Application Note

DA14531 Bluetooth® Direct Test Mode

AN-B-077

Abstract

This application note explains how to setup RF testing modes for DA14531 BLE SoC.

Contents

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1 Terms and Definitions

Bluetooth® LE	Bluetooth® Low Energy
DTM	Direct Test Mode
DUT	Device Under Test, the Bluetooth Low Energy application.
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, Dialog Semiconductor.
[2] AN-B-043, DA1468x Bluetooth Direct Test Mode, Application Note, Dialog Semiconductor.
[3] UM-B-117, DA14531 Getting Started Guide User Manual, Dialog Semiconductor.
[4] Bluetooth Core specification v 5.1, Bluetooth SIG

3 Introduction

The DA14531 is an ultra-low power SoC integrating a 2.4 GHz transceiver and an ARM® Cortex-M0+™ microcontroller with a RAM of 48 kB and a One-Time Programmable (OTP) memory of 32 kB. It can be used as a standalone application processor or as a data pump in hosted systems.

This document describes how to measure the RF performance of the DA14531 with a Bluetooth tester like the R&S CBT, the R&S CMW270 and the Anritsu MT8852B using the Bluetooth Low Energy (Bluetooth LE) Direct Test Mode (DTM).

Additionally, DTM can be used to set the BLE device into different RX and TX modes. To provide an easy access to the DTM commands Dialog provides “RF Master”, a tool that can be found in the SmartSnippets Toolbox.

The Direct Test Mode is described in the Bluetooth 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 tester to control the DUT. The DA14531 SoC supports Direct Test Mode (DTM) for the RF PHY as specified by the Bluetooth SIG. The DUT, the DA14531 SoC, communicates with the Bluetooth tester over a 2-wire UART.
Details for the software setup and the hardware setup are explained in following sections 4.1 and 4.2.

Many items discussed in AN-B-043 (*DA1468x Bluetooth Direct Test Mode*) are also applicable for the DA14531. [2]
Please read this AN-B-043 application note as well. It shows alternative connection possibilities and discusses a larger variety of Bluetooth testers, amongst others the LitePoint IQxel-M.

4 Setting 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:

```
\SDK_6.0.12….\projects\target_apps\prod_test\
```

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

```
\SDK\6.0.12….\binaries\da14531\prod_test
```

The DA14531 Getting Started Guide section 9 explains how to compile and how to program. [3]
Before compiling the software, the user_periph_setup.h has to 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 has to 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 or the Toolbox RF-Master Firmware Download tool.

As an example, how to download the prod_test_531.bin firmware into RAM, the SmartSnippets Toolbox RF-Master tool will be used.

Connect the SmartSnippets Toolbox via JTAG or COM port, choose RF Master, browse to the built binary and press the 'Download' button Figure 1.

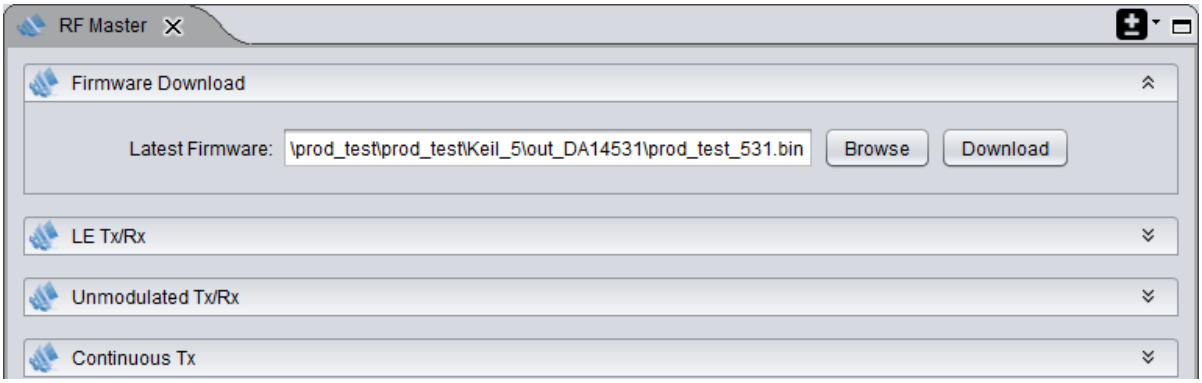

Figure 1: Firmware download in RF-Master

After downloading the firmware, the RF-Master tool can be used to set the DA14531 chip in different receive or transmit modes (e.g. LE Transmitter Continuous Packet).

The UART COM port will be selected by RF-master automatically or a pop-up box will appear, 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 tester and the DUT are set in SmartSnippet's Board Setup.

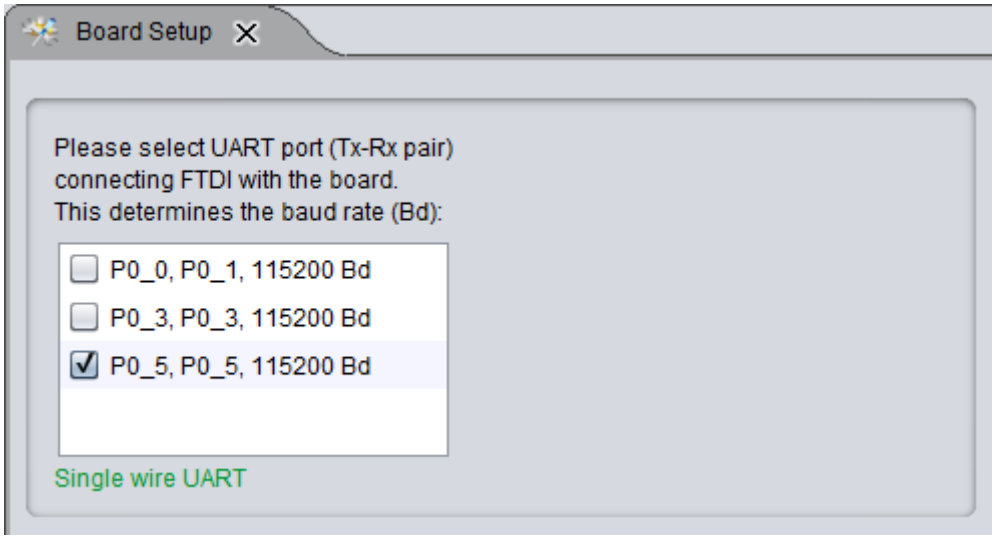

Figure 2: Board Setup in SmartSnippets Toolbox

Summarizing the UART configuration:

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

Parity: None

4.1.1 Setting up Rx/Tx test modes with RF Master

SmartSnippets Toolbox's RF Master can be used to setup different RX and TX modes to check the performance of the DA14531. Please refer to Figure **3**.

1. Choose 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 press Start

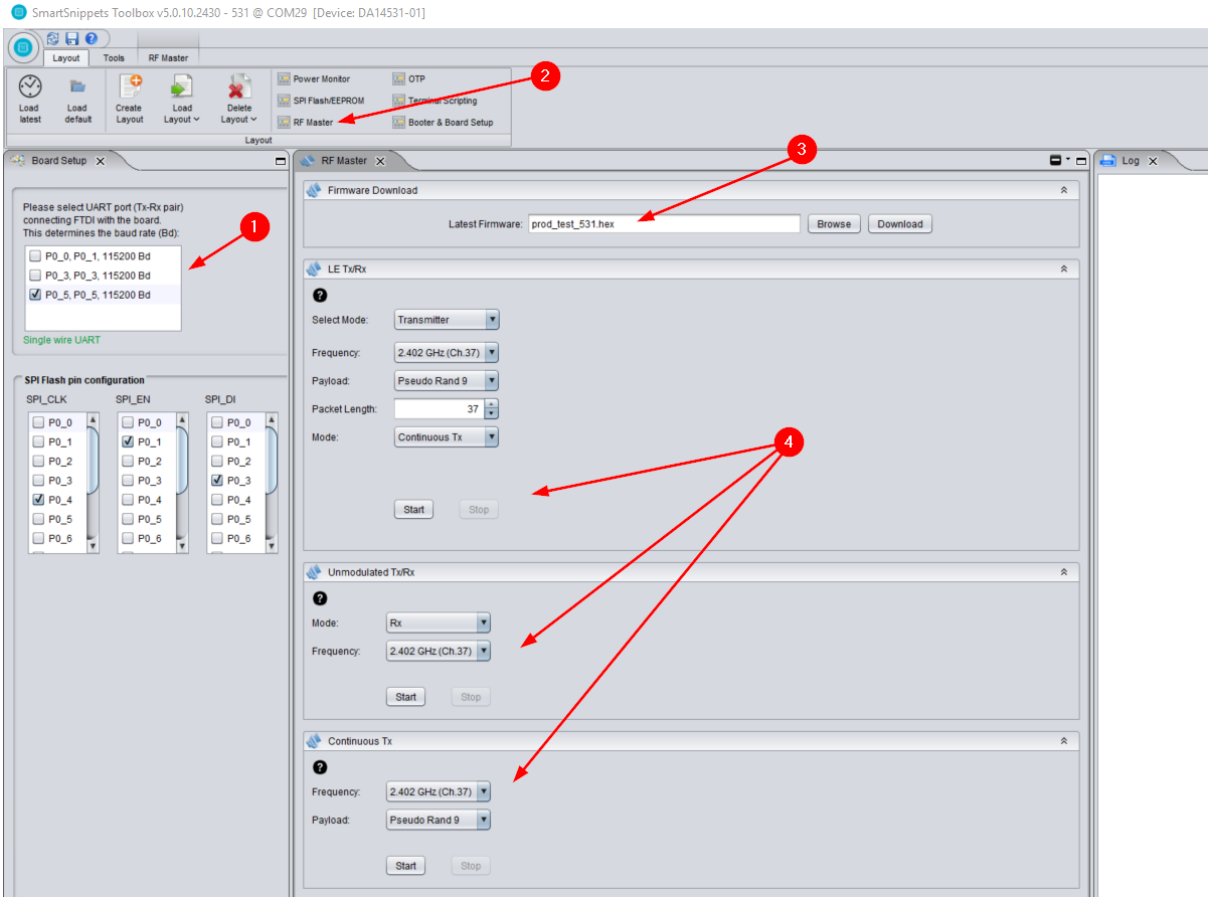

Figure 3: Setting up RF Master

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 degrees centigrade or more, a RF re-calibration will be 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, please issue a HW-reset to the chip at which the chip will reboot and will execute 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 main board since it will be re-loaded from the flash automatically after a reset.
  Normally the RF re-calibration would not be 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 will 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 will be in optimal condition at any temperature.

4.2 Hardware Setup

4.2.1 Main Board

The jumpers on the Pro-DK motherboard must be set as shown in Figure 4, Figure 5 or Figure 6.

Please note, that

- P20 on the main board is routed to P00 on the DA14531 daughter card
- P21 on the main board is routed to P01 on the DA14531 daughter card
- P23 on the main board is routed to P03 on the DA14531 daughter card

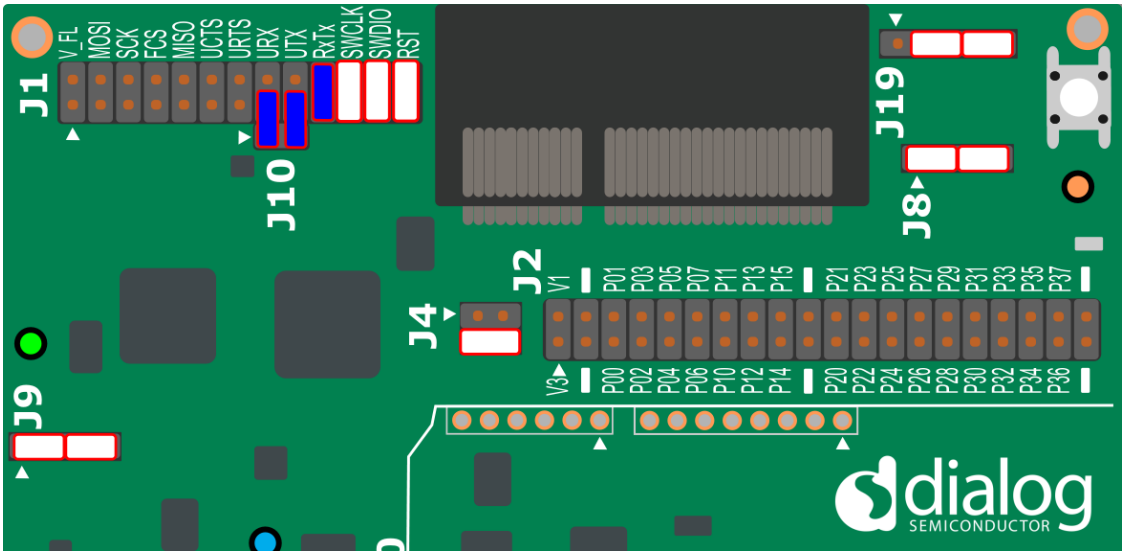

Figure 4: Jumper settings for 1-wire UART P05

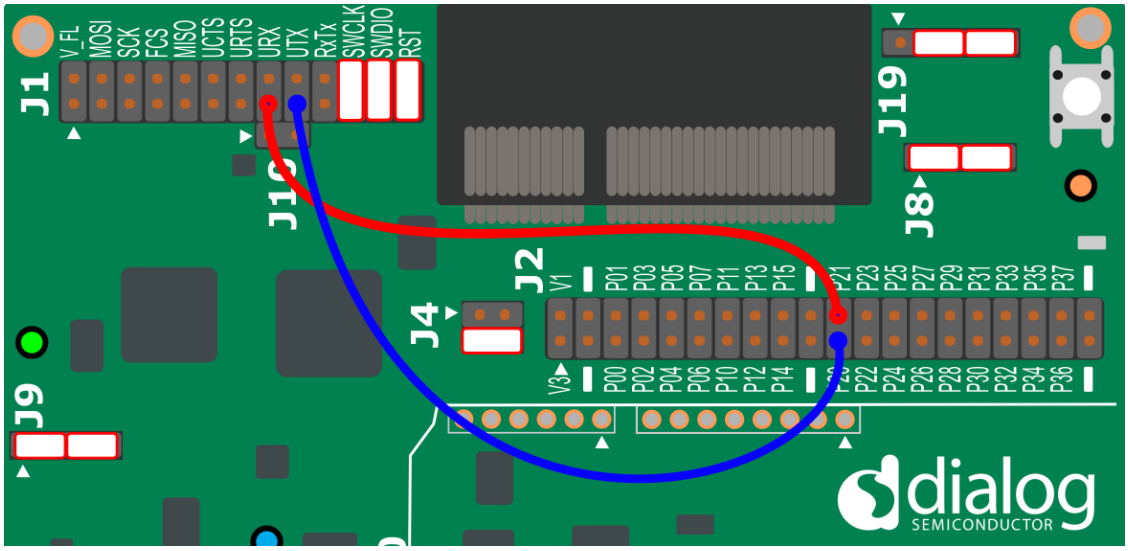

Figure 5: Jumper setting for 2-wire UART P00 P01

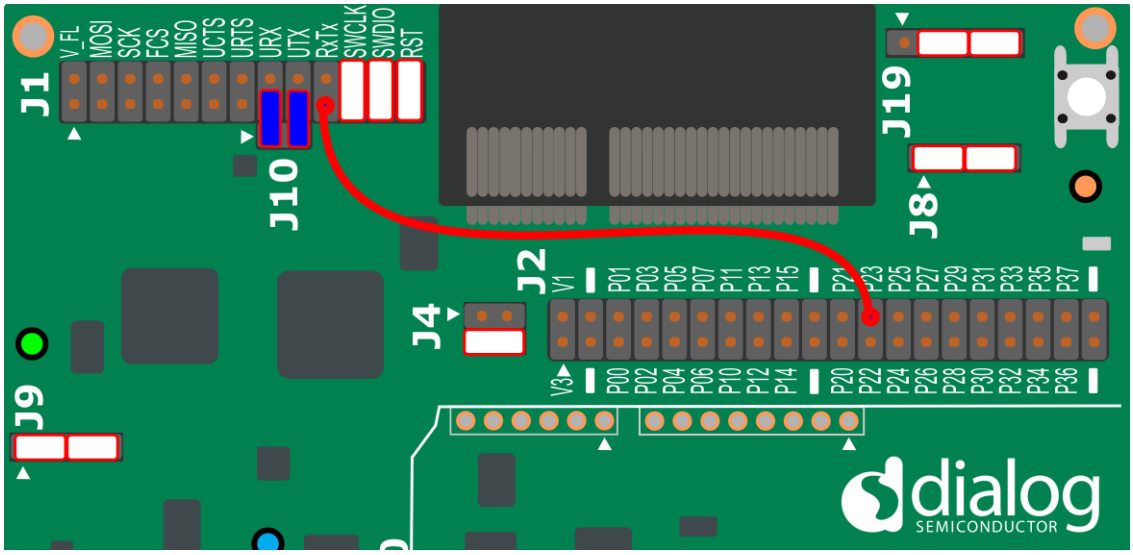

Figure 6: Jumper setting for 1-wire UART P03

Other relevant jumper settings, e.g. the supply, are shown in Appendix A.
Please check whether the board used for DTM RF-testing is configured as shown in Figure 17.

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

4.2.2 Daughter board

The RF connection between the DA14531 board and the Bluetooth tester can be established using an SMA connector. The modifications of the board are shown in Figure 7. The connection to the on-board antenna must be opened by removing Z9 and the connection to the SMA connector has to be made by soldering a 10pF capacitor on position Z7.

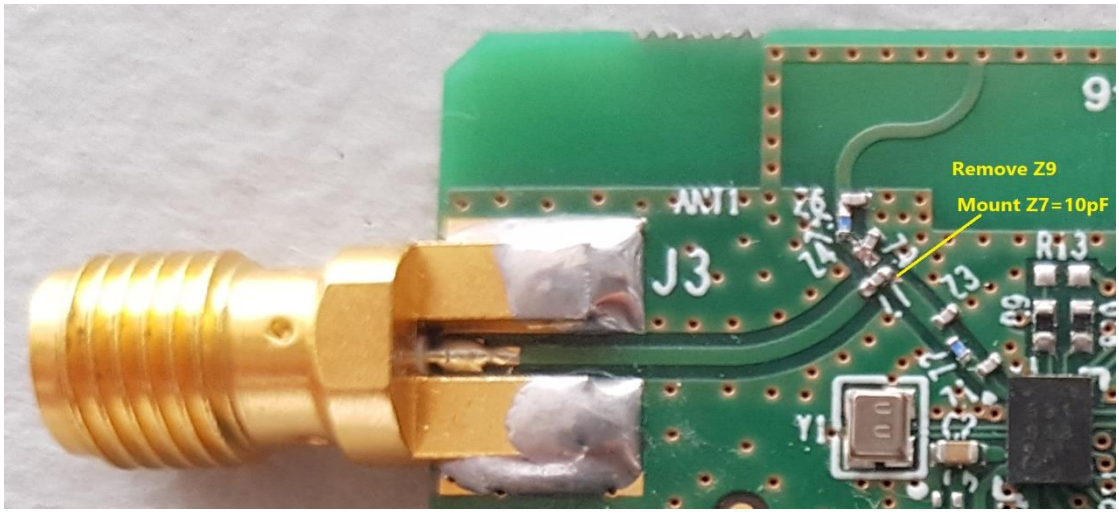

Figure 7: Modifications required for performing conducted measurements

4.2.3 BLE tester

Four RF test setups will be shown and discussed.

First the R&S CMW270 Bluetooth 5 tester is discussed, where the DA14531 Pro-DK 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 5 tester is shown.
Here a PC supplies the Pro-DK board and connects the Bluetooth tester and the DUT via 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 [2]. The PC additionally supplies the Pro-DK board via its USB connector.
Section 4.2.6

At last the RTX2254 setup and connections are shown. The DA14531 Pro-DK 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. Please use prod_test_531_2wire_P00P01.bin, when doing these tests.

4.2.4 R&S CMW270 Bluetooth 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 will be created, e.g. 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).
Following R&S application note deals with how to do this, in sections 3.3 and 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 HW Interface.
- HCI in EUT Communication Protocol.
- RS232 COM port: the virtual COM port, e.g. 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 (e.g. 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. Please refer to Figure 8 below.

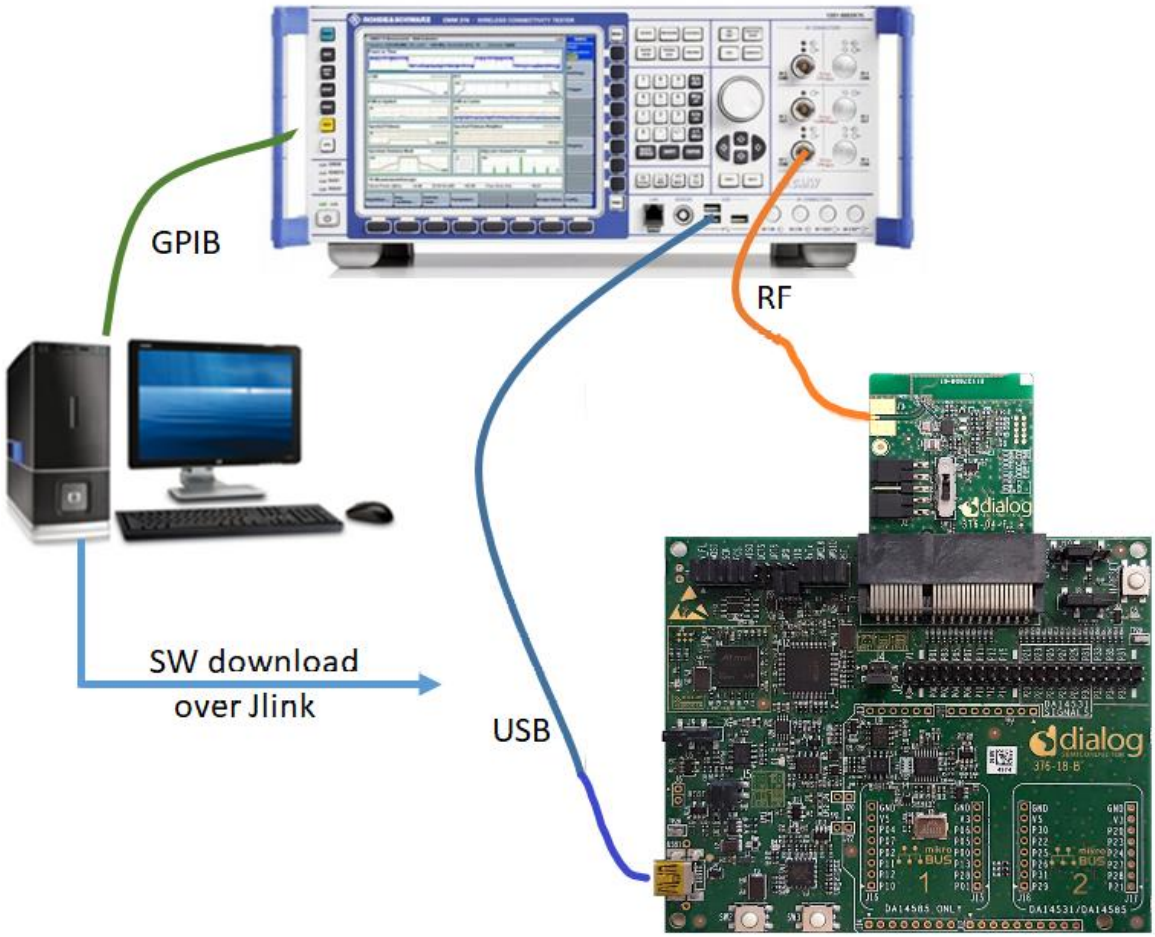

Figure 8: R&S CMW270 connections

4.2.5 Anritsu MT8852B Bluetooth Tester Setup

For this setup case shown in Figure 9, 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, e.g. 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 (e.g. COM1) at which the MT8852B EUT port is connected, to the Pro-DK's virtual COM port (e.g. COM4).
The Pro-DK board will create two virtual COM ports on the PC: e.g. COM4 and COM5.
The COM port having the lowest number (COM4 in this example) must be selected for UART.
The 2nd virtual COM port is the SPI channel, used for transmitting the PowerProfiler data from the motherboard to the SmartSnippets Power Profiler tool running on the PC.
Please find screen captures of the COMM Tunnel tool in Figure 11 and in Figure 12.

The version that was used for this document: http://www.serialporttool.com/CommTunnel.htm

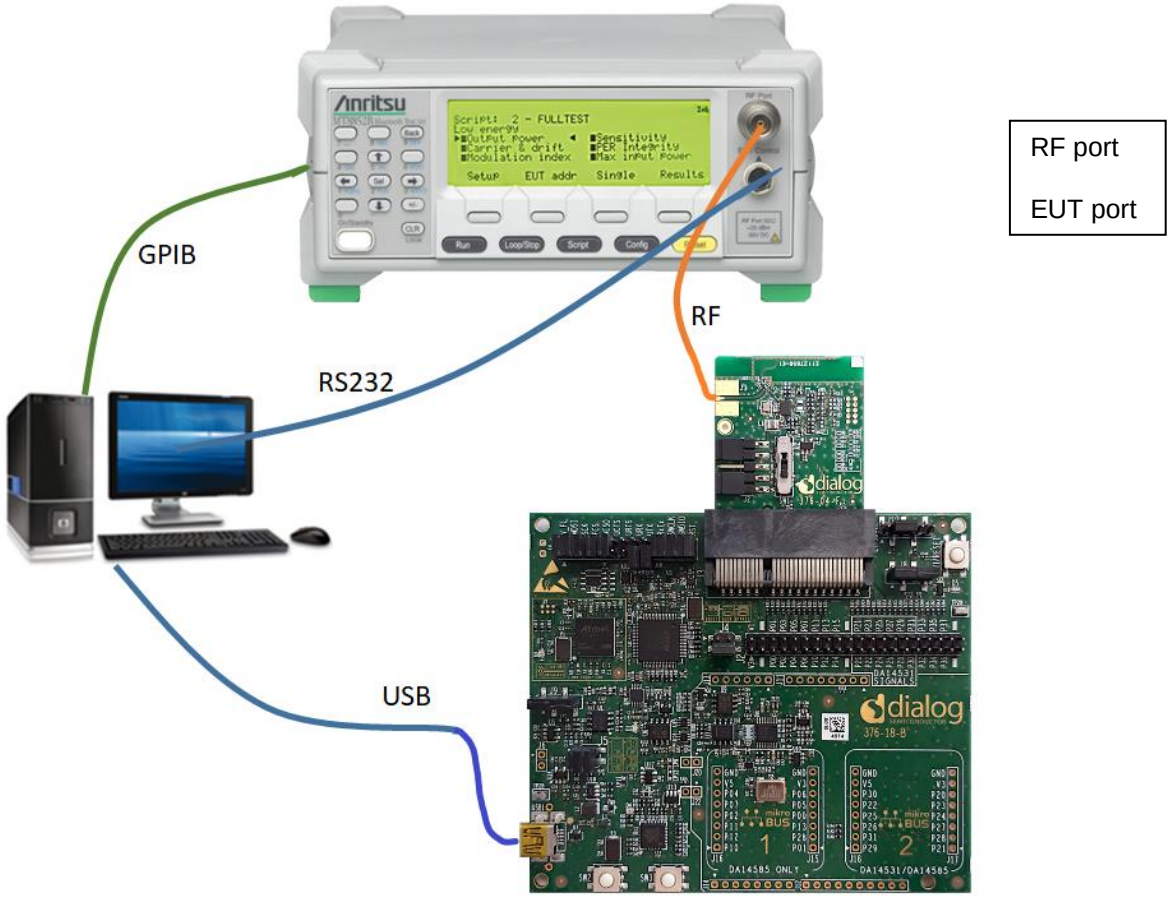

Figure 9: Anritsu MT8852B connections

Figure 9 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. Please refer to 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 e.g. running Anritsu's Bluetooth LE Measurement Software, script testing can be executed and a test-report could be created [2]. The GPIB connection between the tester and the PC is required for this test case.
The MT8852B Connection settings in the Anritsu Bluetooth LE Measurement Software: Figure 10.

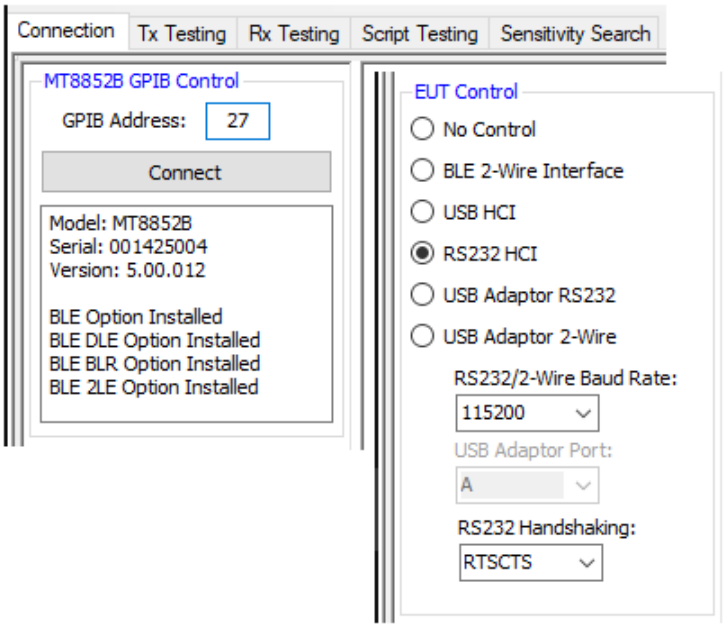

Figure 10: MT8852B connection settings

Comm Tunnel settings: below Figure 11 (Setting) appears when selecting 'Setting' in 'Endpoint 1' (tester) or 'Endpoint 2' (DUT) in Figure 12. After entering the correct values, press the 'Start' button.

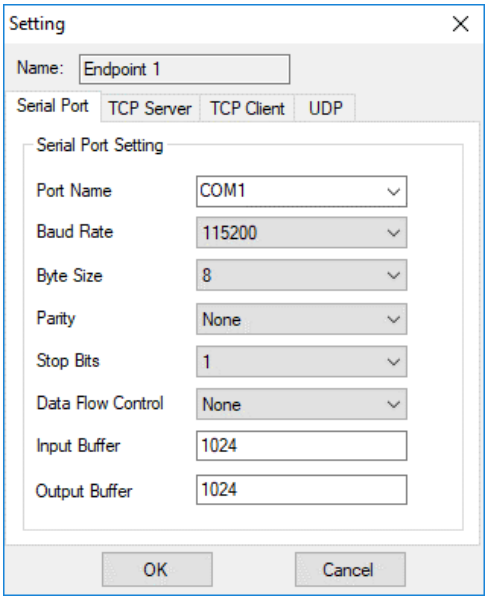

Figure 11: COMM Tunnel Setup

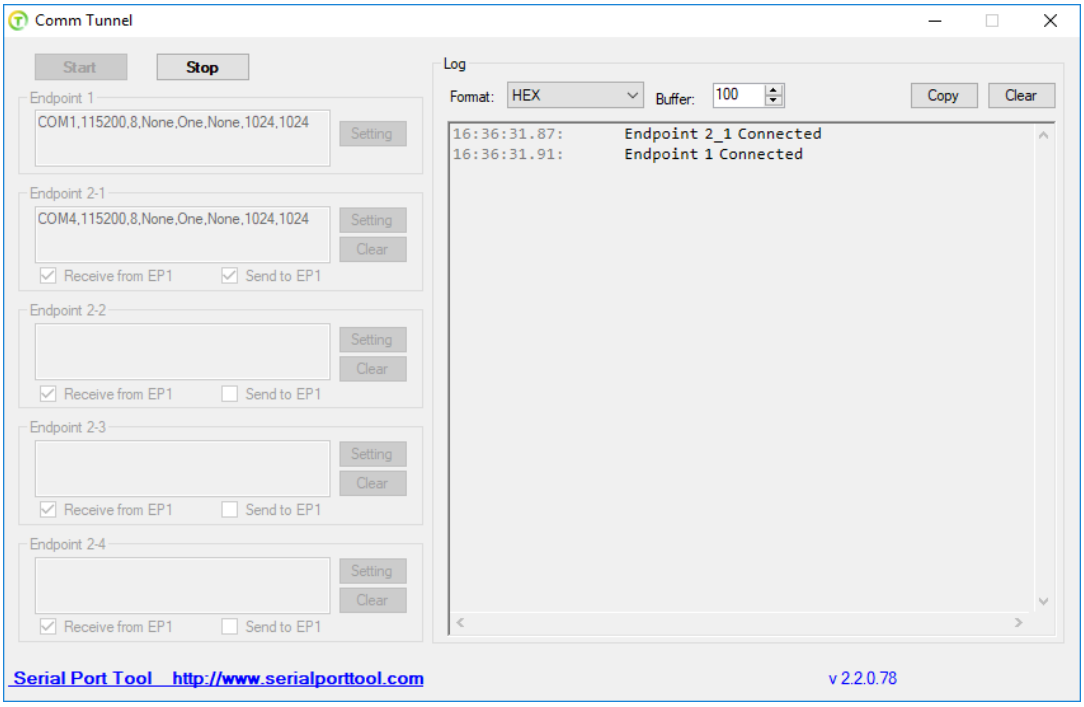

Figure 12: COMM Tunnel Tool

4.2.6 R&S CBT Bluetooth 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. Please refer to below Figure 13 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, please read 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 signalling.

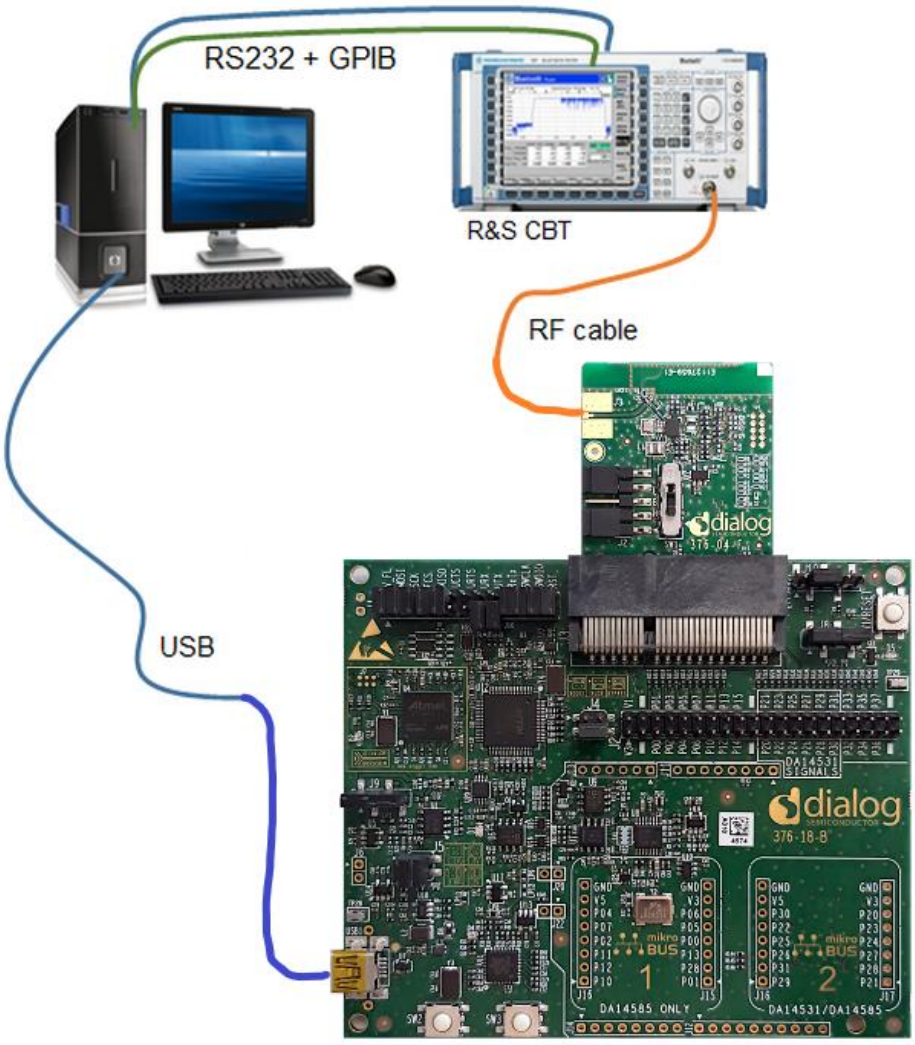

Figure 13: R&S CBT connections

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 will not be 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 Tester Setup

For this setup case shown in Figure 16, the USB connector on the Pro-DK 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 will be created, e.g. 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 14).
- RS232 COM port: the virtual COM port, e.g. COM35 (Figure 15).
- Baud Rate: 115200 (Figure 15)
- HW Flow Control: None (Figure 15)
- Parity: None
- Stop Bits: 1

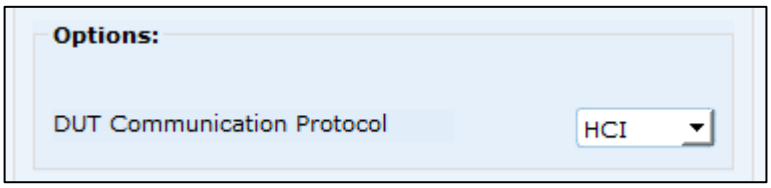

Figure 14: DUT communication protocol setting in RTX2254 GUI

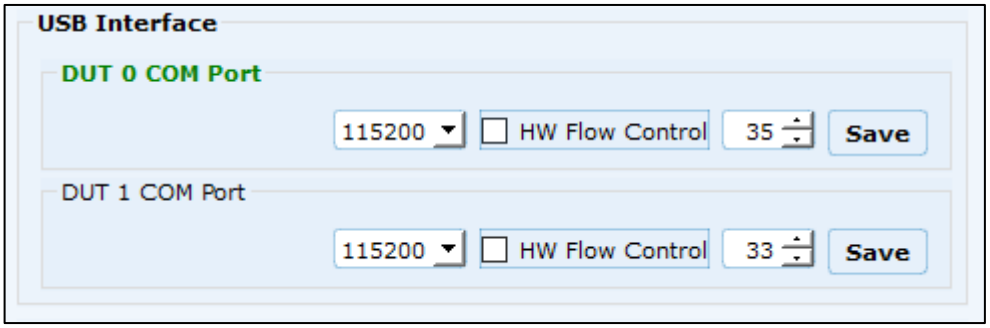

Figure 15: Virtual comport setting in RTX2254 GUI (Pro-DK connected to DUT0)

Following RTX application note does further describe the configuration and operation of the RTX2254 when testing the Dialog Pro-DK in Direct Test Mode and Advertising Mode:
https://www.rtx.dk/media/4222/rtx2254-application-note-dialog-da14531-rf-testing.pdf

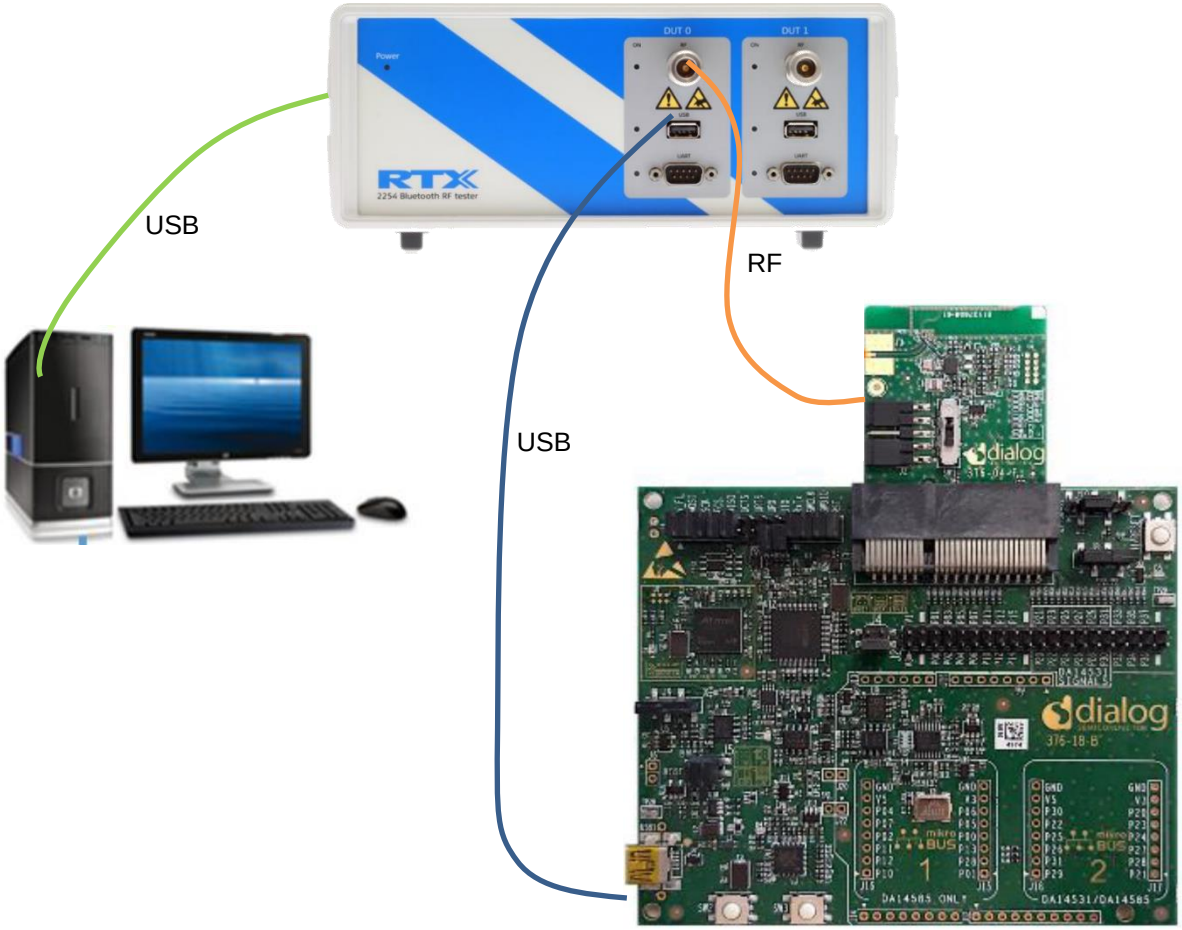

Figure 16: RTX2254 connections

Figure 16 shows the connections between the RTX2254 tester, the Pro-DK 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® PHY Qualification

In order to release a Bluetooth application to the market, the application needs to be Qualified. The Dialog Semiconductor Bluetooth Low Energy Socs have Qualified Design Listings (QDL) with corresponding Qualified Design Identification (QDID) for all Host Subsystems and Controller Subsystems. Enter 'Dialog Semiconductor' in the search field for finding all Dialog Semiconductor listings. By referring to the Dialog Semiconductor QDIDs, the amount of testing required to list a Bluetooth low energy application is greatly reduced.

Typically, Bluetooth PHY testing must be done for new hardware, meaning that Bluetooth PHY testing done by Dialog Semiconductor on the evaluation kits cannot be re-used. This PHY testing has to 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 Low Energy 1 Mbps

PIXIT Reference	Identifier	Sub-Identifier (Optional)	Value	Units
RF-PHY:P1:1	Inband Image frequency	Low frequency	1	MHz
RF-PHY:P1:2		Middle frequency	1	MHz
RF-PHY:P1:3		High frequency	1	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

Appendix A Motherboard

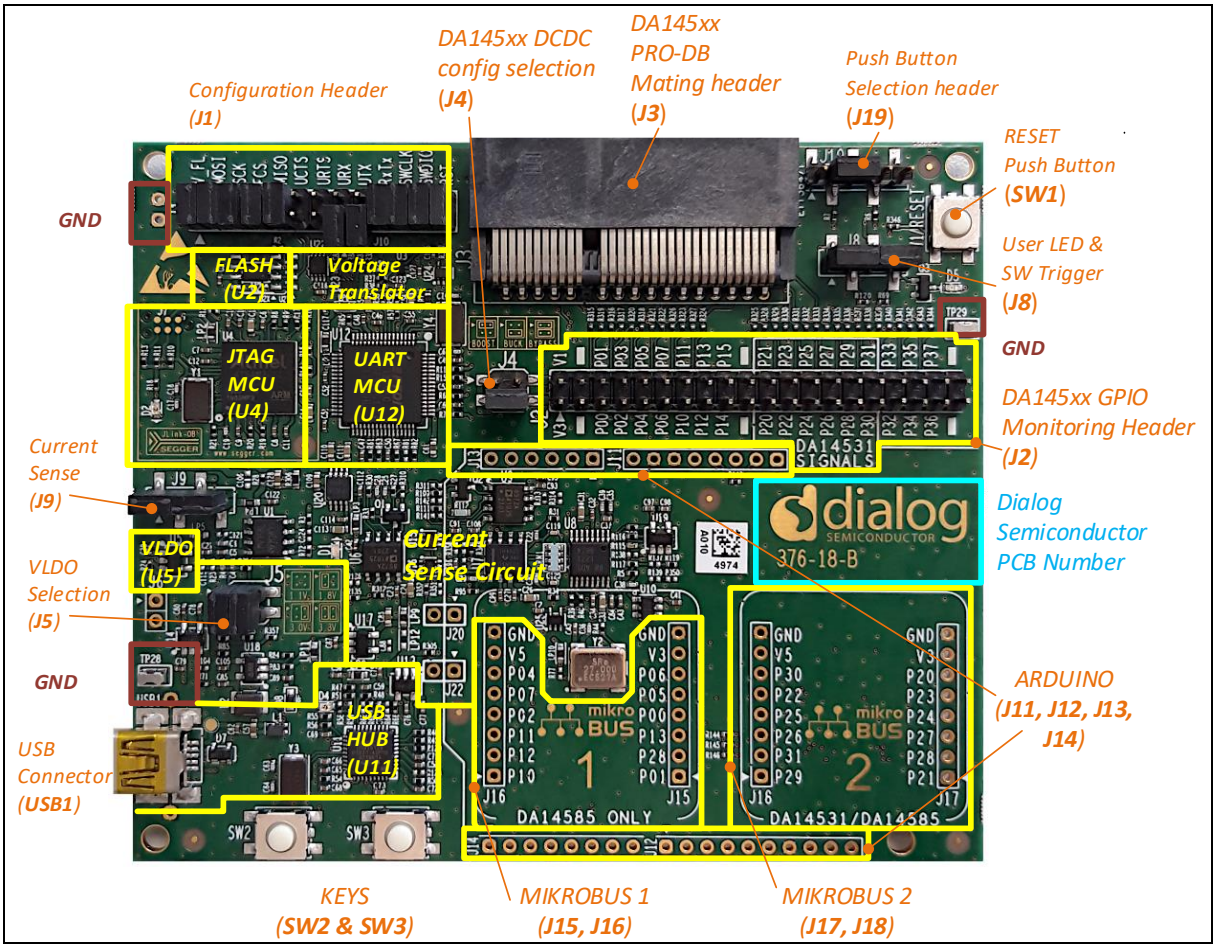

Figure 17: DA14531 Pro-DK motherboard

Appendix B Daughterboard

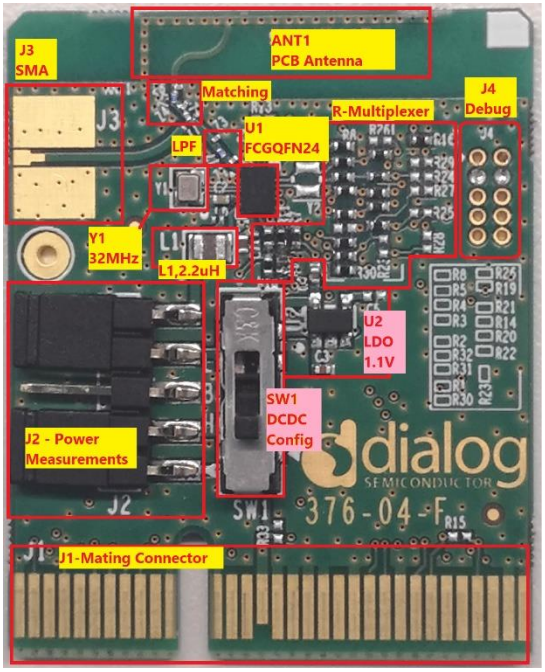

Figure 18: DA14531 QFN24 Pro-DK daughterboard

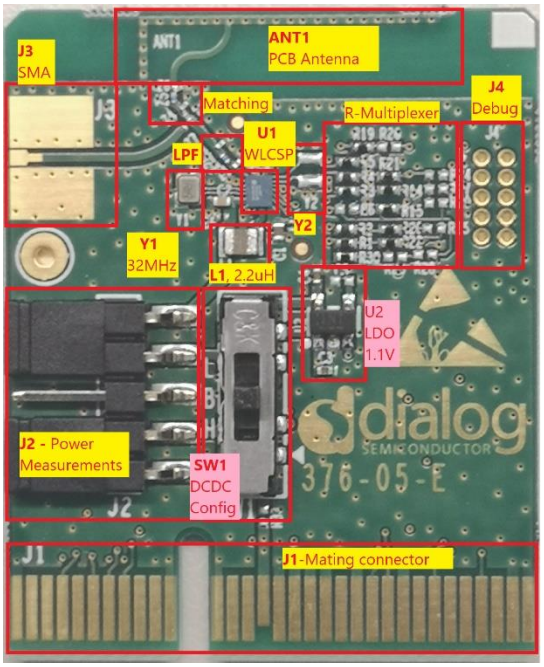

Figure 19: DA14531 WLCSP Pro-DK daughterboard

Appendix C COMM Tunnel and 1-wire UART

COMM Tunnel will cause 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 20).

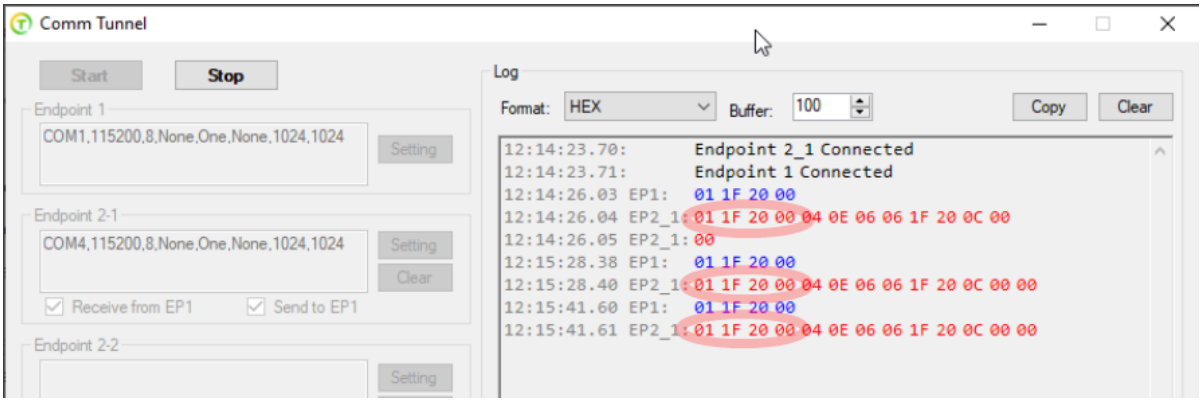

Figure 20: COMM Tunnel 1-wire UART issue

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. Dialog is working on additional tooling to support 1 wire UART in combination with Bluetooth testers.

Revision History

Revision	Date	Description
0.1	08-Oct-2019	Draft version.
1.0	01-Nov-2019	First Release
1.1	05-Nov-2019	Link updated
1.2	17-Mar-2020	RTX tester added

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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