DA1453x Bluetooth® LE Direct Test Mode

The DA1453x ultra-low power SoC family features a 2.4 GHz transceiver and an Arm® Cortex®-M0+™. In this family the DA14531 offers 48 kB RAM and 32 kB OTP memory, while the DA14535/DA14533 provide 64 kB RAM and 12 kB OTP memory.

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1. Terms and Definitions

DTM	Direct Test Mode
DUT	Device Under Test
EUT	Equipment Under Test
GPIB	General Purpose Interface Bus
GPIO	General Purpose Input Output
HCI	Host Controller Interface
OGF	Opcode Group Field
PLT	Production Line Testing
Pro-DK	Professional Development Kit
RF	Radio Frequency
SoC	System on Chip
SWD	Serial Wire Debug
UART	Universal Asynchronous Receiver Transmitter

2. References

[1] DA14531, Datasheet, Renesas Electronics.

[2] AN-B-043, DA1468x Bluetooth® LE Direct Test Mode, Application Note, Renesas Electronics.

[3] UM-B-117, DA14531 Getting Started Guide, Manual, Renesas Electronics.

[4] UM-B-165, DA14531 Getting Started Guide User Manual, Renesas Electronics.

[5] Bluetooth® Core specification v 5.1, Bluetooth® LE SIG.

[6] DA14535, Datasheet, Renesas Electronics.

[7] UM-B-083: SmartSnippets™ Toolbox, Renesa Electronics.

[8] DA14533, Datasheet, Renesas Electronics.

3. Introduction

Both SoCs are versatile, serving as standalone application processors or data pumps in hosted systems. Achieving ultra-low power is facilitated by the integrated Low IQ Buck/Boost DCDC, operational during sleep in Buck mode. These SoCs are designed for efficiency, making them suitable for various applications demanding low-power consumption and reliable performance.

This document describes how to measure the RF performance of the DA1453x with a Bluetooth® LE tester like the Rohde & Schwarz (R&S) CBT, the R&S CMW270 and the Anritsu MT8852B using the Bluetooth LE Direct Test Mode (DTM).

Additionally, DTM can be used to set the Bluetooth® LE device into different RX and TX modes. To provide easy access to the DTM commands Renesas provides "RF Master", a tool that can be found in the Smart Snippets Toolbox.

The Direct Test Mode is described in the Bluetooth LE specification. The Bluetooth LE RF PHY test specification uses DTM for all TX and RX test cases. Frequency hopping and whitening are disabled.

DTM uses a direct communication channel between the Bluetooth LE DUT and the Bluetooth LE tester to control the DUT. The DA1453x SoC supports Direct Test Mode (DTM) for the RF PHY as specified by the Bluetooth LE SIG. The DUT, the DA1453x SoC, communicates with the Bluetooth LE tester over a 2-wire UART.

DA1453x refers to DA14531-00, DA14531-01, DA14530 DA14535 and DA14533. See Ref. [1][6][8]

Details for the software setup and the hardware setup are explained in Section 4.1 and Section 4.2.

Many items discussed in Ref. [2]. are also applicable for the DA1453x, see Ref. [1]. It shows alternative connection possibilities and discusses a larger variety of Bluetooth LE testers, amongst others the LifePoint IQxel M.

4. Set Up Direct Test Mode

4.1 Software Setup

For standard Bluetooth LE DTM testing (Bluetooth LE core commands) it is advised to use the latest SDK prod_test project, which can be found in the following path:

`\...\projects\target_apps\prod_test\`

If you want to use pre-compiled binaries for the DTM you can find a few here:

DA14531 Target: `\..\binaries\da14531\prod_test`
DA14535 Target: `\...\binaries\da14535\prod_test`
DA14533 Target: `\...\binaries\da14533\prod_test`

Ref. [3] explains how to compile and how to program, Ref. [3] or Ref [4]. Before compiling the software, the user_periph_setup.h must be changed to assign the correct UART port.

Here is an example how to set the 1-wire UART mode on port P05:

```
#undef CONFIG_UART_GPIOS

/****************************************************************/

/* UART pin configuration                          */

/* Supported Port/Pin Combinations:                   */

/* Tx: P00, Rx: P01                         */

/* Tx: P02, Rx: P03                         */

/* Tx/Rx: P03 (1-Wire UART)                     */

/* Tx: P04, Rx: P05                         */

/* Tx/Rx: P05 (1-Wire UART)                      */

/* Tx: P06, Rx: P07                         */

/****************************************************************/

#if defined(__DA14531__)

   #define UART1_TX_GPIO_PORT  GPIO_PORT_0

   #define UART1_TX_GPIO_PIN   GPIO_PIN_5     /*1-wire UART P05*/

   #define UART1_RX_GPIO_PORT  GPIO_PORT_0

   #define UART1_RX_GPIO_PIN   GPIO_PIN_5     /*1-wire UART P05*/
```

For 2-wire UART mode on P00 and P01 the file must be changed like this:

```
#undef CONFIG_UART_GPIOS

/****************************************************************/

/* UART pin configuration                          */

/* Supported Port/Pin Combinations:                   */

/* Tx: P00, Rx: P01                         */

/* Tx: P02, Rx: P03                         */

/* Tx/Rx: P03 (1-Wire UART)                     */

/* Tx: P04, Rx: P05                         */

/* Tx/Rx: P05 (1-Wire UART)                      */

/* Tx: P06, Rx: P07                         */

/****************************************************************/
```

```
#if defined(__DA14531__)

    #define UART1_TX_GPIO_PORT  GPIO_PORT_0

    #define UART1_TX_GPIO_PIN   GPIO_PIN_0    /*2-wire UART P00*/

    #define UART1_RX_GPIO_PORT  GPIO_PORT_0

    #define UART1_RX_GPIO_PIN   GPIO_PIN_1    /*2-wire UART P01*/
```

Compile the project and load the binary into RAM using the SmartSnippets™Toolbox Booter, see Ref. [7] or the Toolbox RF-Master Firmware Download tool.

As an example, how to download the prod_test_531.bin, prod_test_535.bin or prod_test_533.bin firmware into RAM, the SmartSnippets™Toolbox RF-Master tool is used.

Connect the SmartSnippets™Toolbox through JTAG or COM port, choose RF Master, browse to the built binary, and click the **Download** button as in Figure 1.
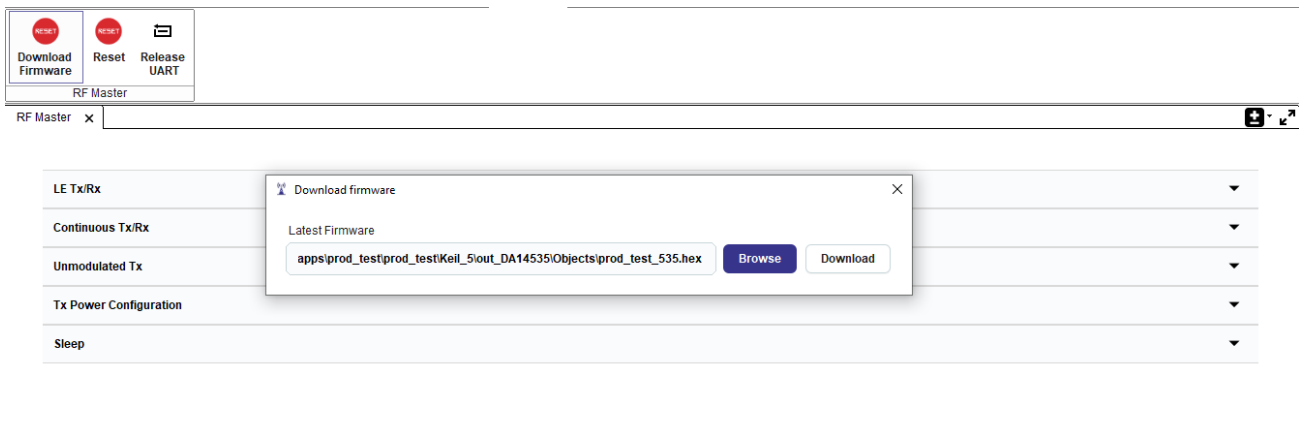

Figure 1. Firmware download in RF-master

After downloading the firmware, the RF-Master tool can be used to set the DA1453x chip in different receive or transmit modes (for example, LE Transmitter Continuous Packet).

The UART COM port is selected by RF-master automatically or a dialog appears, asking for the right COM port.

By default, the UART baud rate is set to 115200 bit/sec and the UART GPIOs used for control and signaling between the Bluetooth LE tester and the DUT are set in SmartSnippets™'s Board Setup.
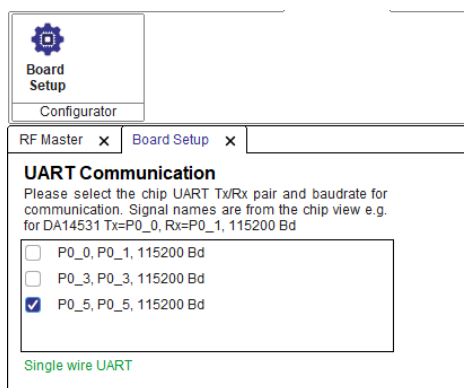

Figure 2. Board setup in SmartSnippets™Toolbox.

Summarizing the UART configuration:

- UART Baud Rate: 115200 bit/s
- HW Flow Control: None
- Byte Size: 8
- Stop Bits: 1
- Parity: None

4.1.1 Set Up RX/TX Test Modes with RF Master

SmartSnippets™Toolbox's RF Master can be used to set up different RX and TX modes to check the performance of the DA1453x. See Figure 3.

1. After Choosing the correct UART configuration in the Board Setup.

2. Select RF Master in the Smart Snippets menu.

3. Download the correct production firmware.
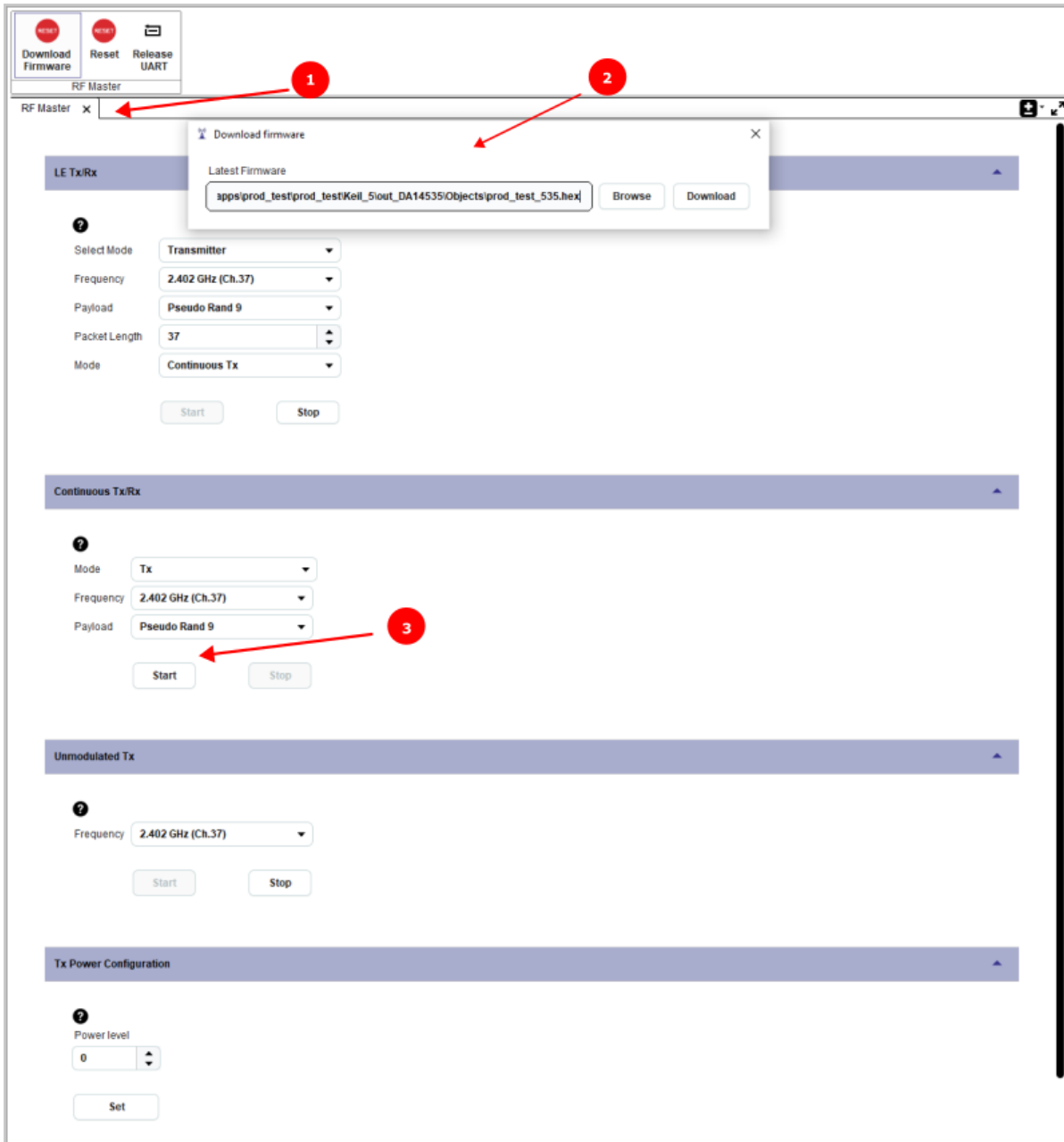
4. Choose the desired RF mode and click **Start**.

Figure 3. Setting Up RF master

4.1.2 Temperature Triggered RF Re-Calibrations

Some notes about the temperature triggered RF re-calibrations used in the SDK:

▪ In the SDK projects temperature triggered RF re-calibrations are provided to make sure the radio is in optimal condition at any temperature. This is realized by shortly waking up the chip at regular intervals at which the ADC is measuring the chip's temperature.

- When the temperature has decreased or increased 8°C or more, an RF re-calibration is triggered and executed.
- In DTM mode though, and only in the DTM mode, these temperature triggered RF re-calibrations are not active. This is intentionally, making sure the RF re-calibration is not interfering with a running RF-test, leading to a failing test.
- When RF testing at low and high temperatures is desired, issue a hardware reset to the chip at which the chip reboots and executes a RF re-calibration at the new temperature before the RF test starts. This makes sure the radio is in optimal condition.
- In this situation it is convenient to have the firmware programmed in the flash memory of the motherboard as it is reloaded from the flash automatically after a reset.
- Normally the RF re-calibration is needed in the temperature range -20°C to +80°C, but it is advised to trigger a RF re-calibration after a 20°C temperature change.
- The RX sensitivity is affected first, degrading a bit at low and high temperatures. The TX performance is more robust and does not vary much over temperature.
- As mentioned, in Bluetooth LE mode – advertising or connected – the temperature triggered RF re-calibrations are in place. The radio is in optimal condition at any temperature.

4.2   Hardware Setup

4.2.1   Motherboard

The jumpers on the 376-18-B motherboard must be set as shown in Figure 4, Figure 5, or Figure 6.

Note the following:

- P20 on the motherboard is routed to P00 on the DA1453x daughterboard
- P21 on the motherboard is routed to P01 on the DA1453x daughterboard
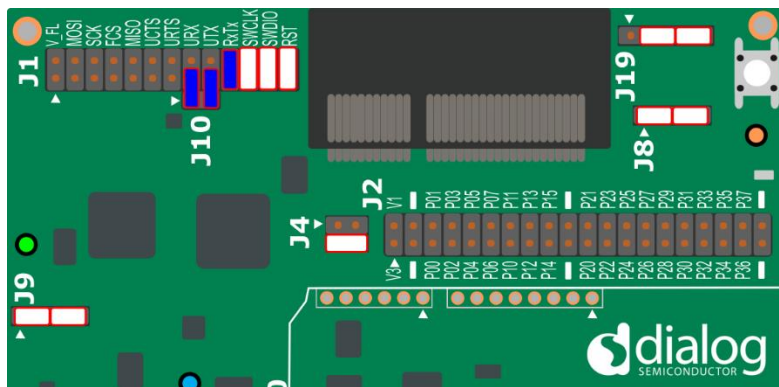- P23 on the motherboard is routed to P03 on the DA1453x daughterboard.

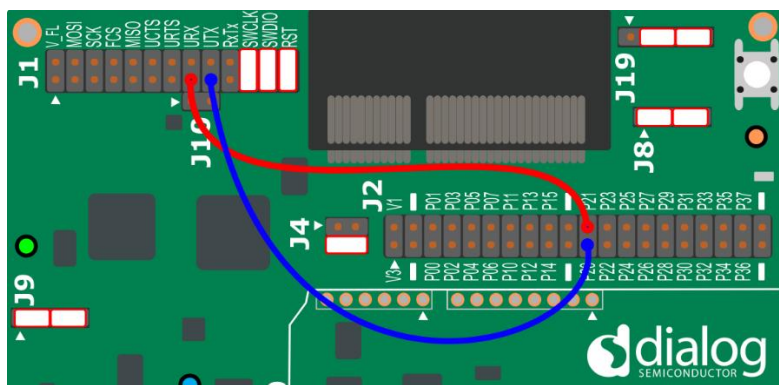**Figure 4. Jumper settings for 1-wire UART P05**
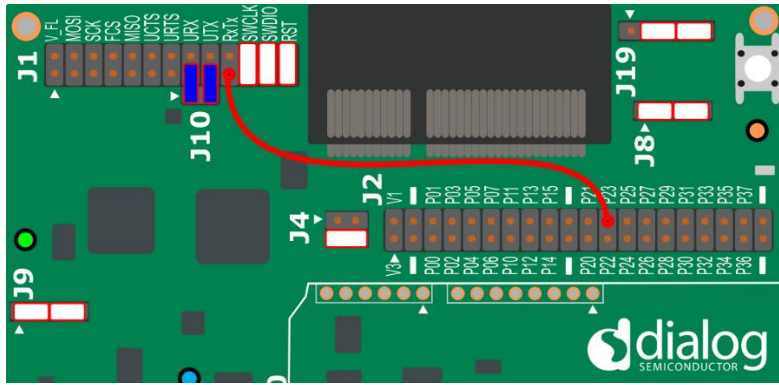

Figure 5. Jumper setting for 2-wire UART P00 P01

Figure 6. Jumper setting for 1-wire UART P03

The jumpers on the DA1453x 610-01-B motherboard must be set as shown in Figure 7, Figure 8, or Figure 9.

Note the following:

- P0-0 on the motherboard is routed to P00 on the DA1453x daughterboard
- P0-1 on the motherboard is routed to P01 on the DA1453x daughterboard
- P0-3 on the motherboard is routed to P03 on the DA1453x daughterboard.
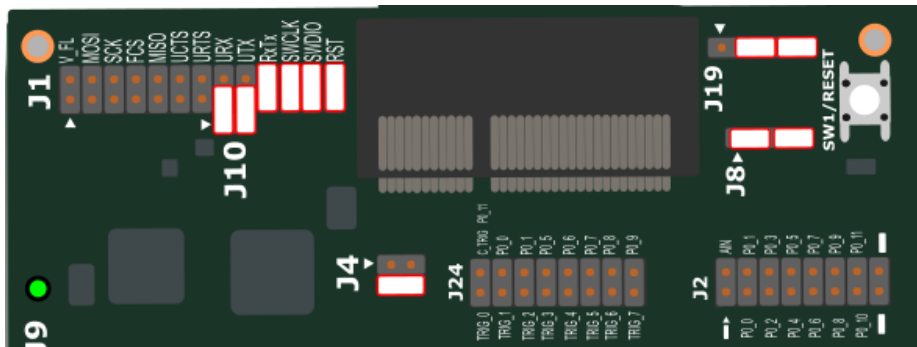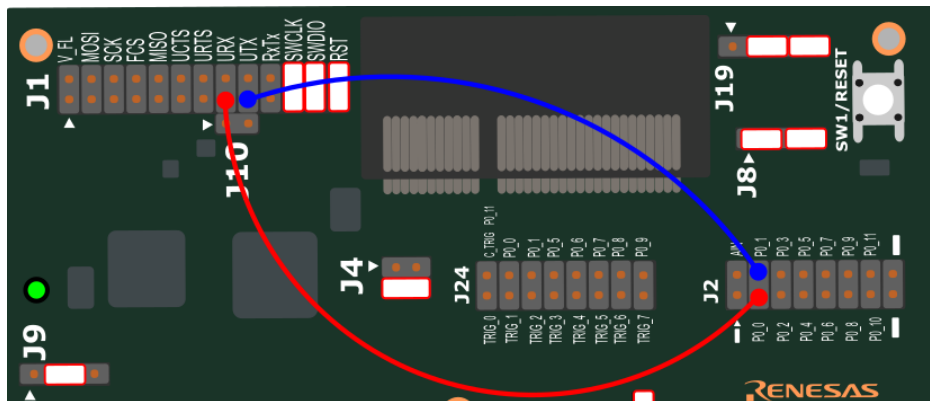

Figure 7. Jumper settings for 1-wire UART P05 DA1453x

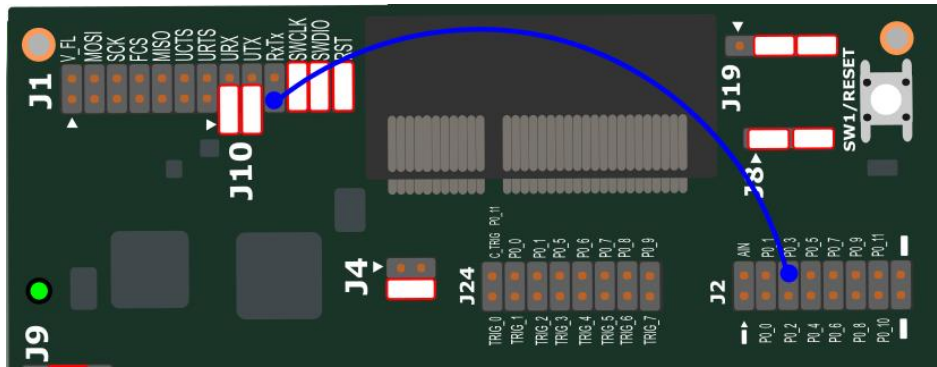**Figure 8. Jumper setting for 2-wire UART P00 P01 DA1453x**

Figure 9. Jumper setting for 1-wire UART P03 DA1453x

Other relevant jumper settings, for example, the supply, see Appendix A. Check whether the board used for DTM RF-testing is configured as shown in Figure 20.

The USB1 connector on the DA14531 Pro-DK motherboard provides the supply and the serial communication to the DA14531 daughterboard.

4.2.2   Daughterboard

The RF connection between the DA1453x daughterboard and the Bluetooth LE tester can be established using an SMA connector. The modifications of the board are shown in Figure 10. The connection to the on-board antenna must be opened by removing Z9 and the connection to the SMA connector must be made by soldering a 10-pF capacitor on position Z7.
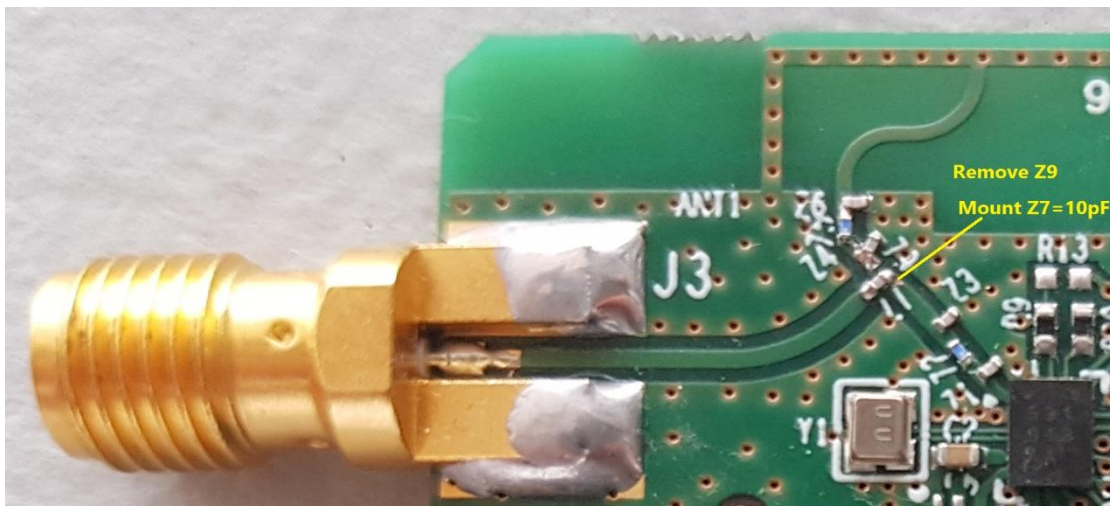

Figure 10. Modifications required for performing conducted measurements

4.2.3   Bluetooth LE Tester

Four RF test setups are shown and discussed:

- First the R&S CMW270 Bluetooth LE 5 tester is discussed, where the DA14531 or DA1453x DEVKT-P is connected and supplied by a (front) USB port of the CM270. Bluetooth LE signaling is executed over the same USB port. Section 4.2.4.

- Secondly, the setup with the Anritsu MT8852B Bluetooth LE 5 tester is shown.
  Here a PC supplies the Pro-DK board and connects the Bluetooth LE tester and the DUT through a COMM Tunnel tool running on the PC. Section 4.2.5.

- Third, the R&S CBT setup and connections are shown. Using again the COMM Tunnel tool for convenience instead of an otherwise required level-shifter, see Ref. [2]. The PC additionally supplies the Pro-DK board through its USB connector. Section 4.2.6.

- Finally, the RTX2254 setup and connections are shown. The DA14531 or DA1453x DEVKT-P is connected and supplied by a (front) USB port of the RTX2254. Bluetooth LE signaling is executed over the same USB port. Section 4.2.7.

These examples are using a 2-wire UART connection between the DUT and the tester. Use prod_test_531_2wire_P00 and P01.bin when doing these tests.

4.2.4   R&S CMW270 Bluetooth LE Tester Setup

For the discussed setup, the FTDI USB-to-Serial driver for the FTDI chip on the Pro-DK must be installed on the CMW270. When the Pro-DK board is connected, two virtual COM ports are created, for example, COM4 and COM5. The first port, COM4 in this example, provides the UART 2-wire connection and this one should be selected in the CMW270's Connection setup (Bluetooth Connection Setup for LE).

The following R&S application note deals with how to do this in Section 3.3 and Section 4.2:

https://www.rohde-schwarz.com/us/applications/configuration-of-the-r-s-cmw-for-Bluetooth®-low-energy-direct-test-mode-application-note_56280-364865.html

Overview of the required CMW270 Connection Settings:

- USB to RS232 adapter as hardware Interface
- HCI in EUT Communication Protocol
- RS232 COM port: the virtual COM port, for example, COM4
- Baud Rate: 115200
- Flow Control Protocol: None
- Parity: None
- Stop Bits: 1

The FTDI driver for the FT2232 FTDI chip used on the Pro-DK motherboard can be found at following download link: https://www.ftdichip.com/Drivers/D2XX.htm

When using front-panel operation, connecting the Pro-DK debug USB port to a front USB-port of the CMW270 and a RF-cable from the CMW270 RF-port (for example, RF1 COM) to the Pro-DK RF-connector is all what is needed to run some basic Bluetooth LE TX and RX tests. As such, the GPIB connection is not needed.

For script testing using the R&S CMWRUN scripting tool, a GPIB connection between the PC and CMW270 must be established. See Figure 11.
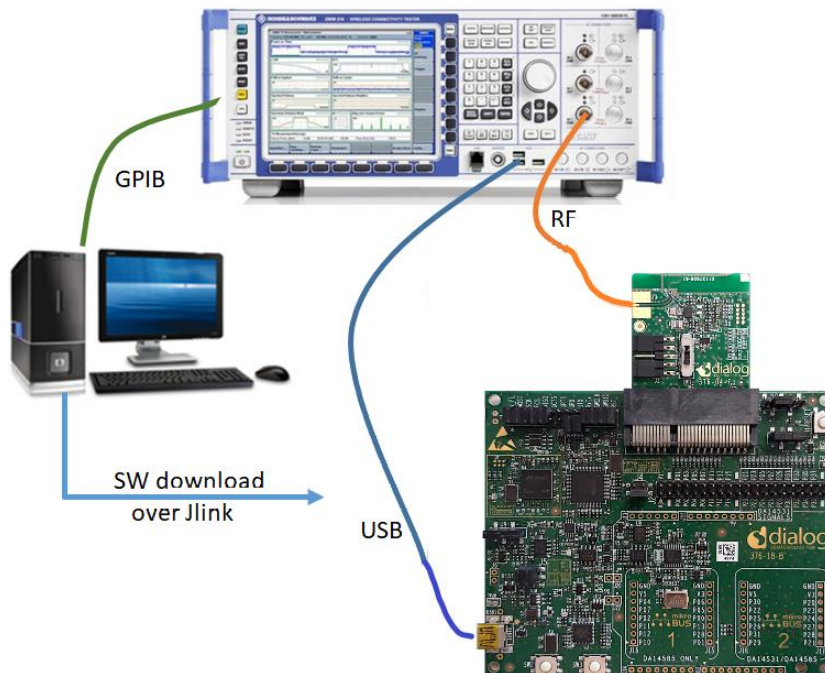

Figure 11. R&S CMW270 connections

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4.2.5   Anritsu MT8852B Bluetooth LE Tester Setup

Figure 12 shows this setup case, the MT8852B's EUT Control-port cable (supplied with the tester) is to be connected to a physical serial port of the PC, or to an USB port when using a Serial-to-USB converter, for example, UC232R-10 or Chipi-X10:

https://www.ftdichip.com/Products/Cables/USBRS232.htm.

The COMM Tunnel tool running on the PC connects the PC's serial port (for example, COM1) at which the MT8852B EUT port is connected to the Pro-DK's virtual COM port (for example, COM4). The DA14531 or DA1453x DEVKT-P creates two virtual COM ports on the PC: for example, COM4 and COM5.

The COM port having the lowest number (COM4 in this example) must be selected for UART. The second virtual COM port is the SPI channel, used for transmitting the Power Profiler data from the motherboard to the SmartSnippets™ PowerProfiler tool running on the PC.

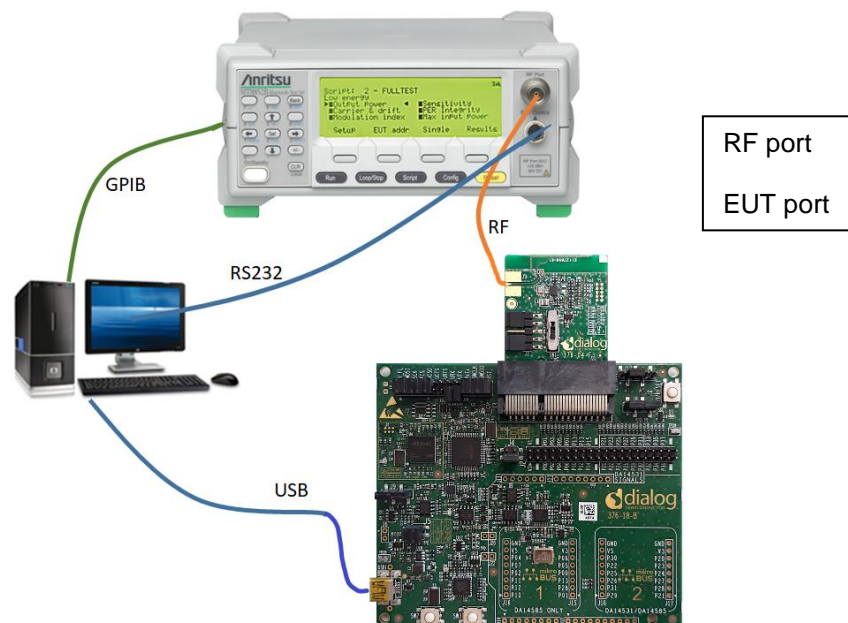Figure 14 and in Figure 15 show the screenshots of the COMM Tunnel tool. The version that was used for this document: http://www.serialporttool.com/CommTunnel.htm.

Figure 12. Anritsu MT8852B connections

Figure 12 shows the connections between the MT8852B tester, the DUT and the PC. A COMM Tunnel tool as described before is running on the PC, connecting the MT8852B's EUT Control port to the virtual UART COM port of the Pro-DK board.

Before starting the Comm Tunnel program, the RF-test firmware can be downloaded using the same PC USB port and the Pro-DK virtual COM port. See Section 4.1.

After the firmware download, the COMM Tunnel can be started, and RF-testing can begin.

Front-panel operation is available for basic TX and RX tests. For this, the COMM Tunnel should be started, but the GPIB connection is not needed.

When, for example, running Anritsu's Bluetooth LE Measurement Software, script testing can be executed and a test-report could be created, see Ref. [2]. The GPIB connection between the tester and the PC is required for this test case.

Figure 13 shows the MT8852B Connection settings in the Anritsu Bluetooth LE Measurement software.
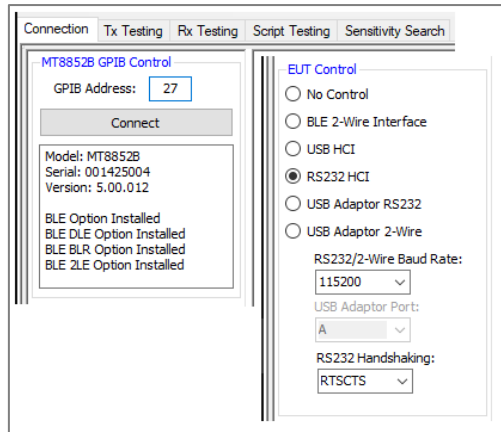
Figure 13. MT8852B connection settings

Comm Tunnel settings: Figure 14 (Setting) appears when selecting **Setting** in "Endpoint 1" (tester) or "Endpoint 2" (DUT) in Figure 15. After entering the correct values, click the **Start** button.
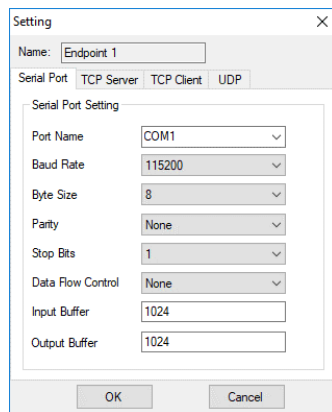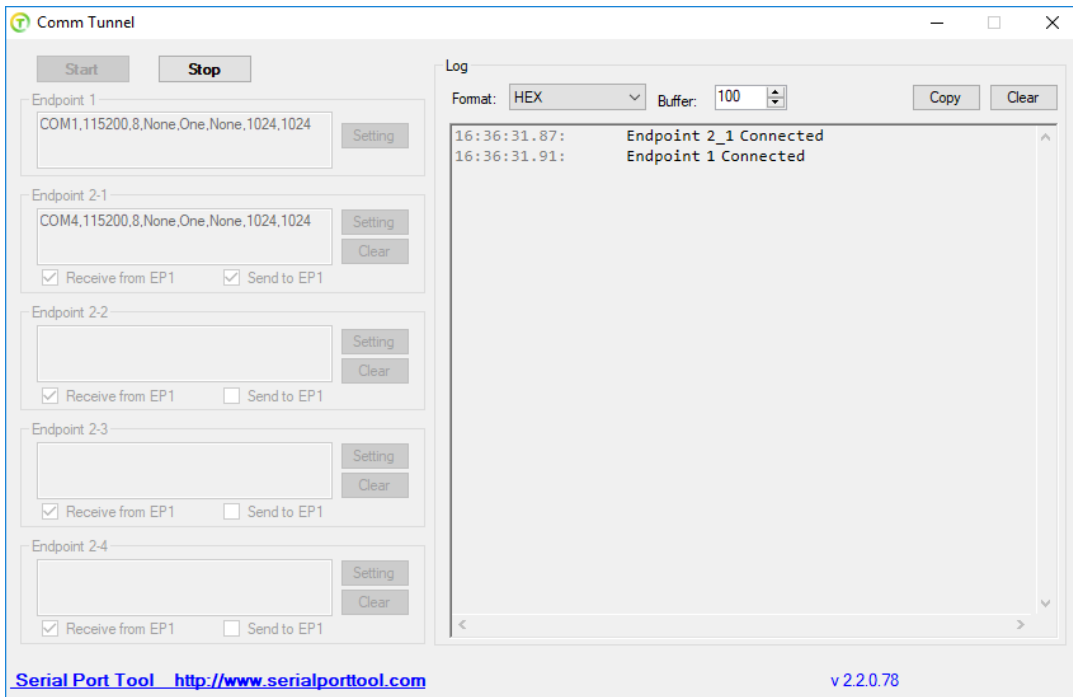

Figure 14. COMM tunnel setup

Figure 15. COMM tunnel tool

4.2.6 R&S CBT Bluetooth LE Tester Setup

The R&S CBT setup is like the MT8852B setup in Section 4.2.5. The CBT's COM port at the back is connected to a serial port on the PC, and the Comm Tunnel program connects the CBT COM port to the UART/HCI port of the DA14531 DUT by means of the virtual COM port created by the DA14531 Pro-DK board. See Figure 16 for the connections.

In case the PC does not have a physical serial port, a Serial-to-USB converter can be applied. For details on this and the Comm Tunnel usage, see Section 4.2.5.

The PC can be used to download the RF-test firmware to the DA14531 chip. After starting the Comm Tunnel tool, the same USB port is used for Bluetooth LE signaling.
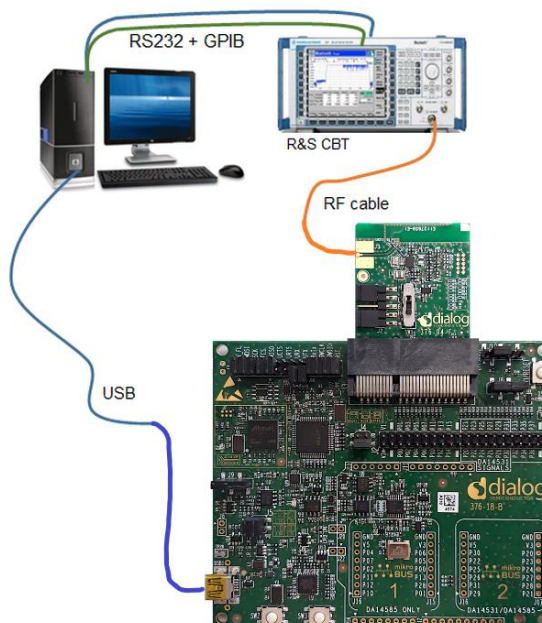

Figure 16. R&S CBT connections

Basic tests like LE TX modulation performance can be executed from the front panel and viewed in the CBT's display. GPIB interfaces and a GPIB cable is not needed. Extended script testing can be done using the R&S CBT-Go tool, which runs on the PC.

The CBT-Go tool can also generate an extensive test report. A GPIB cable must be connected between the PC and the CBT for using CBT-Go.

The CBT communication settings, to be set in the CBT or in the CBT-Go control program.

- EUT Protocol: HCI
- Baud Rate: 115200
- Bits: 8
- Stop bits: 1
- Parity: None
- Flow Control: None

4.2.7 RTX2254 Bluetooth LE Tester Setup

For this setup case shown in Figure 19, the USB connector on the DA14531 or DA1453x DEVKT-P must just be connected to the USB connector (DUT 0 or 1) on the RTX2254 front panel and the RF connector to the RF connector (DUT 0 or 1) on the front panel.

The FTDI USB-to-Serial driver for the FTDI chip on the Pro-DK must be installed on the applied PC.

https://www.ftdichip.com/Products/Cables/USBRS232.htm.

When the Pro-DK board is connected, two virtual COM ports are created, for example, COM35 and COM36. In this example, the first port COM35 provides the UART 2-wire connection, and this one should be selected in the RTX2254 Settings pane.

Overview of the required Connection Settings:

- HCI in EUT Communication Protocol (Figure 17).
- RS232 COM port: the virtual COM port, for example, COM35 (Figure 18).
- Baud Rate: 115200 (Figure 18)
- HW Flow Control: None (Figure 18)
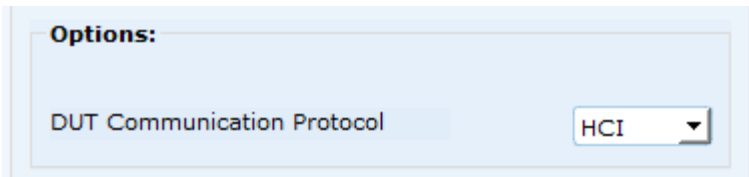- Parity: None
- Stop Bits: 1

Figure 17. DUT communication protocol setting in RTX2254
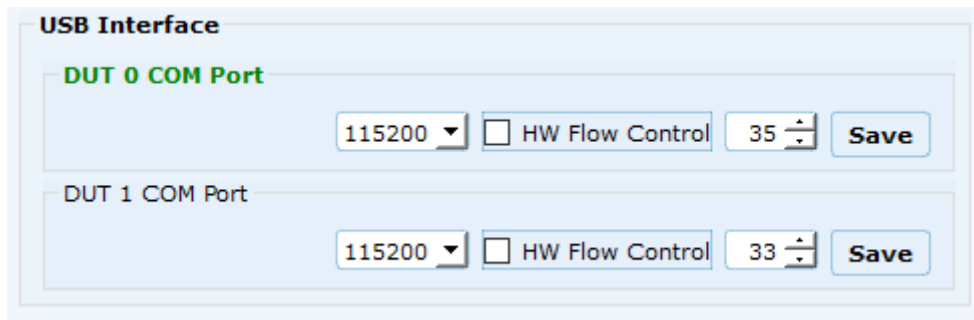

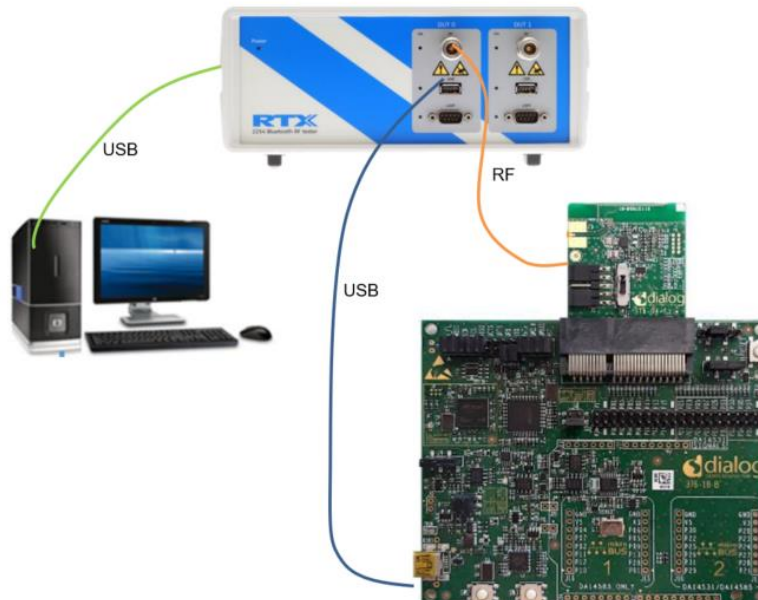**Figure 18. Virtual comport setting in RTX2254 (Pro-DK connected to DUT0)**

Figure 19. RTX2254 connections

Figure 19 shows the connections between the RTX2254 tester, the DA14531 or DA1453x DEVKT-P and the PC. The communication to the Pro-DK and RF tests are all handled by the RTX2254 while the PC is executing the RTX2254 GUI and logging of RF measurements.

5. Bluetooth LE PHY Qualification

To release a Bluetooth LE application to the market, the application needs to be Qualified. The Renesas Bluetooth LE SoCs have Qualified Design Listings (QDL) with corresponding Qualified Design Identification (QDID) for all Host Subsystems and Controller Subsystems. Enter Renesas Electronics in the search field to find all Renesas listings. By referring to the Renesas QDIDs, the amount of testing required to list a Bluetooth LE application is greatly reduced.

Typically, Bluetooth LE PHY testing must be done for new hardware, meaning that Bluetooth LE PHY testing done by Renesas Electronics on the evaluation kits cannot be re-used. This PHY testing must be done by an authorized test house.

Table 1 displays the Protocol Implementation Extra Information for Test (PIXIT) entries, that the test house needs for PHY qualification.

Table 1. PIXIT entries for Bluetooth LE 1 Mbps

PIXIT reference	Identifier	Sub-identifier (optional)	Value	Units
RF-PHY:P1:1	Inband Image frequency	Low frequency	2	MHz
RF-PHY:P1:2		Middle frequency	2	MHz
RF-PHY:P1:3		High frequency	2	MHz
RF-PHY:P2:1	Value n for Intermodulation test	Low frequency	3	Integer
RF-PHY:P2:2		Middle frequency	3	Integer
RF-PHY:P2:3		High frequency	3	Integer
RF-PHY:P3	Type of power source			
RF-PHY:P4:1	Power source voltage	Nominal (NOC)	End product spec	V
RF-PHY:P4:2		Maximum (EOC)	End product spec	V
RF-PHY:P4:3		Minimum (EOC)	End product spec	V
RF-PHY:P5:1	Operating temperature	Nominal (NOC)	End product spec	°C
RF-PHY:P5:2		Maximum (EOC)	End product spec	°C
RF-PHY:P5:3		Minimum (EOC)	End product spec	°C
RF-PHY:P6:1	Air humidity range (relative)	Maximum (EOC)	End product spec	%
RF-PHY:P6:2		Minimum (EOC)	End product spec	%
RF-PHY:P6:3		Air humidity level for NOC/EOC tests	End product spec	%
RF-PHY:P7:1	Test interface implementation	HCI or 2-wire UART	HCI	
RF-PHY:P7:2		Datarate	115000	bps
RF-PHY:P8	Antenna gain	Low	End product spec	dBi
		Middle	End product spec	dBi
		High	End product spec	dBi

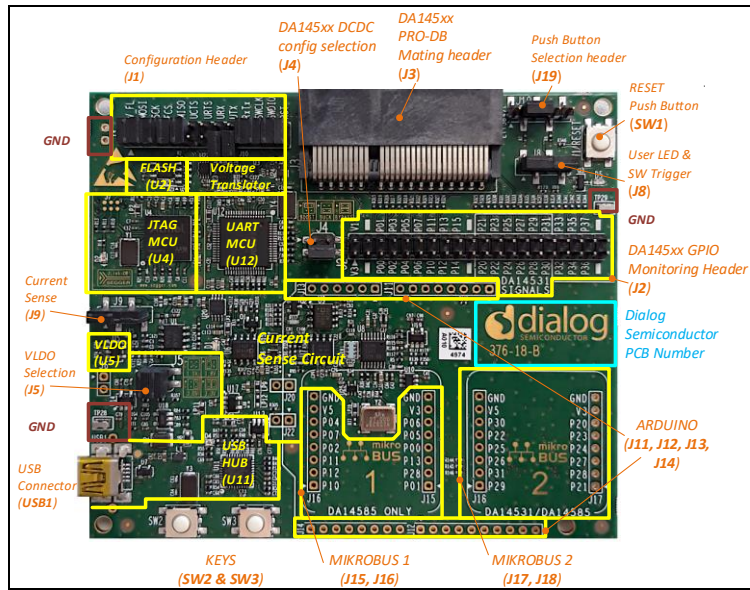| PIXIT reference	Identifier	Sub-identifier (optional)	Value	Units
RF-PHY:P9:1	Maximum TX packet length		251	B
RF-PHY:P9:2	Maximum RX packet length		251	B

Appendix A Motherboard

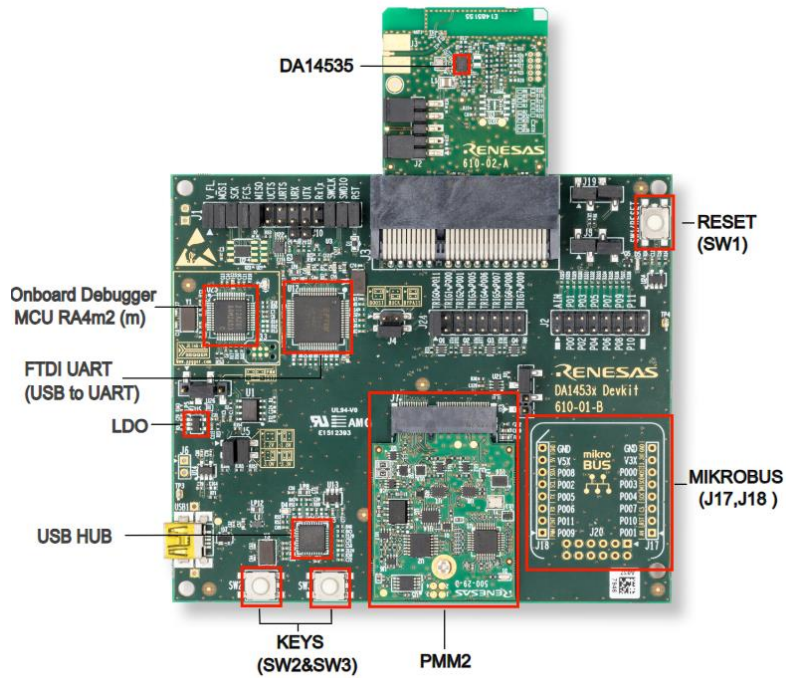**Figure 20. DA14531 DEVKT-P motherboard**

Figure 21. DA1453x DEVKT-P motherboard

Appendix B Daughterboard
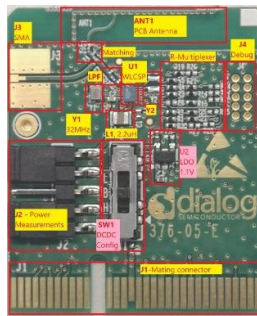

Figure 22. DA14531 QFN24 daughterboard

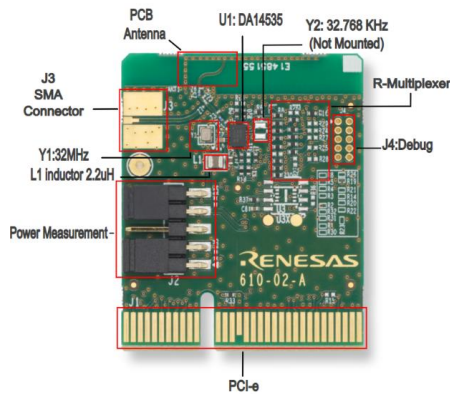**Figure 23. DA14531 WLCSP daughterboard**
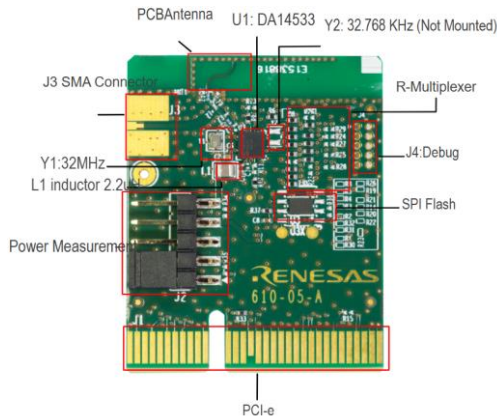

Figure 24. DA14535 QFN24 daughterboard

Figure 25. DA14533 QFN22 daughterboard

COMM Tunnel and 1-wire UART

COMM Tunnel causes an issue, when used in 1-wire UART mode. The reason is the connection of the RX and TX line on the motherboard. Every command transmitted from COMM Tunnel to the motherboard is directly received in the RX buffer. When the motherboard sends the reply, it is added to the wrongly received data (see Figure 26).
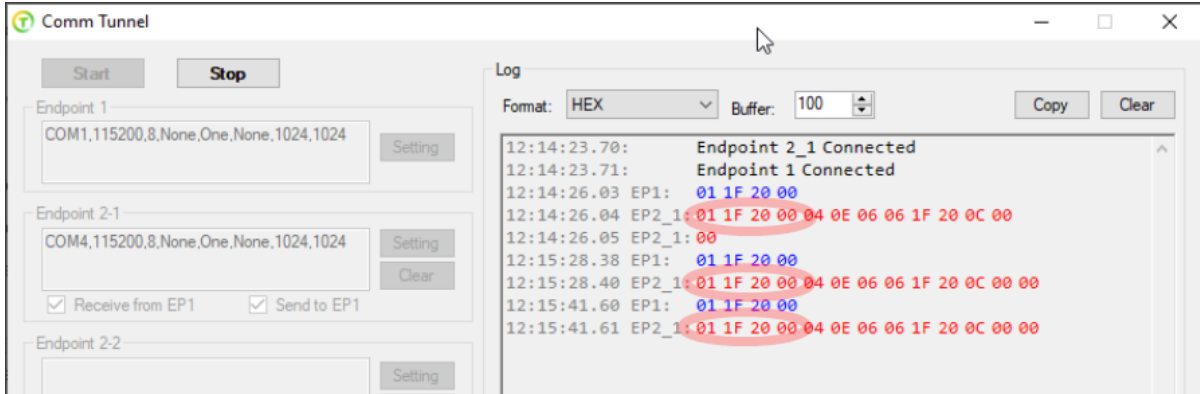

Figure 26. COMM tunnel 1-wire UART issue

To avoid this problem the RX buffer must be deleted after transmitting data to the motherboard. Currently COMM Tunnel is not able to do this. Renesas Electronics is working on additional tooling to support 1-wire UART in combination with Bluetooth LE testers.

6. Revision History

Revision	Date	Description
2.2	Mar 20, 2025	DA14533 added to the document.
2.1	Jan 20, 2025	Converted into Renesas template.
2.0	Feb 20, 2024	DA14535 added to the document.
1.4	Feb 14, 2023	Updated PIXIT
1.3	Jan 21, 2022	Updated logo, disclaimer, copyright.
1.2	Feb 26, 2020	RTX tester added.
1.1	Nov 5, 2019	Updated link.
1.0	Nov 1, 2019	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 or unmarked	The content of this document has been approved for publication.

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