and install it on an Android mobile phone.
2. On the Android phone, a folder named **Suota** is created. Copy in this folder the desired image, which is located under the **binaries/wira/<project_name>/suota_images** folder. The file extension of all SUOTA image files is **.img**.

   For example, to upgrade the development kit with the **wira_tracking_demo** image, copy the file named **wira_tracking_demo_release_xx.img** to the Suota folder of the mobile phone. Where **xx** is:

   - Pro_DK: if the Pro DK will be upgraded
   - USB_DK: if the USB kit without the LCD will be upgraded.
   - WIRA_KIT: If the USB kit with the LCD connected will be upgraded.

   To upgrade the development kit with the **wira_basic_app_demo** image, copy the file named **wira_basic_app_demo_release_xx.img** to the Suota folder of the mobile phone**.**
3. Plug the development kit into the USB port of the PC.
4. Open Bluetooth, Location services, and the SUOTA app on the mobile phone.

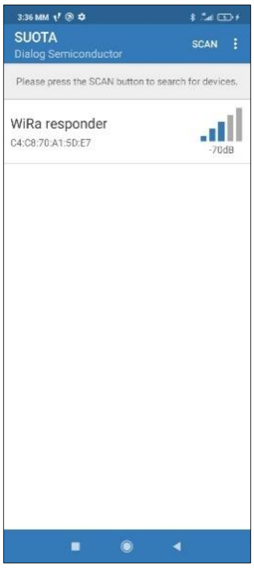



**Figure 35: Initial Screen of SUOTA Application**

5. Connect to the device that needs to be upgraded.


**Figure 36: Screen with the Selected Device for Update**

6. Press **UPDATE DEVICE** and then select the desired image.


**Figure 37: Screen to Select the Desired Image to Update the Device**

7. Press **SEND TO DEVICE.**

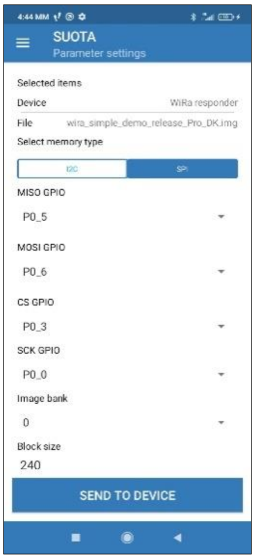



**Figure 38 : Screen to Configure the Communication Way for Update**

8. The upgrade procedure will start automatically. It will take some seconds.


**Figure 39: SUOTA Procedure Started**

9. The upgrade procedure finishes with success if the below pop-up appears. Press **OK** and close the Android app. The device will reboot and start with the new image.

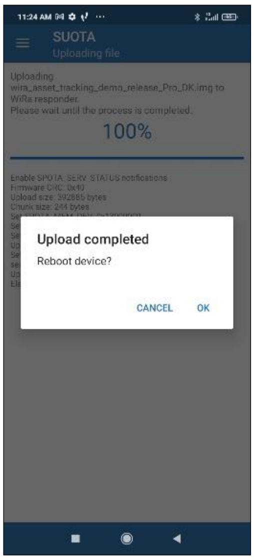



**Figure 40: Successful SUOTA Procedure**

# Appendix D Import, Build, and Burn the WiRa Demo Applications

There are three WiRa demo applications available: **wira_eval_demo**, **wira_basic_app_demo,** and **wira_tracking_demo**. For each demo there are prebuilt binaries and images located under **binaries/wira/<demo_app_name>/binaries** and **binaries/wira/<demo_app_name>/suota_images** folders. The binaries in this folder are updated when a project is rebuilt. The following steps should be executed to import a project:

1. Unzip the WiRa SDK release zip file (for example, WiRa_10.440.10.31.zip) into a known location on your drive.
2. All software development is based on SmartSnippets™ Studio. Follow the setup instructions in Section 1 of Ref. [2] for a fresh installation.
3. After SmartSnippets Studio installation, launch the program. In the first screen, enter the path of the folder where the WiRa SDK is located using the **Browse** button and then click **Launch**.

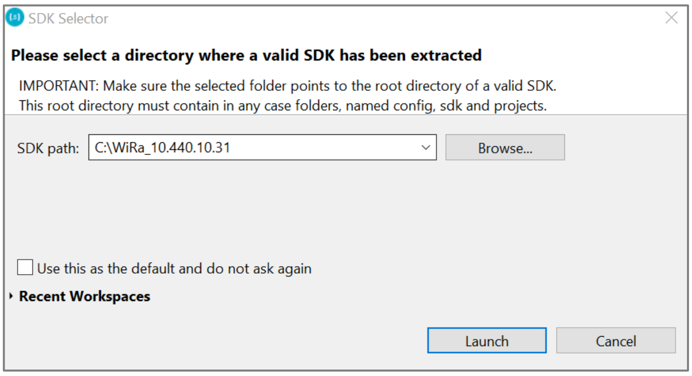



**Figure 41: SDK Location Path Selection**

4. In the **Tools** section of the **Welcome** screen, select **IDE**. The regular Eclipse environment view should now appear.

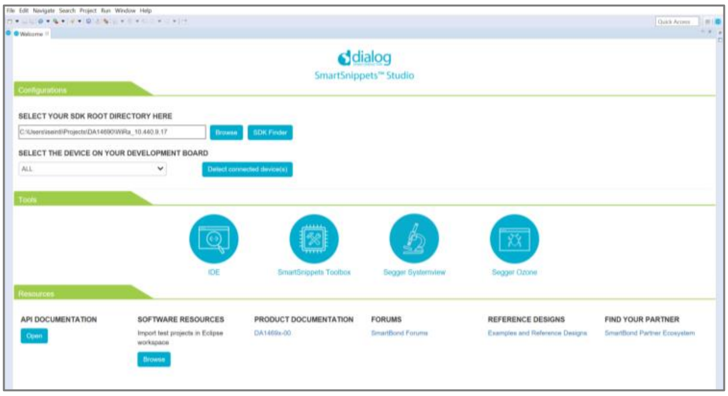



**Figure 42: SmartSnippets Studio Welcome Screen**

5. To import the demo applications, select **File >Import**, then select **General** > **Existing Projects into Workspace,** and click **Next**.

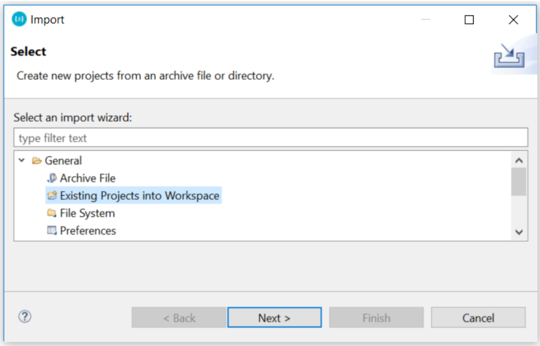



**Figure 43: Import SmartSnippets Studio Project Screen**

6. Browse the path of the SDK release folder, click **Deselect all,** and from the project list select only *wira_eval_demo, wira_basic_app_demo, wira_tracking_demo* projects, and *python_scripts.* Then click **Finish**.

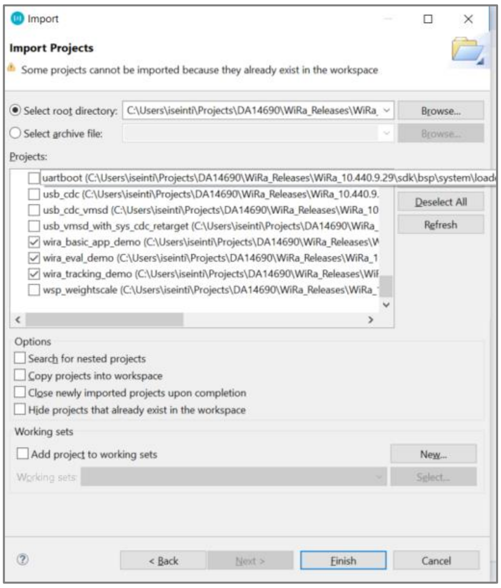



**Figure 44: List with All Available Projects to Import**

Python_scripts are needed to flash the development kits using SmartSnippets Studio. This procedure is described below.

To build one of the projects, first, the proper Build configuration should be selected. There are six build configurations available. The selection depends on the mode (Debug, Release) and the development kit used (DA1469x PRO DK, USB Kit, WiRa Kit):

- **DA1469x-00-Debug_QSPI:** Debug mode for PRO DK
- **DA1469x-00-Debug_QSPI_USB_DK:** Debug mode for USB Kit
- **DA1469x-00-Debug_QSPI_WIRA_KIT:** Debug mode for USB WiRa Kit
- **DA1469x-00-Release_QSPI:** Release mode for PRO DK
- **DA1469x-00-Release_QSPI_USB_DK:** Release mode for USB Kit
- **DA1469x-00-Release_QSPI_WIRA_KIT:** Release mode USB WiRa Kit

The following steps should be followed to build a project:

1. Right-click the project name, go to **Build Configurations** > **Set Active,** and choose the proper build configuration.

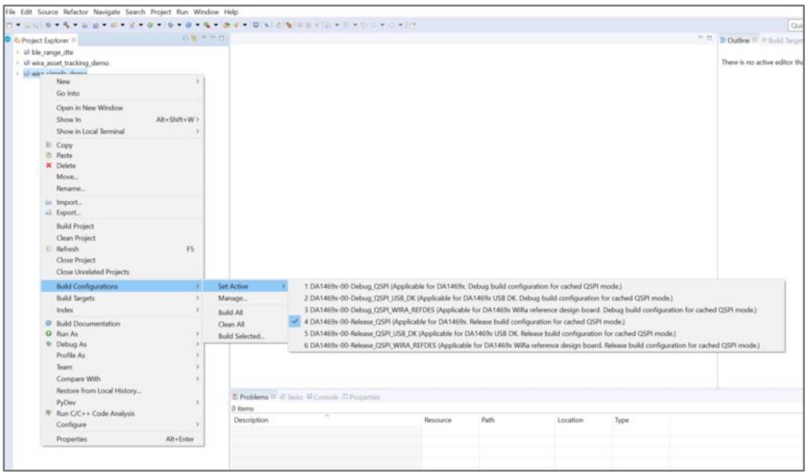


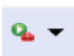
**Figure 45: Selection of Build Configuration**

2. Make desired changes in the code, right-click the project name, and go to **Build project**.
3. After a successful build in the Console Window, you can see the following messages:

```
Building target: wira_tracking_demo.elf
Invoking: Cross ARM C Linker
Memory region         Used Size  Region Size  %age Used
             ROM:      423816 B       440 KB     94.06%
             RAM:      423852 B     523776 B     80.92%
Finished building target: wira_tracking_demo.elf

Prepare SUOTA image.
Invoking: Cross ARM GNU Create Flash Image
Finished building: wira_tracking_demo.bin

Invoking: Mkimage Prepare SUOTA Image
......................................................................
..
.. PREPARE FLASH IMAGE
..
......................................................................
.
.
......................................................................
..
.. FINISHED
..
......................................................................

Invoking: Cross ARM GNU Print Size
   text    data     bss     dec     hex filename
 448544     888  398228  847660   cef2c wira_tracking_demo.elf
Finished building: wira_tracking_demo.siz

Generate linker scripts.

17:06:17 Build Finished. 0 errors, 2 warnings. (took 3m:43s.36ms)
```

**Figure 46: Console Output after Successful Project Build**

The binary and image are copied to the **binaries/wira/<demo_app_name>/binaries** and **binaries/wira/<demo_app_name>/suota_images** folders. The development kits can be upgraded with these images either over SUOTA (see Appendix C), binaries using Smartsnippets Toolbox (see Appendix B), or using python_scripts. To flash a development kit using python_scripts the following steps should be performed:

1. Select in the Project Explorer the project that you would like to write to the QSPI flash.
2. Press the External Tools button  from the toolbar.
3. At the first time, you need to run the configuration script to define which flash is used. Select *program_qpi_config.*

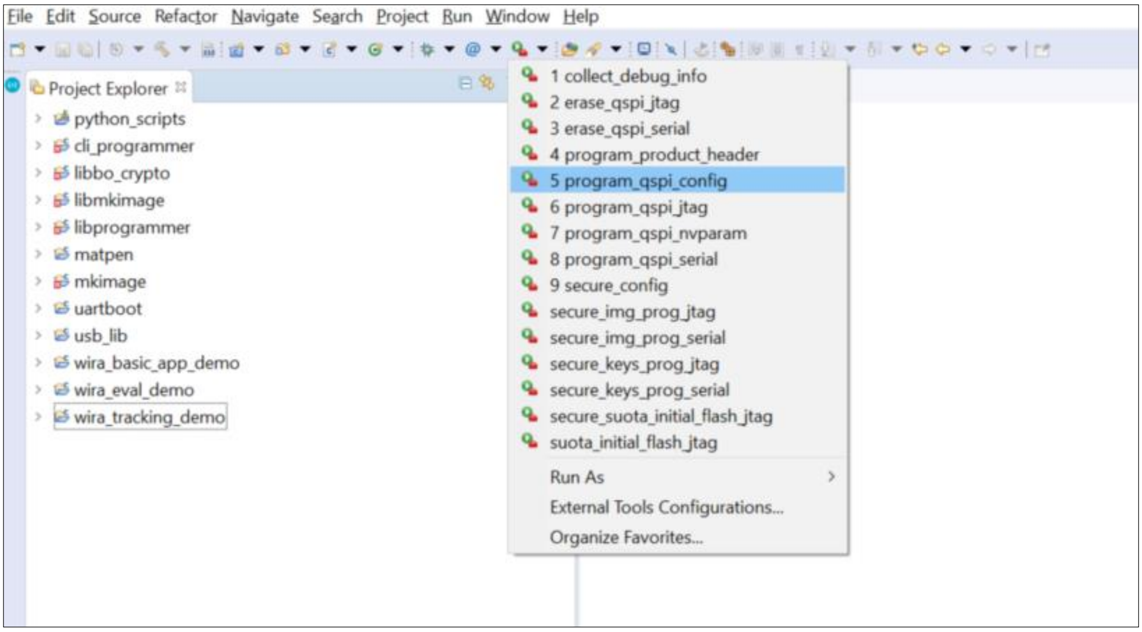



**Figure 47: Configure the Flash Memory for the Desired Board**

4. The following options should be selected for the DA1469x development kit's configuration:
   a. Product ID: DA1469x-00
   b. Flash configuration: MX25U3235F
   c. Active FW image address: 0x2000
   d. Update FW image address: 0x2000

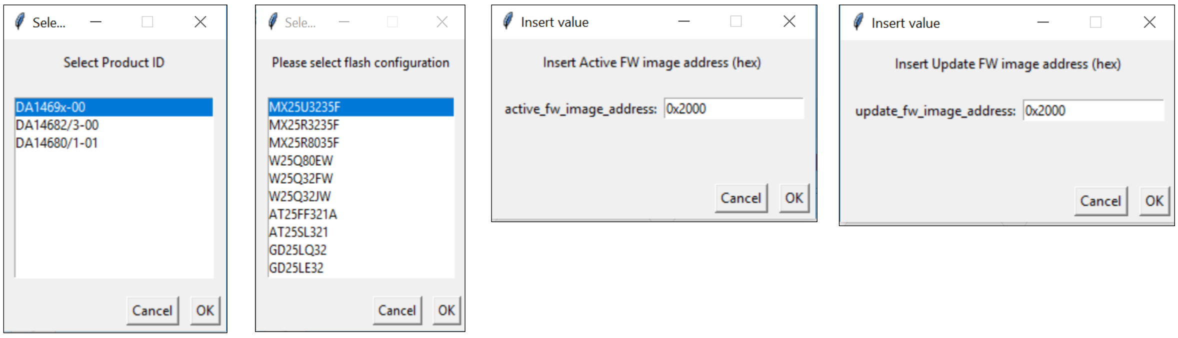



**Figure 48: DA1469x Development Kit's Configuration**

The configuration is done. Now the flash can be erased if needed or burned directly skipping step 4 and following instructions in step 5.

5. To erase the QSPI flash, select the **erase_qspi_jtag** option.

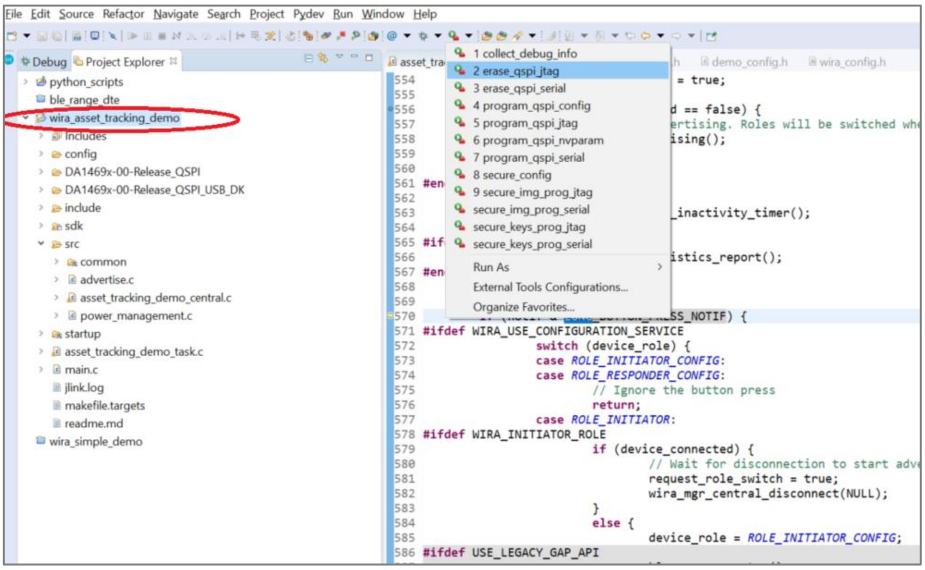


**Figure 49: Erase Flash Memory through Python Scripts**

6. To write the binary to QSPI flash, select the **program_qspi_jtag** option.

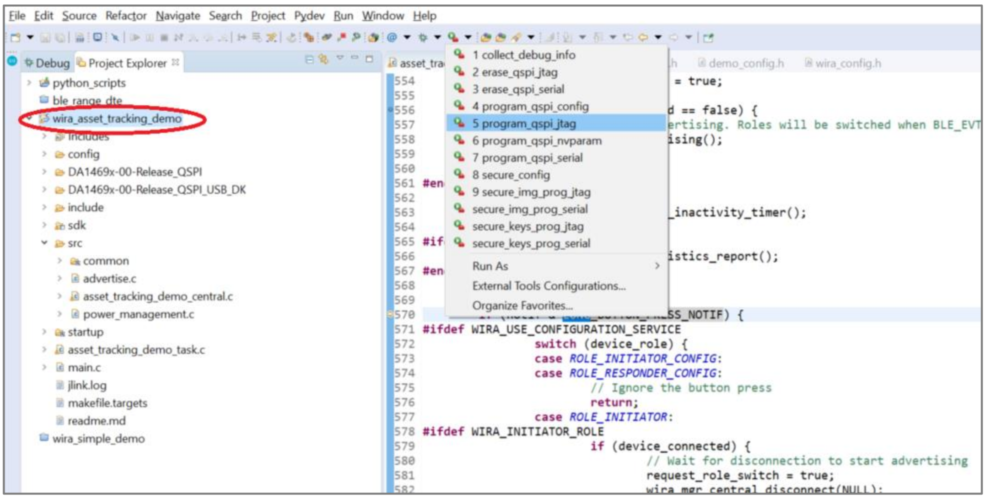


**Figure 50: Burn Flash Memory through Python Scripts**

If more than one development kit are connected to the PC, the pop-up window as in Figure 51 appears in steps 3, 4, and step 5, asking a user to select which one should be erased or flashed respectively.

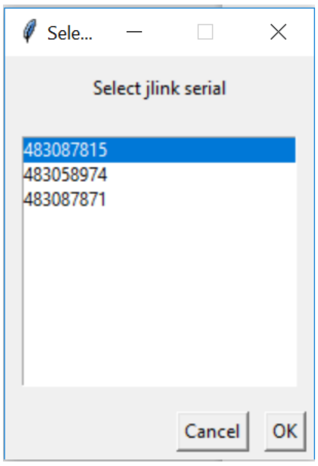



**Figure 51: Pop-up to Select the Desired Board**

After selecting the desired device, click **OK** and the procedure will start. When the write-to-flash procedure succeeds, in the console window, a user will see the output as in Figure 52.


**Figure 52: Console Output after Successful Flash Programming**

# Appendix E Using the Android Application

Download from Play Store the "Renesas WiRa" Android application and install it to a mobile phone.

Using the WiRa application, a user can:

- Change the configuration of a development kit (Initiator, Responder)
- Read/change parameters of an existing Initiator or Responder
- Monitor one or more Initiators. A graph is created with the calculated distances for each Initiator

After launching WiRa application, the "Bluetooth" and "Location" services should be enabled on Android mobile phone.

## E.1 Change Role from Responder to Initiator

1. Press button K1 of the board for more than 1 second to enter the configuration mode. The device remains in this mode for 10 seconds to allow the Android application to connect to the device.
2. Press the **SCAN** button or under the 3 dots menu the **Refresh** button to find the current available Responders. Select the WiRa Responder of which you want to change the configuration.

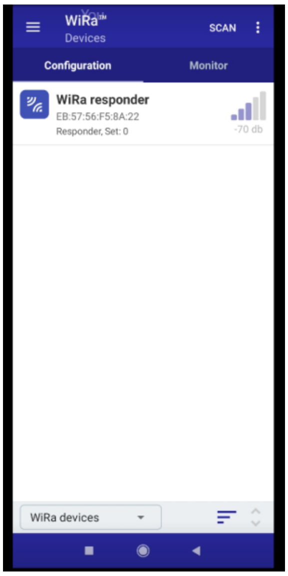



**Figure 53: Initial Screen of WiRa Application with Scan Results**

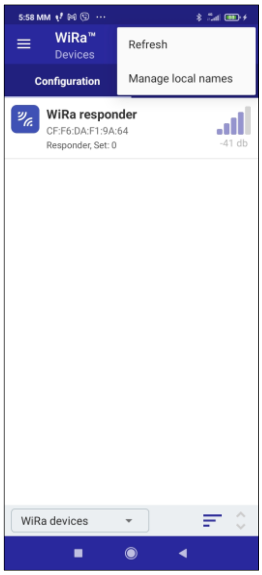



**Figure 54: Menu for Refreshing Scan Results**

3. Change Role to Initiator in the drop-down list, then press **APPLY,** and then **DISCONNECT**. The development kit starts to scan as Initiator for Responders.

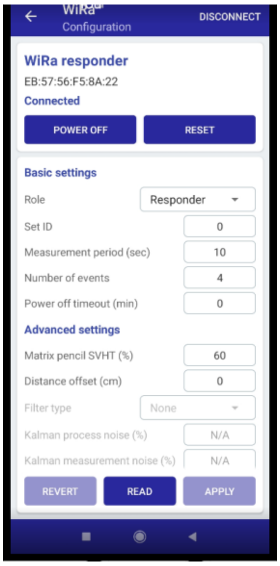



**Figure 55: Configuration Screen to Change the Role to Initiator**

## E.2 Change Role from Initiator to Responder

1. Press Button K1 of the board for more than 1 second to enter the configuration mode. The device remains in this mode for 10 seconds to allow the Android application to connect to the device.
2. Press the **SCAN** button or under the 3 dots menu the **Refresh** button to find the current available Initiators. Select the WiRa Initiator of which you want to change the configuration.
3. Change Role to Responder in the drop-down list, then press **APPLY,** and then **DISCONNECT**. The development kit starts to advertise as a Responder.

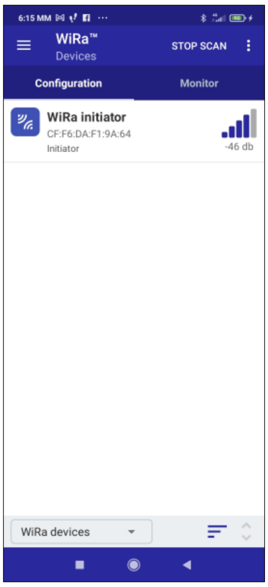



**Figure 56: Initial Screen of WiRa Application with Scan Results**

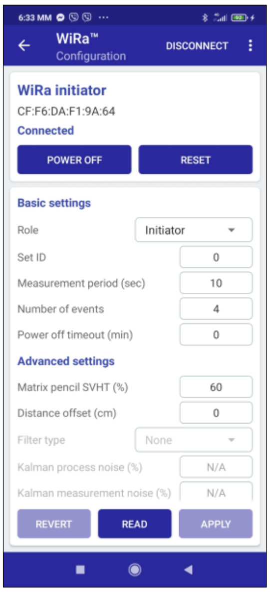



**Figure 57: Configuration Screen to Change the Role to Responder**

## E.3 Change Parameters Using WiRa Application

The WiRa application gives the ability to the user to change real-time parameters either for a Responder or for an Initiator. The parameters that can be changed are the following:

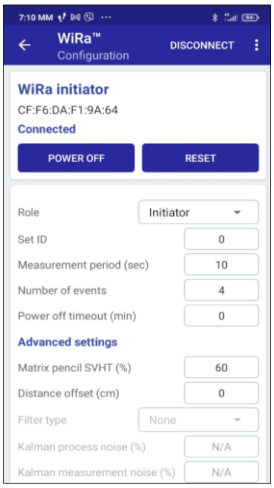



**Figure 58: Configuration Parameters (Part 1)**

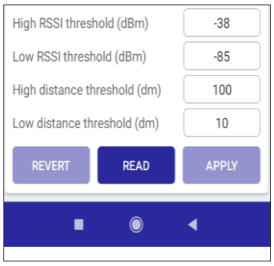



**Figure 59: Configuration Parameters (Part 2)**

- **Set ID**: Initiator and Responder with the same ID match and a connection between them will be established automatically
- **Measurement period (s)**: In this period a number of WiRa events are performed
- **Number of events:** Number of WiRa events that are executed in one measurement period
- **Power off timeout (min)**: After this timeout, the device goes to sleep. If it is set to 0, the device remains forever active
- **Matrix pencil SVHT (%)**: Singular Value Hard Threshold scale for Matrix Pencil
- **Distance offset (cm)**: A constant offset that is deducted from the WiRa measurement
- **Filter type**: A sliding average or Kalman filter can be applied to the WiRa measurements
- **Kalman process noise (%):** The process noise parameter of the Kalman filter as described in Section 4.3.3
- **Kalman measurement noise (%):** The measurement noise parameter of the Kalman filter as described in Section 4.3.3
- **RSSI and distance thresholds**: Two RSSI and two distance thresholds can be defined. These are application-specific thresholds and the use of which are described for each demo in Section 5.2.2.2 and Section 5.3.3. The default description of the above parameters can be customized for each demo

Moreover, the application gives the option to display demo-specific descriptions for each parameter, if "Use description" is selected in the three-dot menu. Figure 60, Figure 61, and Figure 62 show how a description of a parameter changes for a specific demo, after checking the "Use description" option.

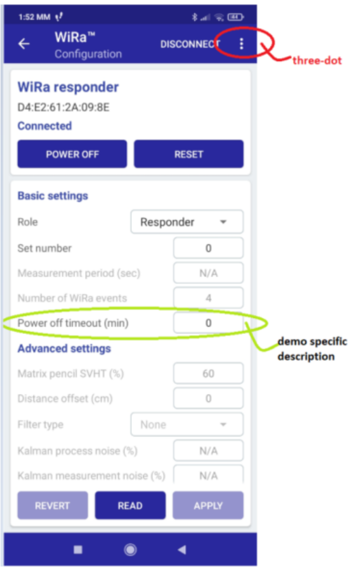



Figure 60: Initial Configuration Screen

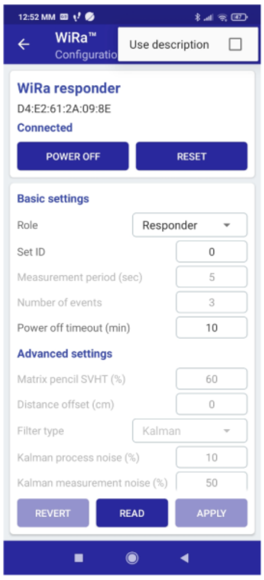



Figure 61: "Use Description" Pop-Up

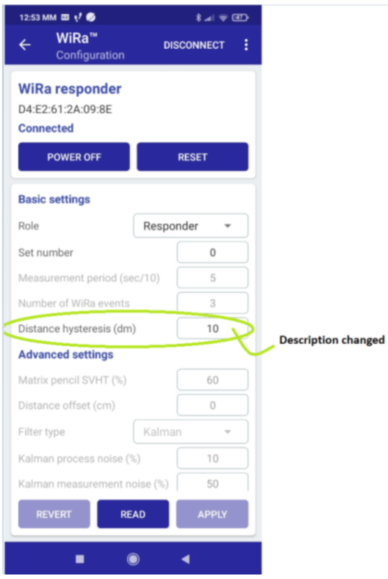



Figure 62: Result after Checking "Use Description"

## E.4 Monitor One or More Initiators

The measurements reported by one or more Initiators can be monitored using the WiRa Android application.

Follow the steps below for monitoring:

1. Go to the Monitor subtab and press **Monitor**.


Figure 63: "Monitor" Tab Screen

2. Select the first Initiator and on the next page, press **Device** + to monitor the second Initiator.

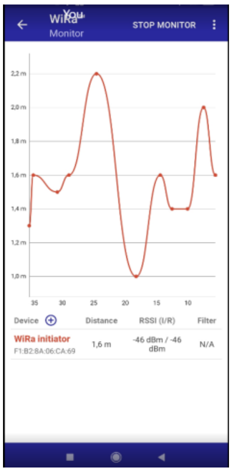



**Figure 64: Monitor the Distance between an Initiator and a Responder**

Each Initiator is monitored with a different color as it is shown in Figure 65.

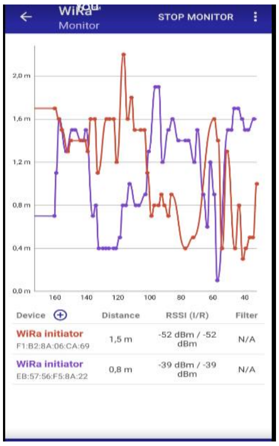



**Figure 65: Monitor the Distance from a Responder for two Initiators**

There is also the ability to monitor a rolling distance average. This feature can be enabled by pressing the **Filter** option for the desired Initiator. A pop-up window appears and the user should define a time window in seconds. For this time window, the distance average will be calculated and updated continuously and monitored on the screen with dots.

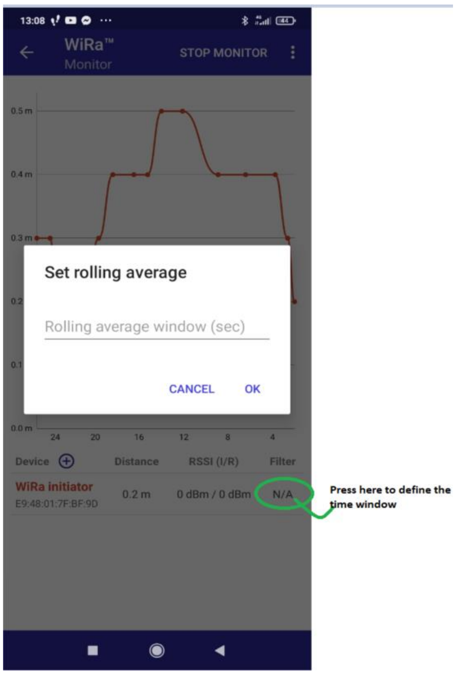



Figure 66: Pop-up to Set the Rolling Average Window

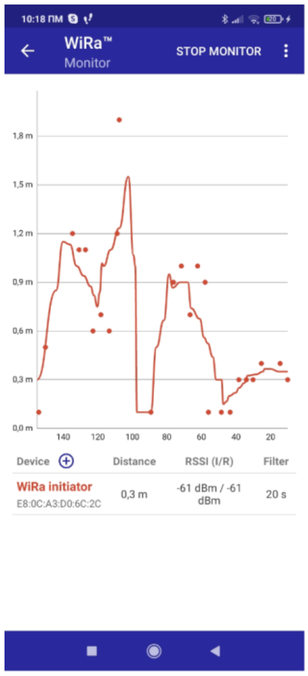



Figure 67: Monitor the Rolling Distance Average

# Revision History

| Revision | Date | Description |
|---|---|---|
| 3.5 | 15-Nov-2022 | Removed Appendix D, Standalone Flash Programmer |
| 3.4 | 02-Nov-2022 | Created Appendix E<br>Updated the demos and other Appendixes |
| 3.3 | 01-Sep-2022 | Added WiRa manager section |
| 3.2 | 29-July-2022 | Update Appendixes A, B, and C |
| 3.1 | 02-Jun-2022 | New version for WiRa SDK 10.440.10 |
| 2.2 | 31-May-2022 | Rebranded to Renesas<br>Editorial changes |
| 2.1 | 22-July-2020 | Added image of USB Kit with ZOR antenna |
| 2.0 | 02-July-2020 | Maintenance update |
| 1.0 | 07-May-2020 | Initial version |

### Status Definitions

| Status | Definition |
|---|---|
| DRAFT | The content of this document is under review and subject to formal approval, which may result in modifications or additions. |
| APPROVED<br>or unmarked | The content of this document has been approved for publication. |

### RoHS Compliance

Renesas suppliers certify that its products are in compliance with the requirements of Directive 2011/65/EU of the European Parliament on the restriction of the use of certain hazardous substances in electrical and electronic equipment. RoHS certificates from our suppliers are available on request.