

Using Direct Test Mode

BL654 Series

Application Note

v1.3

1 INTRODUCTION

The BL654 firmware natively supports Direct Test Mode (DTM) commands as specified in the Bluetooth SIG's *Bluetooth Core Specifications v 5.0 vol. 6 part F - Direct Test Mode*: (www.bluetooth.com/specifications/bluetooth-core-specification)

The purpose of DTM is to test the operation of radio at the physical layers such as for transmit power and receiver sensitivity. This is useful for regulatory EMC testing or for co-located radio testing with another radio system.

This radio test can be carried out by dedicated test equipment (such as RF Creations Moreph30, Anritsu MT8852 or similar) with the BL654 in DTM mode as the device under test. Alternatively, you can send DTM commands from a PC using a terminal program such as UwTerminalX. In both cases, the DTM commands remain the same.

This document describes BL654 radio testing using the in-built Direct Test Mode (DTM) firmware and Nordic's nRF Connect or nRFgo Studio.

- Entering DTM mode for the BL654
- Using Nordic nRF Connect for Desktop Direct Test Mode tool (or legacy Nordic nRFgoStudio DTM tool) to BLE radio test the BL654 in either BLE transmit or BLE receive mode
- Exiting DTM mode for the BL654

2 REQUIREMENTS

To use DTM, you need the following:

- DVK-BL654-1.0 development board
- Windows PC
- UwTerminalX by Laird Connectivity (available at <https://github.com/LairdCP/UwTerminalX/releases>)
- Nordic nRF **Connect for Desktop Direct Test Mode** tool – This Nordic Direct Test Mode tool is installed when the Nordic nRF **Connect** is installed.
Nordic nRF **Connect for Desktop** application software (the complete install) found at the following link:
<https://www.nordicsemi.com/Software-and-Tools/Development-Tools/nRF-Connect-for-desktop>
<https://www.nordicsemi.com/Software-and-tools/Development-Tools/nRF-Connect-for-desktop/Download#infotabs>
- Legacy Nordic nRFgoStudio application software (the complete install found on the Downloads panel at the following link:
<http://www.nordicsemi.com/eng/Products/Bluetooth-low-energy/nRF52832>

Note: Please install the correct version (32- or 64-bit) for your operating system.

3 SETUP

We assume the DVK-BL654-1.0 development kit has its default out-of-the-box settings as described in the BL654 Quick Start Guide (available from the BL654 product page <https://www.lairdconnect.com/wireless-modules/bluetooth-modules/bluetooth-5-modules/bl654-series-bluetooth-module-nfc>). In this mode, it is in AT or interactive mode (no *smartBASIC* application loaded or running) on power up.

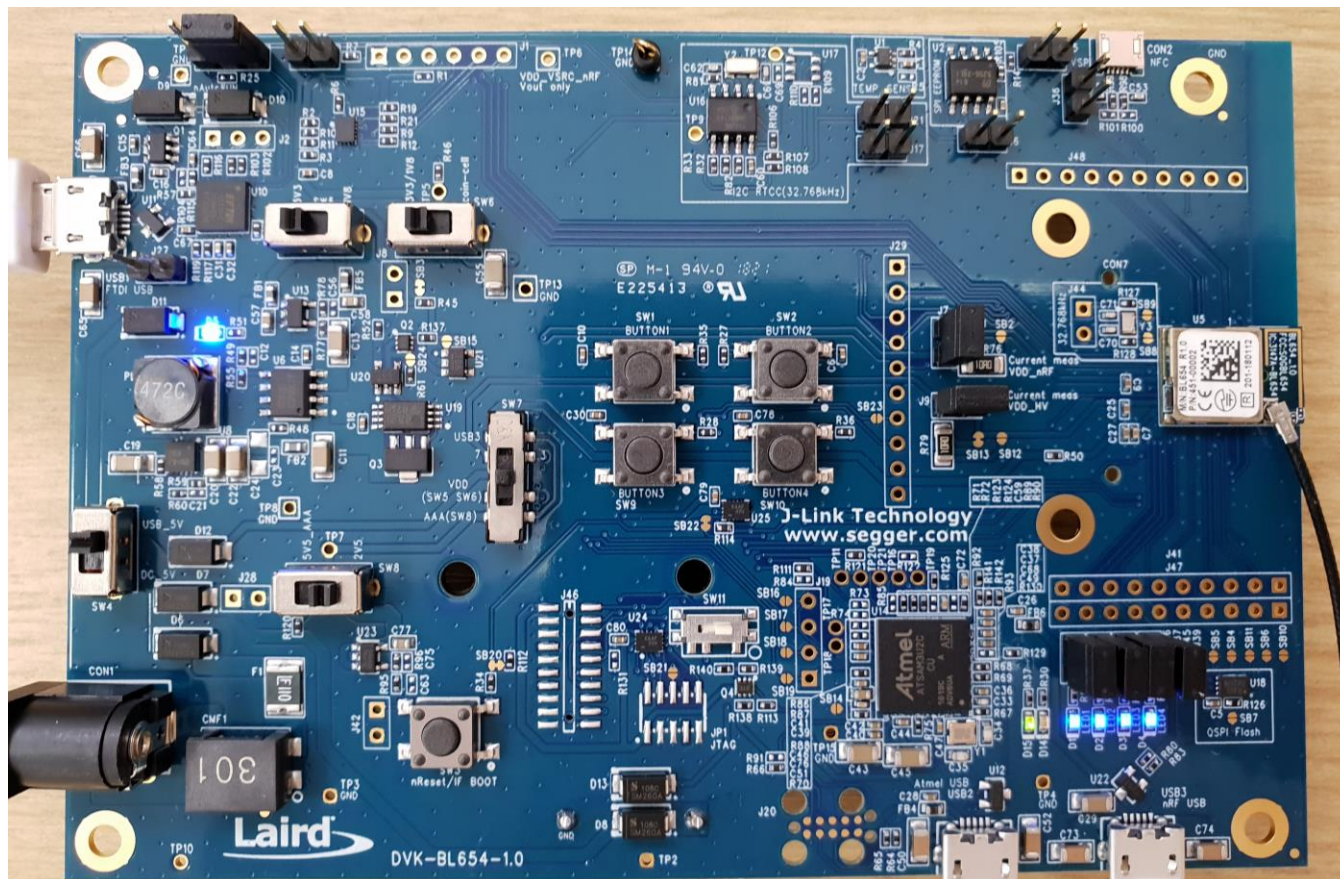


Figure 1: J12 fitted over pins 1 and 2, and SW3 (reset button)

4 ENTERING DIRECT TEST MODE

To enter DTM, follow these steps:

1. Open UwTerminalX.
2. Ensure you're using the latest version of UwTerminalX by clicking the Update tab and then, in the UwTerminalX panel, click **Check for Updates**.
3. When you're running the newest version of UwTerminalX, open the *Config* tab.
4. In the device drop down, select *BL654* to populate the default communications settings.
5. Select the correct COM port.

If you cannot select *BL654*, manually select the following UART settings (shown in Figure 2):

COM Port	Port corresponding to your development kit
Baud Rate	115200
Parity	None
Stop Bits	1
Data Bits	8
Handshaking	CTS/RTS

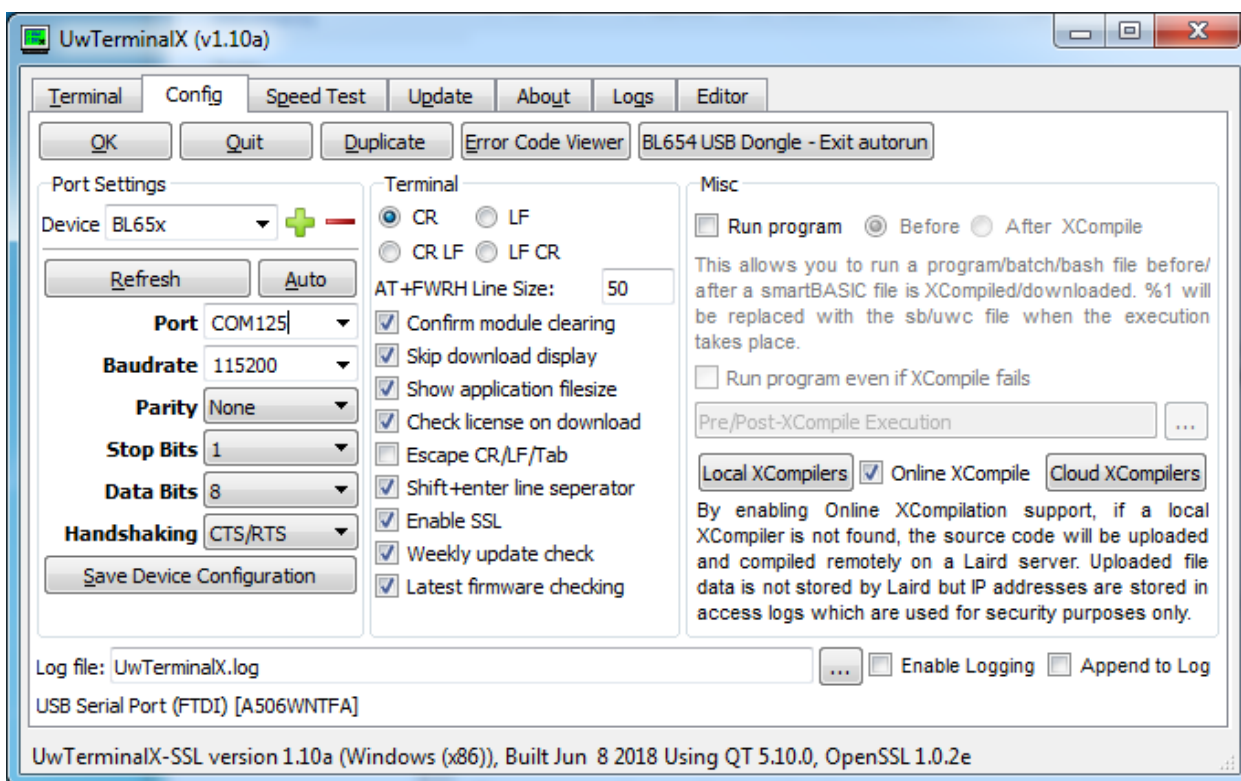


Figure 2: UwTerminalX Settings

6. Click **OK** to connect.
7. Set up the module into Direct Test Mode, you will need to retrieve two sets of four characters each which function as a unique passcode to enter direct test mode. To retrieve the characters, issue the following command:

```
AT I 14
```

You should receive a response such as:

```
10 14 01 123456789ABC
```

Note the characters in the highlighted positions above. In our example in Figure 3, they are CB71 and 7B03.

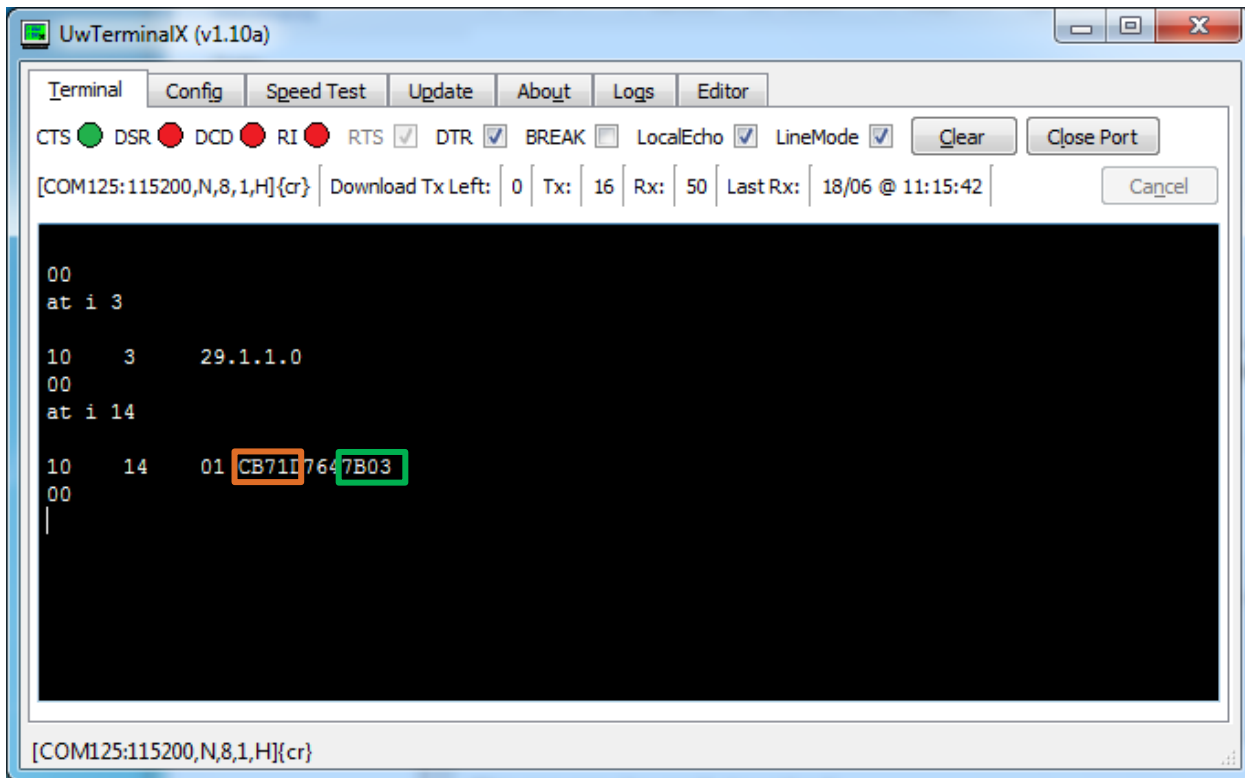


Figure 3: Return from at i 14

- 8. To enter Direct Test Mode, using the characters you found in the previous steps, issue the AT+DTM command as follows:

```
AT+DTM 0xCB717B03
```

The module is now in Direct Test mode.

- 9. Click **Close Port** to disconnect the development board from UwTerminalX.

5 USING DIRECT TEST MODE

Now that the module is in Direct Test Mode, it accepts DTM commands as specified in the *BT SIG Bluetooth Core Specifications*. See *Bluetooth Core Specifications v 5.0 vol. 6 part F - Direct Test Mode*, at <https://www.bluetooth.com/specifications/bluetooth-core-specification>.

Once the BL654 is in DTM mode, you can communicate with the BL654 over the UART with UwTerminalX using the following communications settings:

COM Port	Same as before
Baud Rate	19200
Parity	None
Stop Bits	1
Data Bits	8
Handshaking	None

5.1 Configuration of Module Settings (Optional)

Before entering DTM Mode, you may configure TX Power, Baud Rate, and DCDC. Changing these values is optional. However, if you choose, you may set these values as follows (Note that if using BL654 firmware 29.5.7.2 and an option is changed, you must enter the command **AT+DTMCFG 19 1** prior to entering DTM mode to allow the radio to operate):

TX Power

Command	AT+DTMCFG 1 n
Values for n	8, 7, 6, 5, 4, 3, 2, 0, -4, -8, -12, -16, -20, -40
Default	8

Baud Rate

Command	AT+DTMCFG 2 n
Values for n	9600, 14400, 19200, 38400, 57600, 115200
Default	19200

DCDC REG1 (for Normal Voltage Mode operation)

Command	AT+DTMCFG 3 n
Values for n	0 (Disabled), 1 (enabled)
Default	1

DCDC REG0 (for High Voltage Mode operation)

Command	AT+DTMCFG 11 n
Values for n	0 (Disabled), 1 (enabled)
Default	0

Enable 32KHz Crystal based LF Clock

Command	AT+DTMCFG 4 <i>n</i>
Values for n	0 (Disabled), 1 (enabled)
Default	1

Additionally, the current configuration can be queried by using a question mark (?) instead of a new value (on firmware version 29.5.7.2 or newer only), e.g. the command **AT+DTMCFG 2 ?** will output the baud rate setting.

Refer to the [Appendix](#), for setting a GPIO if it needs to be set for some particular purpose whilst in DTM mode.

5.2 Start Direct Test Mode Tool Within nRF Connect

Nordic's **nRF Connect Direct Test Mode** tool allows all BLE PHY data rates to be tested, 1 Mbps, 2 Mbps, and coded PHY 500 kbps (s=2) and 125 kbps (s=8).

To begin using Nordic **nRF Connect Direct Test Mode** tool, follow these steps:

1. Open nRF Connect.

Note: If a new version of the app becomes available, an **Update** button displays next to the **Open** button. Click this button to install the latest version.

2. Then click **Open** in **Direct Test Mode** tool, as shown in [Figure 4](#).

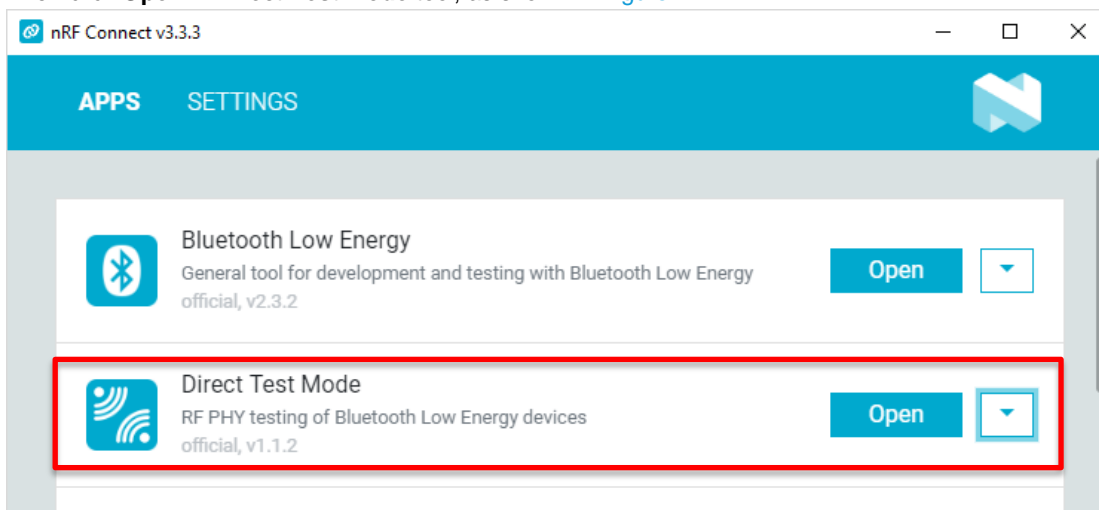


Figure 4: Click Open in Direct Test Mode

Note: Press the drop-down arrow to view release notes or more information (recommended).

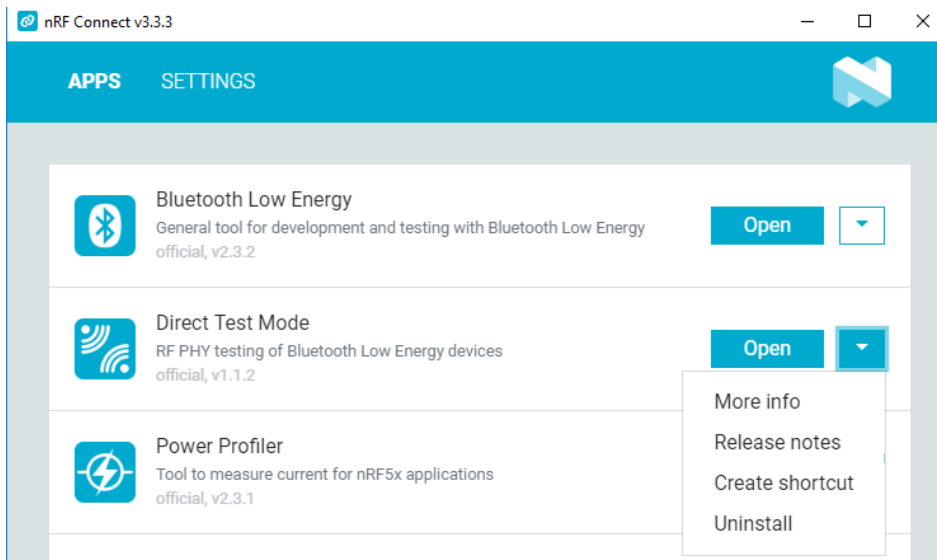


Figure 5: Access release notes and more information

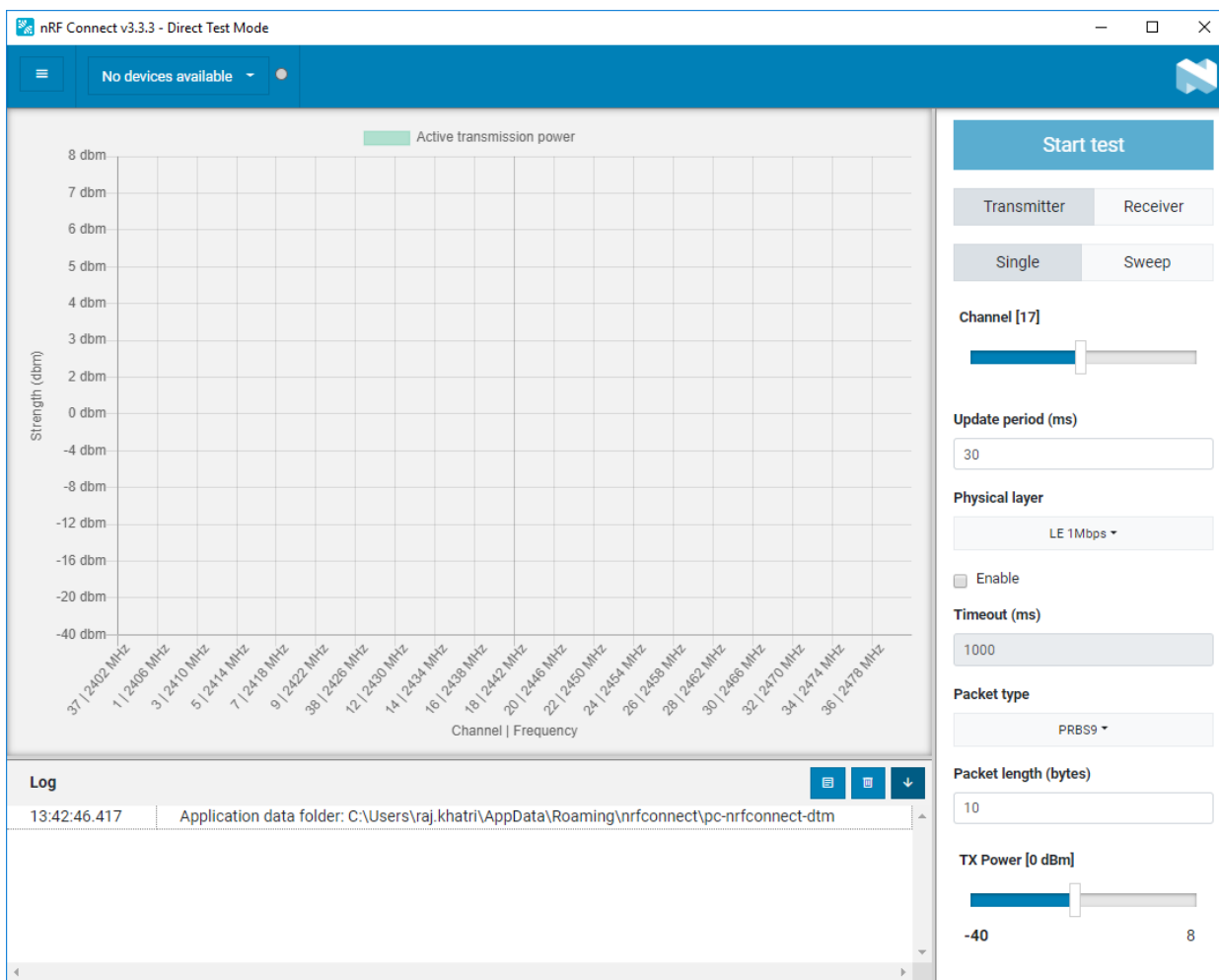


Figure 6: Opening the Nordic nRF Connect Direct Test Mode tool

3. **Select device** for the COM port of the connected Device Under test (from the drop-down menu).

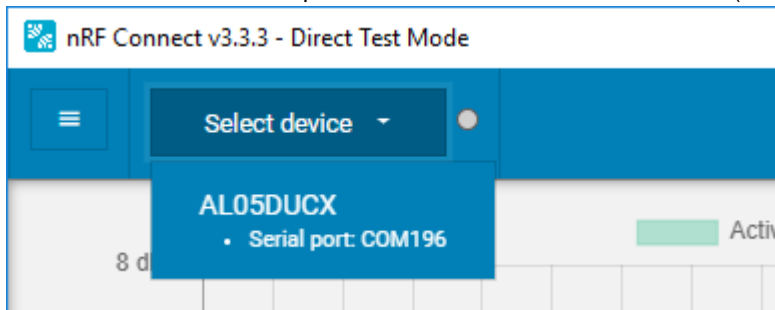


Figure 7: Device selection

4. From here, you can place the module in BLE (duty cycled) TX or CW (sine wave) TX or BLE RX mode.

Note: If at any time, the Nordic nRF Connect for Desktop Direct Test Mode tool is not responding or there is unexpected behavior (see example in [Figure 8](#)), press **CTRL+R** to refresh the **nRF Connect for Desktop Direct Test Mode** tool.

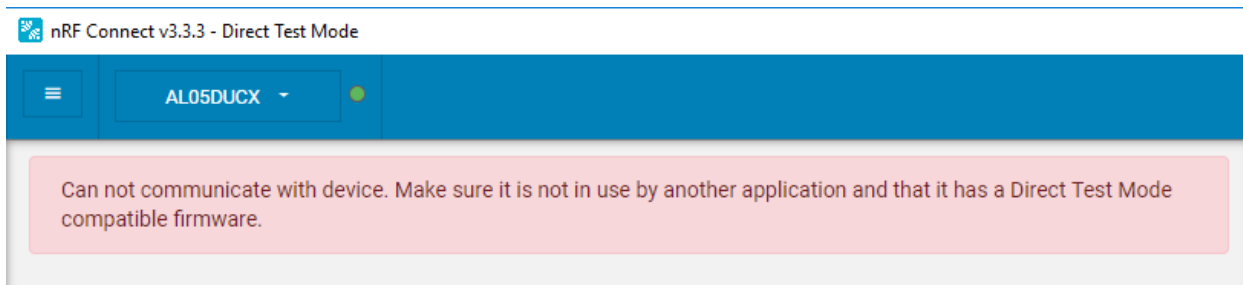


Figure 8: Unexpected behavior when opening or running the Nordic nRF Connect for Desktop Direct Test Mode tool

5.3 Nordic nRF Connect Direct Test Mode tool TX and RX Tests

The nRF Connect for Desktop Direct Test Mode tool allows all BLE PHY data rates to be tested, 1 Mbps, 2 Mbps, and coded PHY 500 kbps (s=2) and 125 kbps (s=8).

5.3.1 Transmit Test with BLE modulation signal or CW sinewave signal

To perform a transmit test, follow these steps:

1. Configure the applicable BLE transmitter options in the **nRF Connect for Desktop Direct Test Mode** tool.

Table 1: Transmitter test Direct Test Mode options

COM Port	D.U.T COM port
Test Type	Select Transmitter, Single
Channel	17 (2440 MHz, for example)
Update period (ms)	30 (default)
Physical layer	Select <i>LE 1 Mbps</i> (as an example). Other options are LE 2 Mbps, LE Coded S8 (500 kbps), LE Coded S2 (125 kbps).
Timeout (ms)	Not enabled. This is a timeout for the specific command. Setting timeout to 1000 ms stops the current operation when the timer expires.

	Packet Type Value	Description
Packets Type	PRBS9	PRBS9 Packet Payload (Pkt Type 00)
	11110000	11110000 Packet Payload (Pkt Type 01)
	10101010	10101010 Packet Payload (Pkt Type 10)
	Constant Carrier	Vendor-specific (Pkt Type 11)
	Prior to Nordic nRF Connect for Desktop (version 1.1.5) Direct Test Mode tool did not have vendor-specific type that produces a 100% ON continuous wave (CW) RF TX signal. Refer to the DTM Command to Produce CW RF TX Signal section for additional information on how to do this manually without nRF Connect.	
Payload Length (bytes)	Options range from 1 byte to 255 bytes.	
TX Power [dBm]	Options include: 8 dBm, 7 dBm, 6 dBm, 5 dBm, 4 dBm, 3 dBm, 2 dBm, 0 dBm, -4 dBm, -8 dBm, 12 dBm, -16 dBm, -20 dBm, -40 dBm.	
TRANSMIT	To start TX test, press Start test .	

2. Once configured, click **Start test**. [Figure 9](#) shows an active BLE transmitter test.

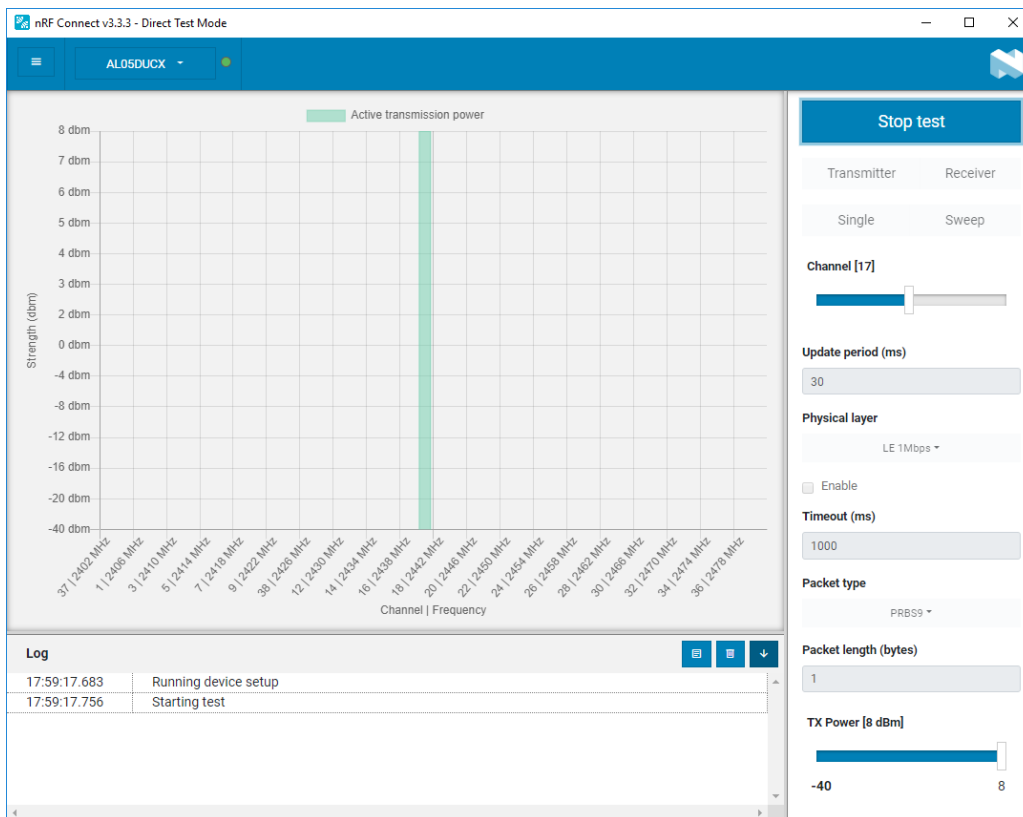


Figure 9: Successful initiation of BLE transmitter test

With the module is in a transmit test, you can measure the RF Tx signal on a spectrum analyzer. Check the RF Tx packet duration of your RF transmission (using zero span mode on the spectrum analyzer). The RF Tx signal is NOT 100% on and has a Tx duty cycle as per *BT SIG Bluetooth Core Specifications*. See *Bluetooth Core Specifications v 5.0 vol. 6 Part F - Direct Test Mode*.

5.3.2 Receive Test

To conduct the BLE receive test, do the following:

1. Configure the applicable BLE receiver options in the nRF Connect for Desktop Direct Test Mode tool.

Table 2: Receive test Direct Test Mode options

COM Port	DUT COM port
Test Type	Select Receiver, Single
Channel	17 (2440 MHz, for example)
Update period (ms)	30 (default)
Physical layer	Options include: LE 2 Mbps, LE Coded S8 (500 kbps), LE Coded S2 (125 kbps)
Timeout (ms)	Not enabled. This is a timeout for the specific command. Setting timeout to 1000 ms will stop the current operation when the timer expires.
RECEIVER	To start RX test, press Start test .

Note: DUT RX mode produces an RX LO leakage at the following frequency: $(2 \times f_{RX}) - 1\text{MHz}$.

2. Once configured, to start Receiver test, click **Start test**. **Figure 10** shows a BLE receiver test running.

The **Received packets** shows how many packets are received. Since the number of packets sent per second by transmitter is known (as per Bluetooth SIG's *Bluetooth Core Specifications v 5.0 vol. 6 part F - Direct Test Mode*), the DUT received packets Rx Packet Error Rate can be calculated.

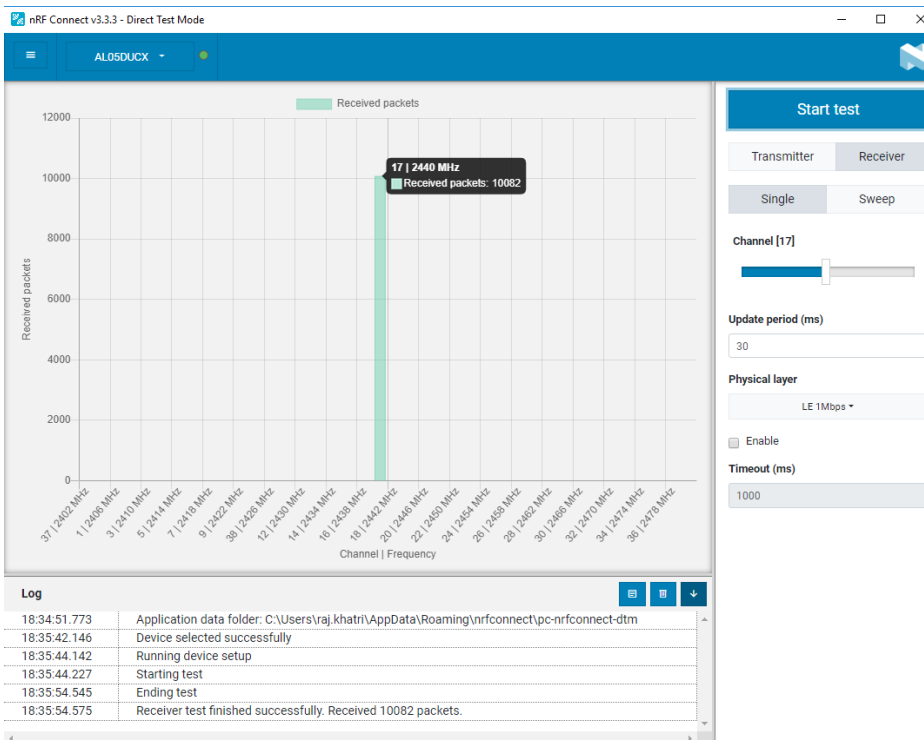


Figure 10: Successful initiation of BLE receiver rest (received packets)

Note: nRF Connect v3.3.3 Direct Test Mode 1.1.2 has a known issue with counting **Received packets** inaccurately. Please look out for a fix from Nordic in upcoming version of nRF Connect Direct Test Mode tool.

5.4 Start Direct Test Mode with nRFgo Studio

nRFgoStudio is a legacy Nordic BT4.0 tool and is mentioned here for completeness. In all cases, it is recommended that Nordic’s **nRF Connect for Desktop Direct Test Mode tool** should be used. Additionally, nRFgoStudio does not allow the BLE data rate to be changed; default is 1Mbps and other PHY data rates such as 2Mbps, coded PHY 500kbps (s=2) and 125kbps (s=8) may not be selected. Also, nRFgoStudio cannot select long packets like 255byte payload.

To begin using Direct Test Mode, follow these steps:

1. Open Nordic nRFgo Studio.
2. In nRFgo Studio, click **Direct Test Mode** in the features panel to open the Direct Test Mode panel as shown in [Figure 11](#).

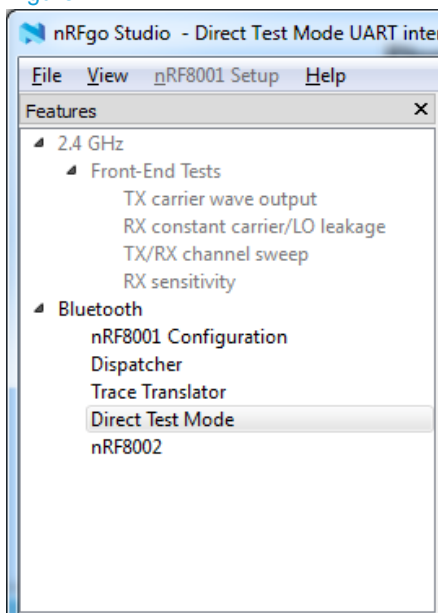


Figure 11: Opening the Direct Test Mode panel

3. From there, you can place the module in constant TX or RX mode. Consult the nRFgo Studio built-in help for more information.

5.2.1 Transmit Test

To conduct a transmit test, configure the options in the Direct Test Mode panel as follows:

COM Port	Same as previous
Mode	Transmit
Channel	19 (2440 MHz)
Payload Model	PRBS9 – If a BLE-modulated TX signal is required -or- Constant Carrier – If a continuous [CW] TX signal is required
Payload Length	37 bytes

Once configured, click **Start Test**. If successful, no errors should show, as illustrated in [Figure 12](#).

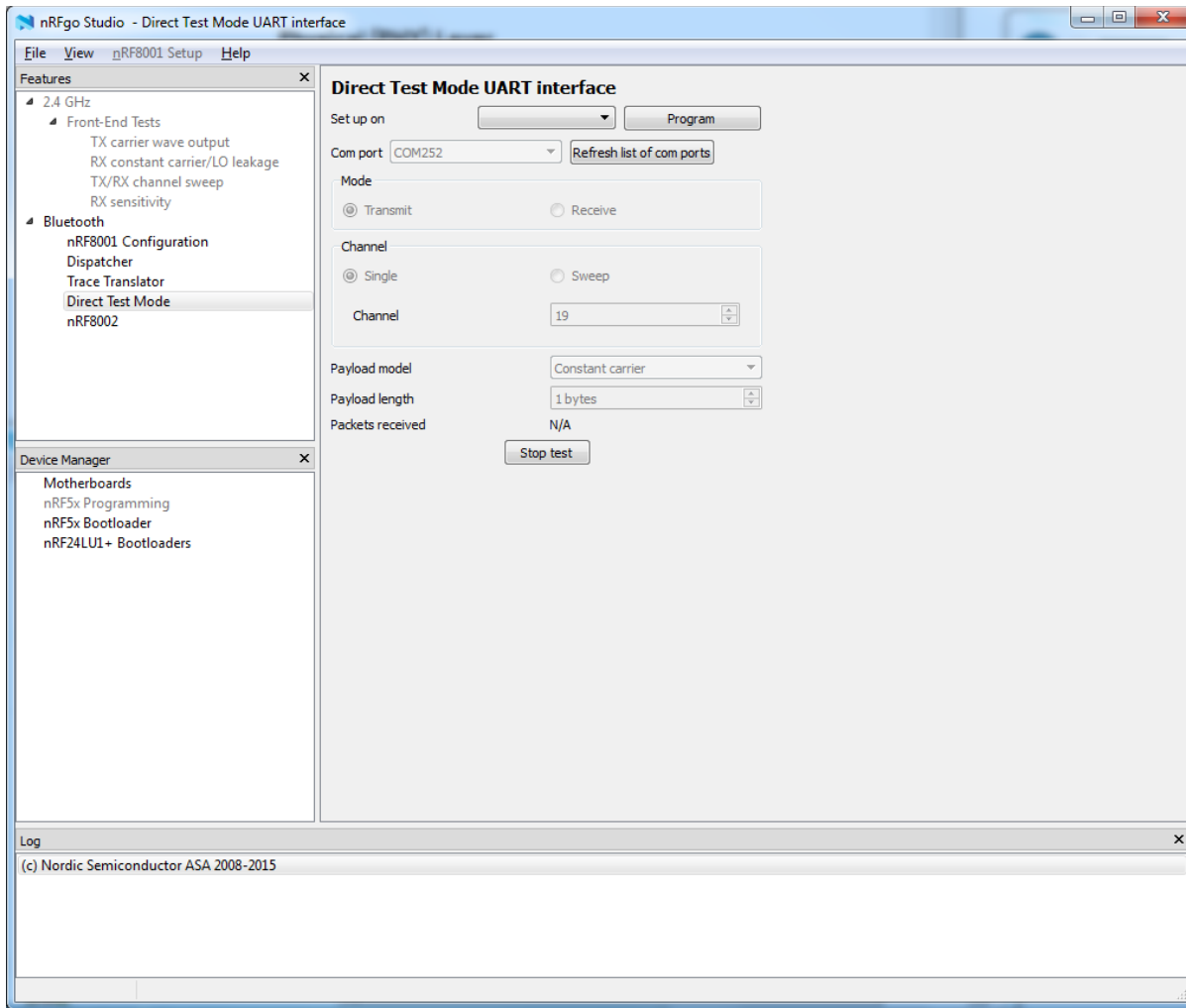


Figure 12: Successful initiation of TX Test

With the module is in a Transmit test, you can measure the signal on a spectrum analyzer.

5.2.2 Receive Test

To conduct a receive test, configure the options in the Direct Test Mode panel as follows:

COM Port	Same as previous
Mode	Receive
Channel	0 (2402 MHz)

Once configured, click **Start Test**. If successful, no errors should show.

Note: Rx Mode produces an RX LO leakage at the following frequency: $2 * f_{Rx} - 1 \text{MHz}$.

6 DTM COMMAND TO PRODUCE CW RF TX SIGNAL

nRF Connect for Desktop (version 1.1.5) Direct Test Mode tool added Constant carrier (sine wave for transmitter signal). Prior to version 1.1.5 of the **nRF Connect for Desktop Direct Test Mode** tool did not have a way to produce continuous wave (CW) RF Transmit signal. One can manually send a DTM command using UwTerminalX to produce continuous wave (CW) RF Transmit signal.

To do this, follow these steps:

1. Open UwTerminalX with the following settings:

COM Port	Same as previous
Baud Rate	19200
Parity	None
Stop Bits	1
Data Bits	8
Handshaking	None

2. Click **OK** to connect.

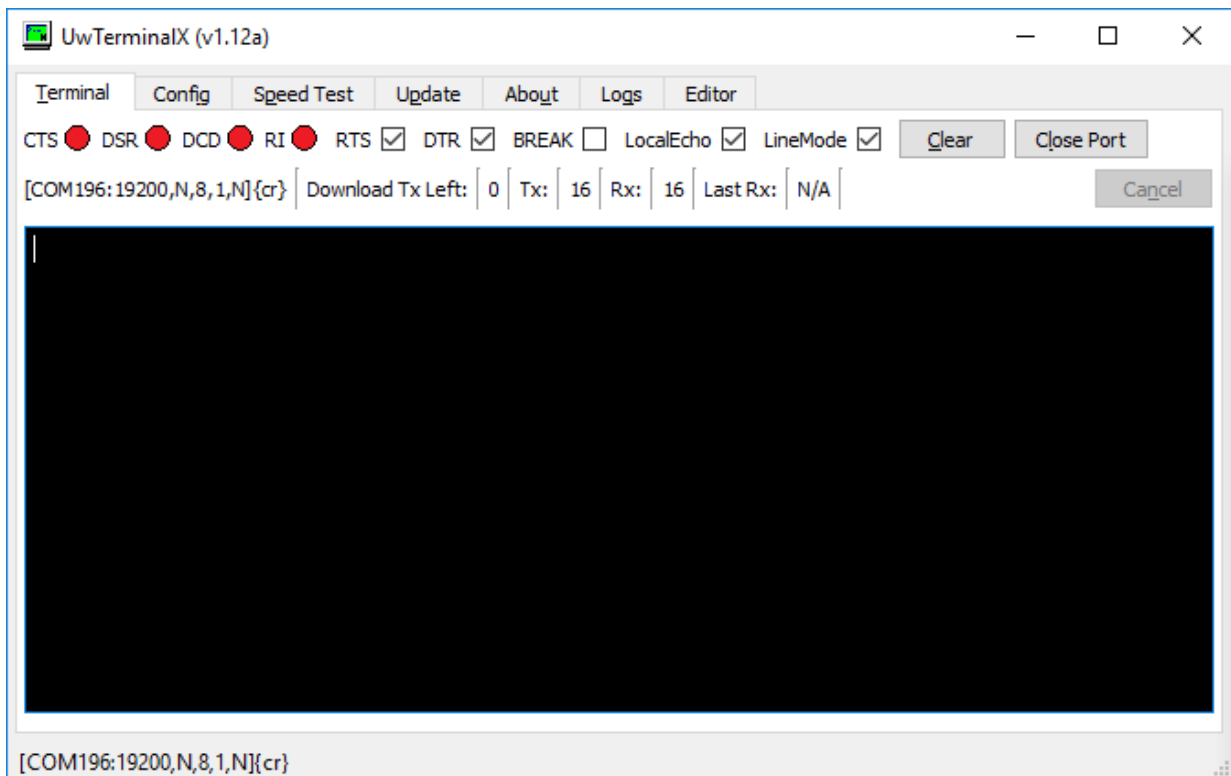


Figure 13: Opened UwTerminalX

3. Right-click the terminal screen and in the context menu, click **Automation**.
4. In the following screen, modify the fields as shown in [Figure 14](#).
 - In the first field, enter **\00\00** (the DTM command for reset)
 - In the second field, enter **\93\00** (the DTM command to produce a CW RF transmit signal) For example, at frequency **2440 MHz**.
 - Tick the box for De-Escape Strings.

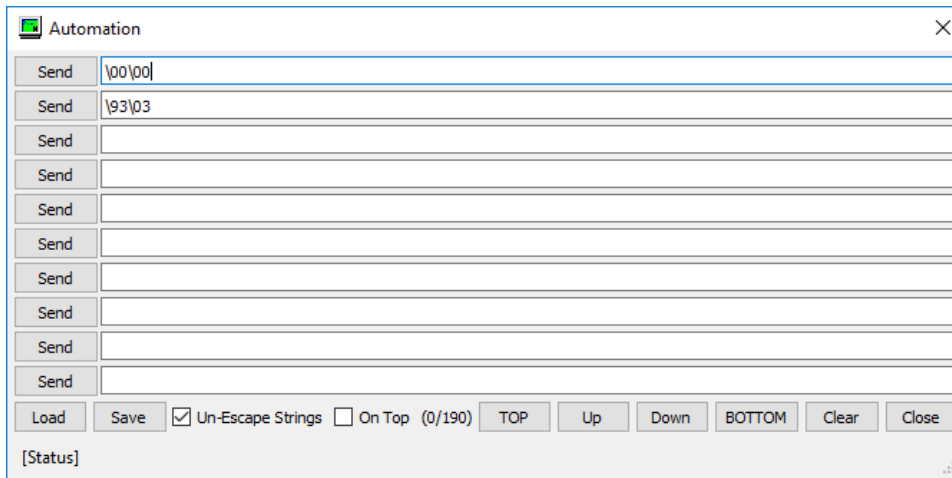


Figure 14: Automation dialogue for entering DTM commands

- Click **Send** to send DTM command `\00\00` for reset (always do this first).
If successful you should get a response back `\00\00`.

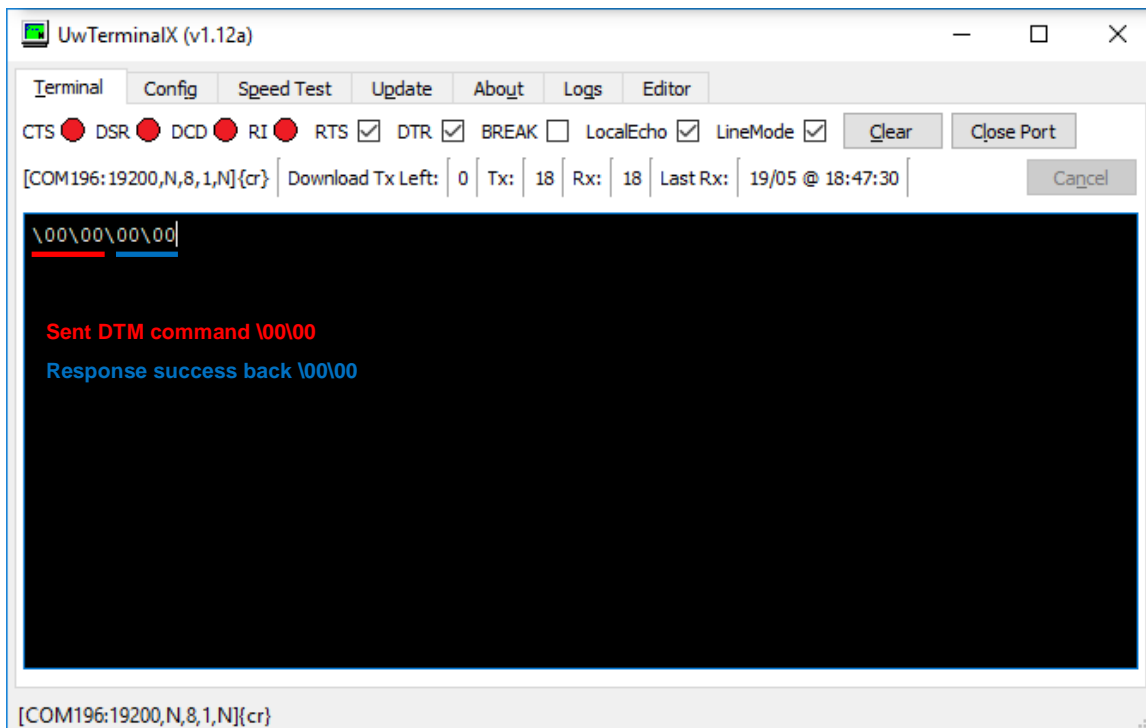


Figure 15: Automation dialogue DTM command `\00\00` for reset and response.

- Click **Send** to send DTM command `\93\00` to produce a CW RF transmit signal at frequency 2440 MHz. If successful, you should get a response back `\00\00`.

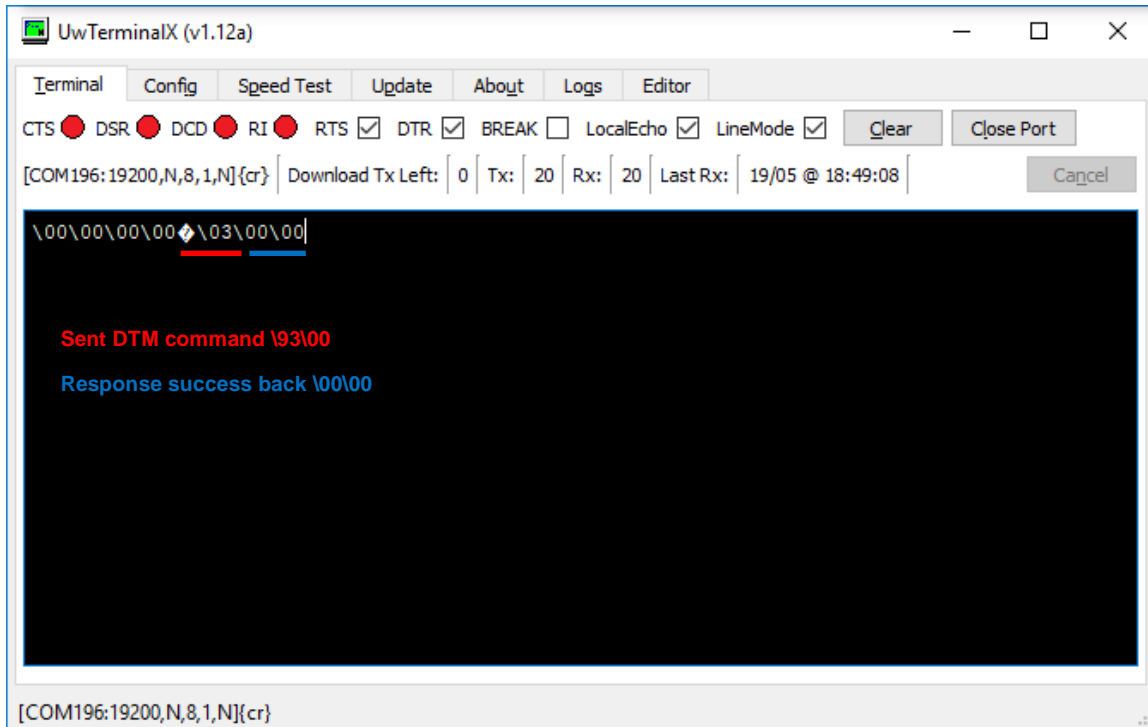


Figure 16: Automation dialogue DTM command \093\00 to produce continuous wave (CW) RF Transmit signal at frequency 2440 MHz and response.

The following table (Table 3) shows the DTM command to produce continuous wave (CW) RF TX signal frequency.

Table 3: DTM command to send for each RF TX frequency to produce a CW RF transmit signal

Continuous Wave RF Transmit Signal Frequency	DTM Command	Continuous Wave RF Transmit Signal Frequency	DTM Command	Continuous Wave RF Transmit Signal Frequency	DTM Command
2402 MHz	\80\03	2430 MHz	\8E\03	2458 MHz	\9C\03
2404 MHz	\81\03	2432 MHz	\8F\03	2460 MHz	\9D\03
2406 MHz	\82\03	2434 MHz	\90\03	2462 MHz	\9E\03
2408 MHz	\83\03	2436 MHz	\91\03	2464 MHz	\9F\03
2410 MHz	\84\03	2438 MHz	\92\03	2466 MHz	\A0\03
2412 MHz	\85\03	2440 MHz	\93\03	2468 MHz	\A1\03
2414 MHz	\86\03	2442 MHz	\94\03	2470 MHz	\A2\03
2416 MHz	\87\03	2444 MHz	\95\03	2472 MHz	\A3\03
2418 MHz	\88\03	2446 MHz	\96\03	2474 MHz	\A4\03
2420 MHz	\89\03	2448 MHz	\97\03	2476 MHz	\A5\03
2422 MHz	\8A\03	2450 MHz	\98\03	2478 MHz	\A6\03
2424 MHz	\8B\03	2452 MHz	\99\03	2480 MHz	\A7\03
2426 MHz	\8C\03	2454 MHz	\9A\03		
2428 MHz	\8D\03	2456 MHz	\9B\03		

7 EXITING DTM MODE

To exit DTM, follow these steps:

1. Open UwTerminalX with the following settings:

COM Port	Same as previous
Baud Rate	19200
Parity	None
Stop Bits	1
Data Bits	8
Handshaking	None

2. Click **OK** to connect.
3. Right-click the terminal screen and in the context menu, click **Automation**.
4. In the following screen, modify the fields as shown in [Figure 17](#).
 - In the first field, enter **\3f\xff**
 - In the second field, enter **\3f\fe** (Note: this command is applicable to BL654 firmware version 29.5.7.2 onwards only).
 - Tick the box for **De-Escape Strings**.
5. To temporarily go back into *smart*BASIC interactive mode (which will go back to DTM mode after a reset or power cycle) click the first **Send** button. To permanently exit DTM mode and return to *smart*BASIC interactive mode, click the second **Send** button (this feature is only available in firmware versions 29.5.7.2 or newer).

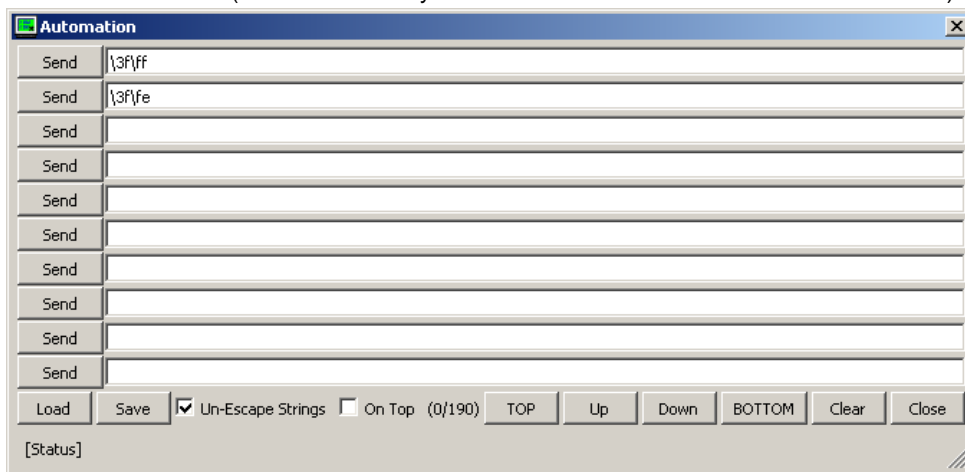


Figure 17: Automation dialogue

6. After this command is complete, close UwTerminalX. Then re-open it and connect to the BL654 with the following default parameters:

COM Port	Same as previous
Baud Rate	115200
Parity	None
Stop Bits	1
Data Bits	8
Handshaking	CTS/RTS

7. Click **OK** to connect.
8. Check that you get a response by pressing **Enter** in the terminal window. You should the following response:

```
00
```


9. You can now change any DTM configuration as desired. You can also query what the current DTM configuration is by using the command **at+dtmcfg X?** where X is the index to query, as specified in the [Configuration of Module Settings \(Optional\)](#) section.
10. If you would like to erase all non-volatile data and the module's file system, enter this command:

```
at&f*
```

The module erases its file system and reboot, as shown in [Figure 18](#).

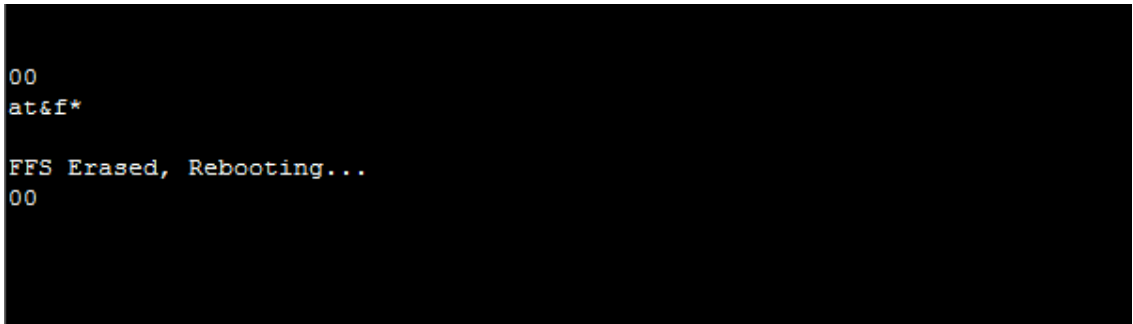


Figure 18: at&f* to erase and reboot module

8 APPENDIX

This section describes how to set a GPIO if necessary while in DTM mode.

8.1 Configuration of Module GPIO Settings (Optional)

GPIO control enable

Command	AT+DTMCFG 5 <i>n</i>
Values for n	0 (Disabled), 1 (enabled)
Default	0

GPIO (0..31) Enable Bitmask

This will be ignored if **AT+DTMCFG 5** is set to 0 (which is the default). If a bit is set then the bit number corresponds to the GPIO number which is enabled.

Command	AT+DTMCFG 6 bitmask
Values for n	0x00000000 to 0xFFFFFFFF (bit 0 is the lowest significant bit)
Default	0

GPIO (0..31) Direction Bitmask

This will be ignored if **AT+DTMCFG 5** is set to 0 (which is the default). If a bit is set then the bit number corresponds to the GPIO number will have the direction input when the bit is 0 and an output when the bit is 1.

Command	AT+DTMCFG 7 bitmask
Values for n	0x00000000 to 0xFFFFFFFF (bit 0 is the lowest significant bit)
Default	0

GPIO (0..31) State Bitmask

This will be ignored if **AT+DTMCFG 5** is set to 0 (which is the default). If a bit is set then the bit number corresponds to the GPIO number will have the output set to this value if DTMCFG 7 was used to set the direction as output.

Command	AT+DTMCFG 8 bitmask
Values for n	0x00000000 to 0xFFFFFFFF (bit 0 is the lowest significant bit)
Default	0xFFFFFFFF

GPIO (32..47) Enable Bitmask

This will be ignored if **AT+DTMCFG 5** is set to 0 (which is the default). If a bit is set then the bit number corresponds to the GPIO number which is enabled.

Command	AT+DTMCFG 16 bitmask
Values for n	0x0000 to 0xFFFF (bit 0 is the lowest significant bit)
Default	0

GPIO (32..47) Direction Bitmask

This will be ignored if **AT+DTMCFG 5** is set to 0 (which is the default). If a bit is set then the bit number corresponds to the GPIO number will have the direction input when the bit is 0 and an output when the bit is 1.

Command	AT+DTMCFG 17 bitmask
Values for n	0x0000 to 0xFFFF (bit 0 is the lowest significant bit)
Default	0

GPIO (32..47) State Bitmask

This will be ignored if **AT+DTMCFG 5 is set to 0** (which is the default). If a bit is set then the bit number corresponds to the GPIO number will have the output set to this value if DTMCFG 7 was used to set the direction as output.

Command	AT+DTMCFG 18 bitmask
Values for n	0x0000 to 0xFFFF (bit 0 is the lowest significant bit)
Default	0xFFFFFFFF

9 REVISION HISTORY

Version	Date	Notes	Contributor(s)	Approver
1.0	25 June 2018	Initial Release	Raj Khatri	Jonathan Kaye
1.1	2 Oct 2019	Updated with new DTMCFG keys	Mahendra Tailor	Jonathan Kaye
1.2	18 Jan 2021	Updated with DCDC REG0, clear DTM config and firmware 29.5.7.2 workaround	Jamie Mccrae	Jonathan Kaye
1.3	21 July 2021	Added 5.3 Nordic nRF Connect Direct Test Mode tool TX and RX Tests and removed Laird Connectivity BleDtmRfTool . Added note for at+dtmcfgr X. Added section 6 DTM Command to Produce CW RF TX Signal .	Raj Khatri	Jonathan Kaye