Using Direct Test Mode

Pinnacle 100

Application Note *v1.0*

1 Introduction

The Pinnacle 100 has a special firmware which 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*, accessible from the following link: www.bluetooth.com/specifications/bluetooth-core-specification

The purpose of DTM is to test the radio operation 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 RFCreations Moreph30, Anritsu MT8852, or similar) with the Pinnacle 100 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 Pinnacle 100 radio testing using the Direct Test Mode (DTM) firmware and Nordic nRF Connect for Desktop Direct Test Mode tool.

- Loading DTM firmware to Pinnacle 100
- Entering DTM mode on the Pinnacle 100
- Using Nordic nRF Connect for Desktop Direct Test Mode tool to BLE radio test the Pinnacle 100 in either BLE transmit or BLE receive mode
- How to manually send DTM command (via UwTerminalX) to produce continuous wave [CW] RF TX signal
- Restoring Pinnacle 100 to default state

2 Requirements

To use DTM, you need the following:

- Pinnacle 100 development board
- PC (Windows 7/Linux/Mac supported, this guide is based on and was tested with Windows 10)
- Pinnacle 100 DTM firmware (available from Downloads on https://www.lairdconnect.com/wireless-modules/cellular-solutions/pinnacle-100-modem)
- UwTerminalX (available at https://github.com/LairdCP/UwTerminalX/releases)
- *For UART Flashing*: UwFlashX (available at https://github.com/LairdCP/UwFlashX/releases)
- *For JLINK Flashing:* nRF command line tools (available at https://www.nordicsemi.com/Software-and-tools/Development-Tools/nRF-Command-Line-Tools/Download#infotabs)
- 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) can be downloaded from https://www.nordicsemi.com/Software-and-tools/Development-Tools/nRF-Connect-for-desktop/Download#infotabs

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Note: Please install the correct version for your operating system.

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3 SETUP

We assume the Pinnacle 100 development kit has its default out-of-the-box settings. In this mode, it is in bootloader mode on power up. A USB cable must be connected between the PC and development board to the FTDI USB port.

3.1 Restoring to Factory Defaults

This guide assumes that the Pinnacle 100 module being used for loading the DTM firmware to has the Laird Connectivity bootloader programmed on it and that it may have had some development use. If the module has not been used then it does not need to be restored to factory defaults, continue to the Programming DTM Firmware section.

To restore the Pinnacle 100 to factory defaults:

1. Open UwTerminalX.
2. From the Config tab, in the device drop down list, select BL65x to populate the default communications settings.
3. Select the correct COM port.

   If you cannot select *BL65x,* manually select the following UART settings (shown in **Error! Reference source not found.**):

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

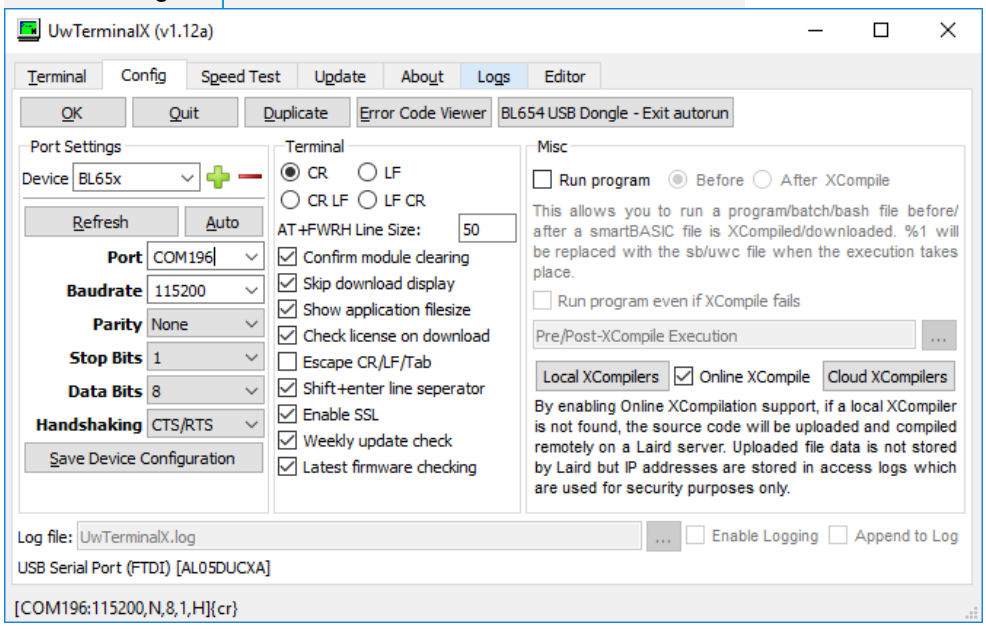

Figure 1: UwTerminalX settings

4. Click **OK** to connect.
5. Hold down SW1 on the Pinnacle 100 development board and momentarily press the NRF_RESET button, after 2 seconds, release the SW1 button
6. CTS should be showing as green in UwTerminalX
7. Press M and enter in UwTerminalX, the module should respond with the version of the bootloader, similar to:

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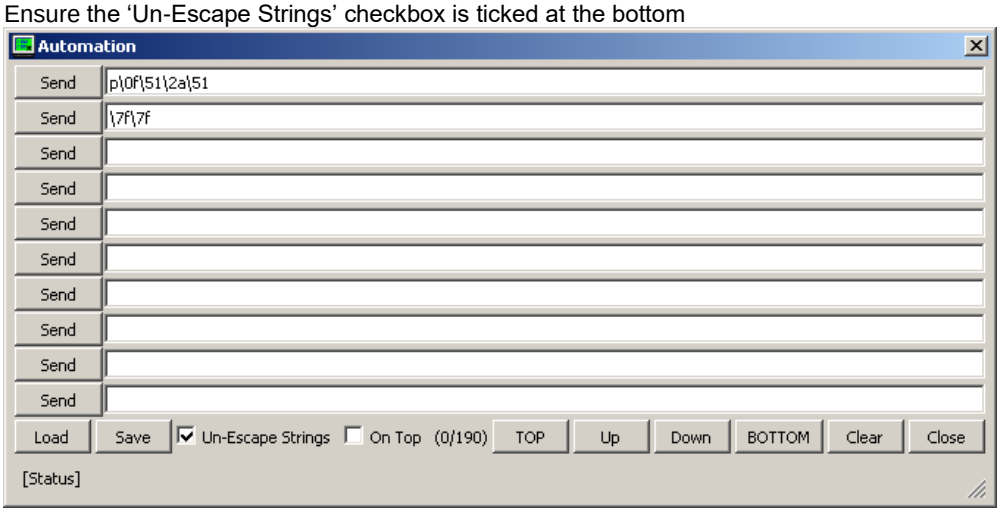
```
Model: 124, Variant: 0, Name: PINNACLE100, Bootloader version: 3 (FUP: 6.011, Ext.
struct: 1, Ext. function: 2)
```

8. Right click on the terminal window and select 'Automation'
9. In the first input box, put this data: p\0f\51\2a\51
10. In the second input box, put this data: \7f\7f
11. Ensure the 'Un-Escape Strings' checkbox is ticked at the bottom



12. Click the first send button, the module should respond with an 'a', if the module responds with an 'f and a hex escape character then check you are communicating with a Pinnacle 100.
13. Click the second send button, this starts the restore to factory defaults process which can take 2-5 minutes and will respond with an 'a' once complete. if the module responds with an 'f and a hex escape character then there was an error restoring the module to factory defaults.
14. The module is now restored to factory defaults.

4 Programming DTM Firmware

The DTM firmware for the Pinnacle 100 is provided in ubu format (which can be loaded over UART using UwFlashX) and in hex format (which can be loaded over SWD/JLINK)

4.1 UwFlashX Programming

To program the DTM firmware using UwFlashX:

1. If UwTerminalX is open on the serial port of the Pinnacle 100, close the port before continuing.
2. Open UwFlashX.
3. Click the '…' button on the right-hand side and select the DTM ubu firmware upgrade file you obtained from the Laird Connectivity website
4. Select the serial port of the Pinnacle 100 from the port drop down menu
5. As the Pinnacle 100 does not have a firmware loaded, no bootloader entrance method is required, ensure that the entrance method is set to none.

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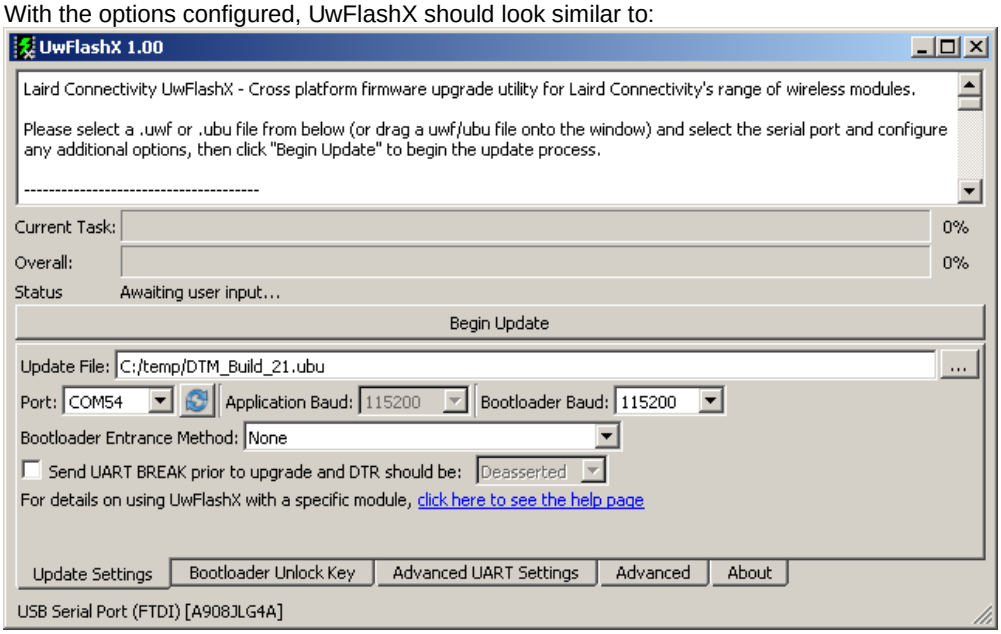
6. With the options configured, UwFlashX should look similar to:



7. Click the 'Begin Update' button to transfer the DTM firmware to the Pinnacle 100 (this process takes about 18 seconds when using a baud rate of 1M).
8. Once finished, close UwFlashX, the DTM firmware is loaded.

4.2 SWD Programming

To program the DTM firmware using SWD/nrfjprog, follow these steps:

1. Ensure there is a USB connection from the PC to the Pinnacle 100 development board to the JLINK USB port and that the ATMEL SUPPLY switch is in the ON position and the DEBUG SELECT switch is in the INT position.
2. Open a terminal or console in the directory in which the firmware hex file resides.
3. Ensure that the Nordic nRF command line tools are in your path. If they are not, add them.
4. Flash the hex file to the module and begin execution using the following command (replacing <file.hex> with the name of the hex file):
   `nrfjprog -f NRF52 --program <file.hex> --sectorerase --qspisectorerase --reset`

   The application outputs the progress of downloading the application to the module and resets the Pinnacle 100 after it is programmed.
5. The module automatically resets and the bootloader performs the requested firmware update. This may take up to two minutes but is typically much faster. The green LED on the Pinnacle 100 development board (LED4) will blink to indicate that the firmware upgrade is in progress.
6. The process is complete, close the terminal or console, the DTM firmware is loaded.

5 Entering DTM

To enter DTM, follow these steps:

1. Open UwTerminalX.
2. In the device drop down, select BL65x to populate the default communications settings.
3. Select the correct COM port.

   If you cannot select *BL65x,* manually select the following UART settings (shown in **Error! Reference source not found.**):

COM Port	Port corresponding to your development kit

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Baud Rate	115200
Parity	None
Stop Bits	1
Data Bits	8
Handshaking	CTS/RTS

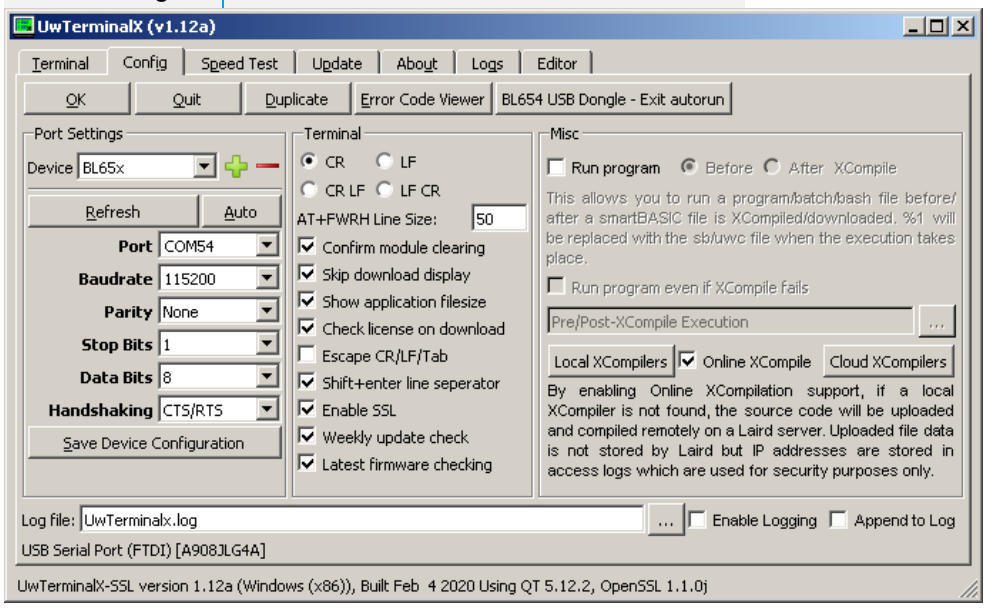

Figure 2: UwTerminalX settings

4. Click **OK** to connect.

5.1 DTM configuration (optional)

Before entering DTM Mode, you may optionally configure TX power, baud rate, crystal, GPIO and DCDC status. Changing these values is optional. If no options need to be set, continue to the Entering DTM section, however, if you choose, you may set these values as follows:

TX RF Power (dBm)

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 (bps)

Command	AT+DTMCFG 2 *n*
Values for n	9600, 14400, 19200, 38400, 57600, 115200, 230400, 460800, 921600, 1000000
Default	19200

DCDC (REG1)

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

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Enable 32KHz Crystal based LF Clock

Command	AT+DTMCFG 4 *n*
Values for n	0 (Disabled), 1 (enabled)
Default	1

DCDC (REG0)

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

Enable 32MHz Crystal based HF Clock

Command	AT+DTMCFG 19 *n*
Values for n	0 (Disabled), 1 (enabled)
Default	1

Refer to the APPENDIX, for setting a GPIO if it needs to be set for some particular purpose whilst in DTM mode.

5.2 Entering DTM

1. Set up the module into Direct Test Mode. You must 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 **Error! Reference source not found.**, they are C8AE and 5584.

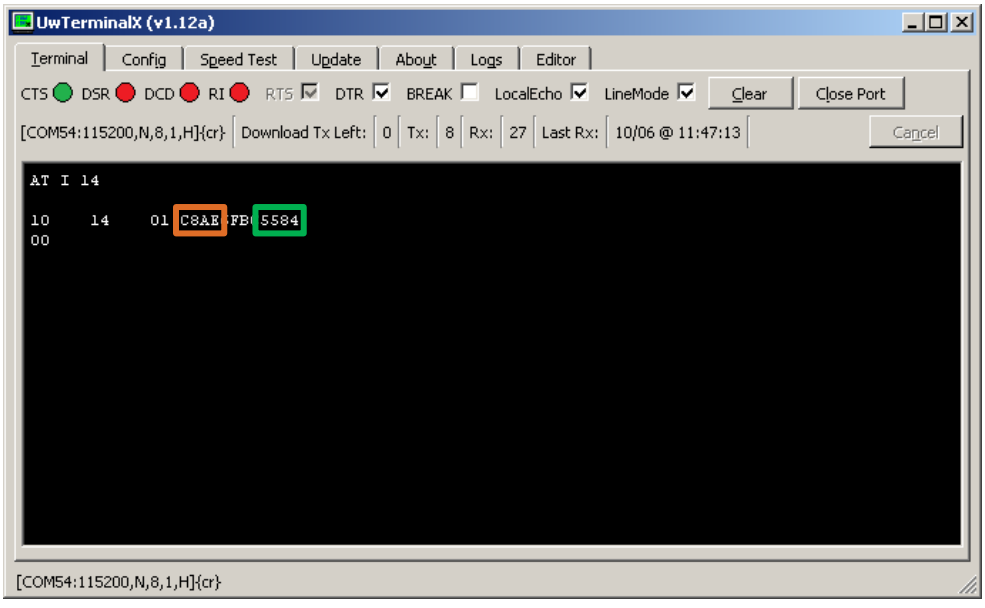

Figure 3: Return from AT I 14

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

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```
AT+DTM 0xC8AE5584
```

The module is now in Direct Test mode.

3. Click **Close Port** to disconnect the module from UwTerminalX.

6 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.

To use Direct Test Mode, you need Nordic's **nRF Connect Direct Test Mode** tool. Once the Pinnacle 100 is in DTM mode, you can communicate with the module 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

6.1 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 6.

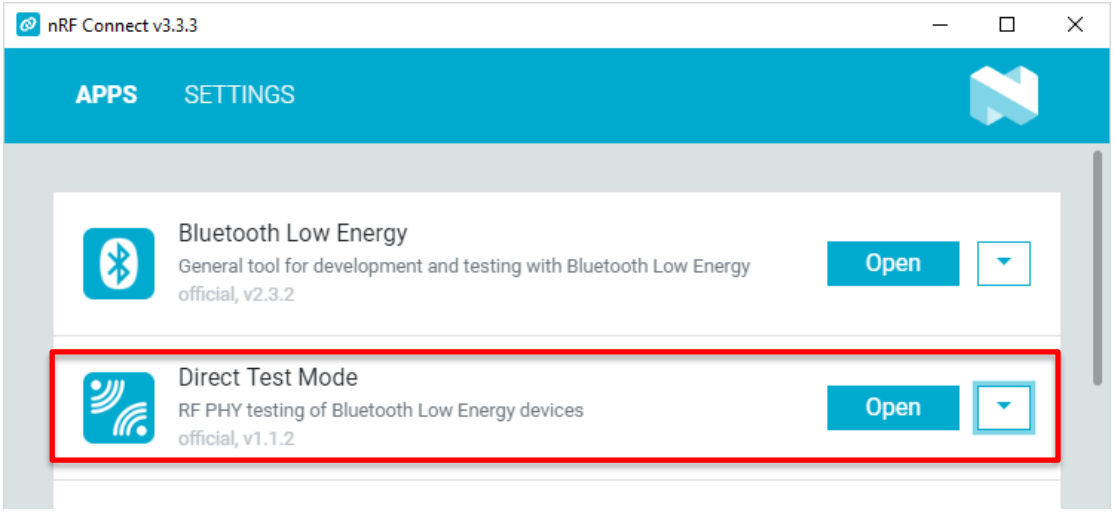

Figure 4: Click Open in Direct Test Mode

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

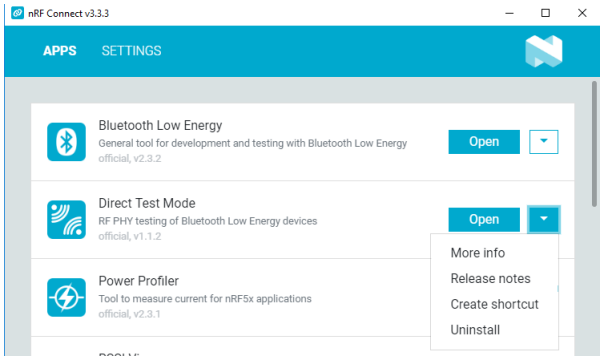

Figure 5: Access release notes and more information

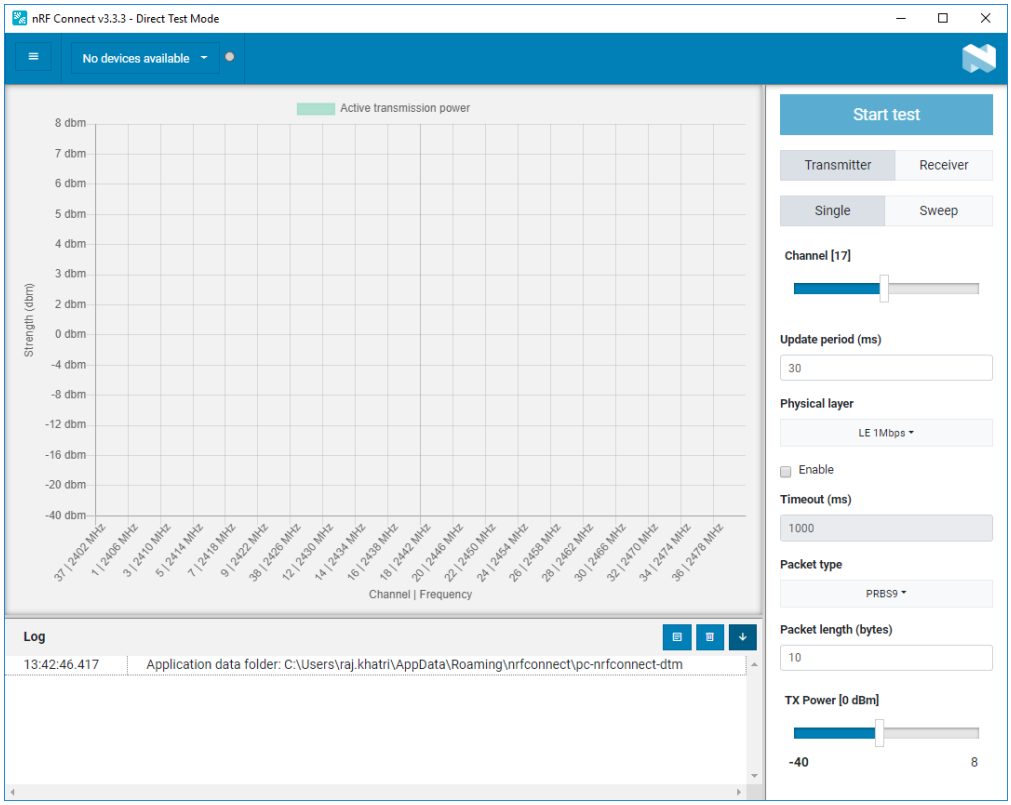

Figure 6: Opening the Nordic nRF Connect Direct Test Mode tool

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

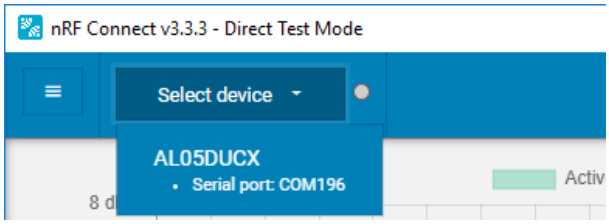

Figure 7: Device selection

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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.

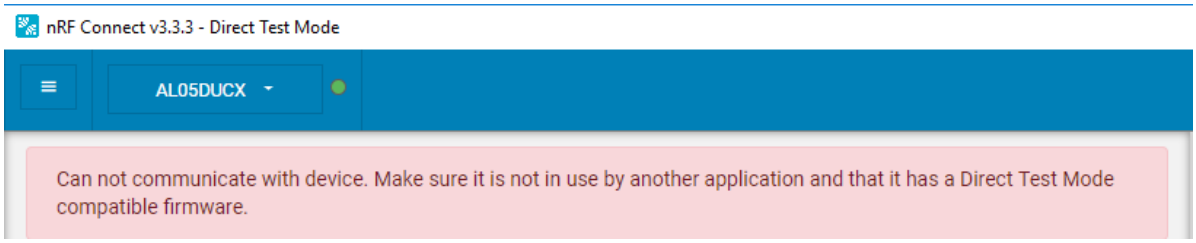

Figure 8: Unexpected behavior when opening or running the Nordic nRF Connect for Desktop Direct Test Mode tool

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

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).

6.2.1 Transmit Test

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 *LE 1 Mbps* (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.
Packets Type	**Packet Type Value** / **Description** PRBS9 / PRBS9 Packet Payload (Pkt Type 00) 11110000 / 11110000 Packet Payload (Pkt Type 01) 10101010 / 10101010 Packet Payload (Pkt Type 10) TBD / Vendor-specific (Pkt Type 11) Currently Nordic nRF Connect for Desktop Direct Test Mode tool does 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* for additional information on how to do this.
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**.

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2. Once configured, click **Start test**. Figure 8 shows an active BLE transmitter test.

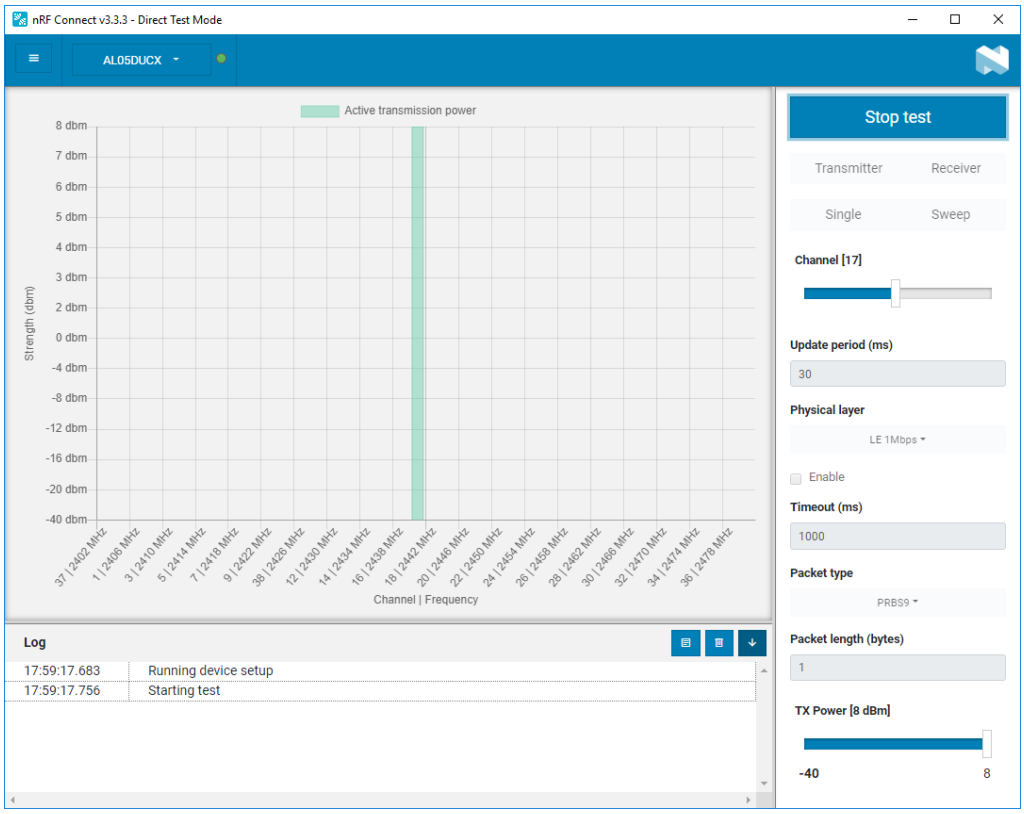

Figure 8: Successful initiation of BLE transmitter test

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.*

6.2.2 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*f_{Rx})-1MHz**.

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2. Once configured, to start Receiver test, click **Start test**. Figure 9 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.

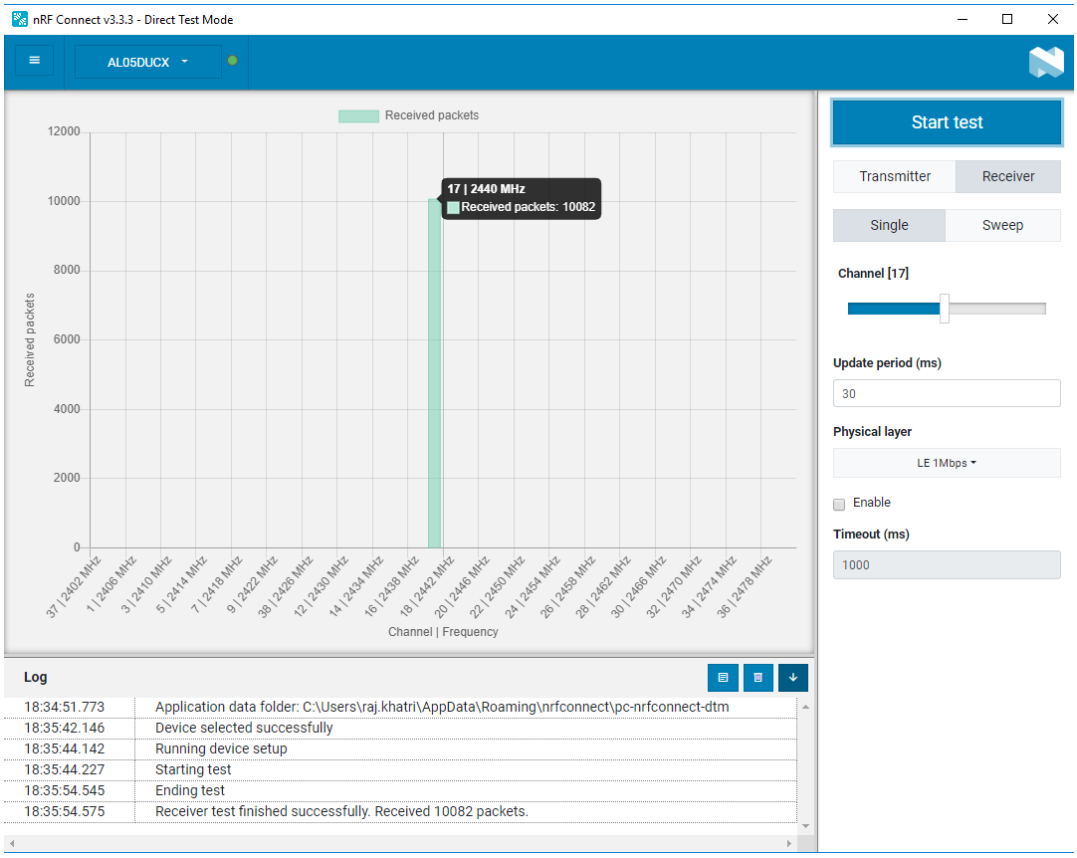

Figure 9: Successful initiation of BLE receiver rest (received packets)

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.

7 DTM Command to Produce CW RF TX Signal

nRF Connect for Desktop Direct Test Mode tool currently (20 May 2020) does not have a way to produce continuous wave (CW) RF Transmit signal. You can send a DTM command manually 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

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2. Click **OK** to connect.

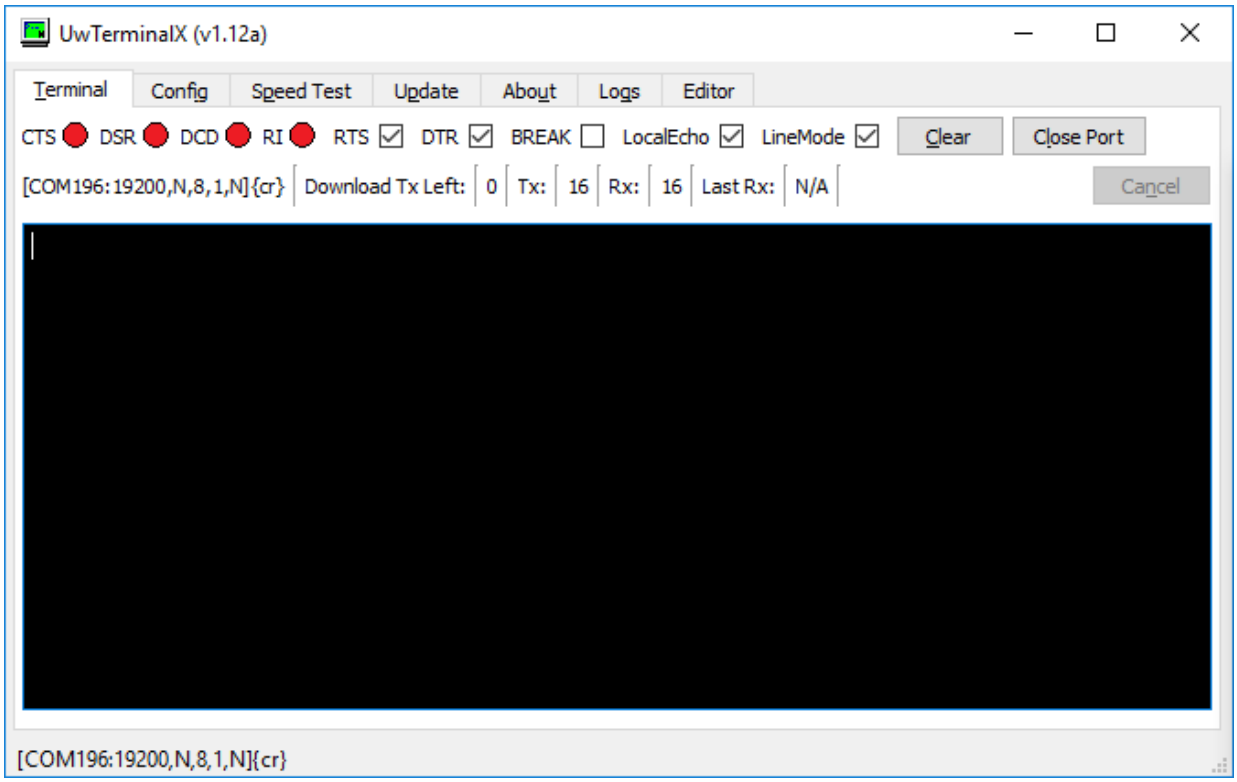

Figure 10: Opened UwTerminalX

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 11.
   - 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**.**

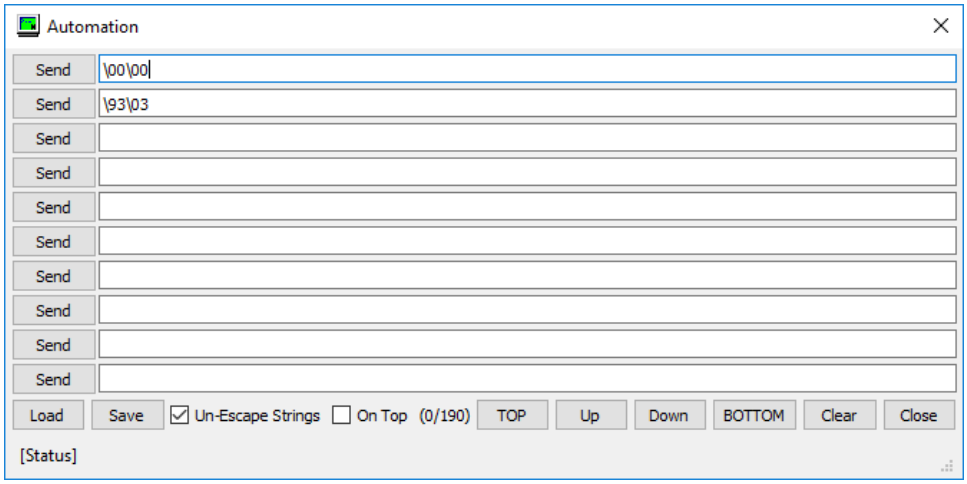

Figure 11: Automation dialogue for entering DTM commands

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5. Click **Send** to send DTM command **\00\00** for reset (always do this first).

   If successful you should get a response back \00\00.

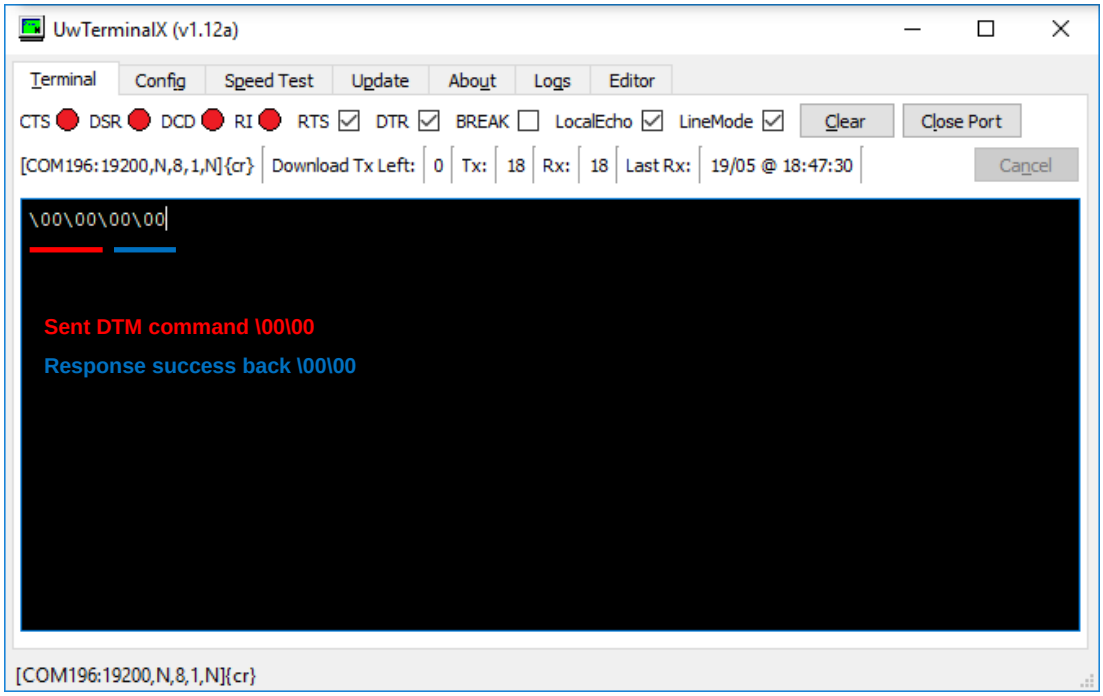

Figure 12: Automation dialogue DTM command** \00\00 **for reset and response.

6. 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.

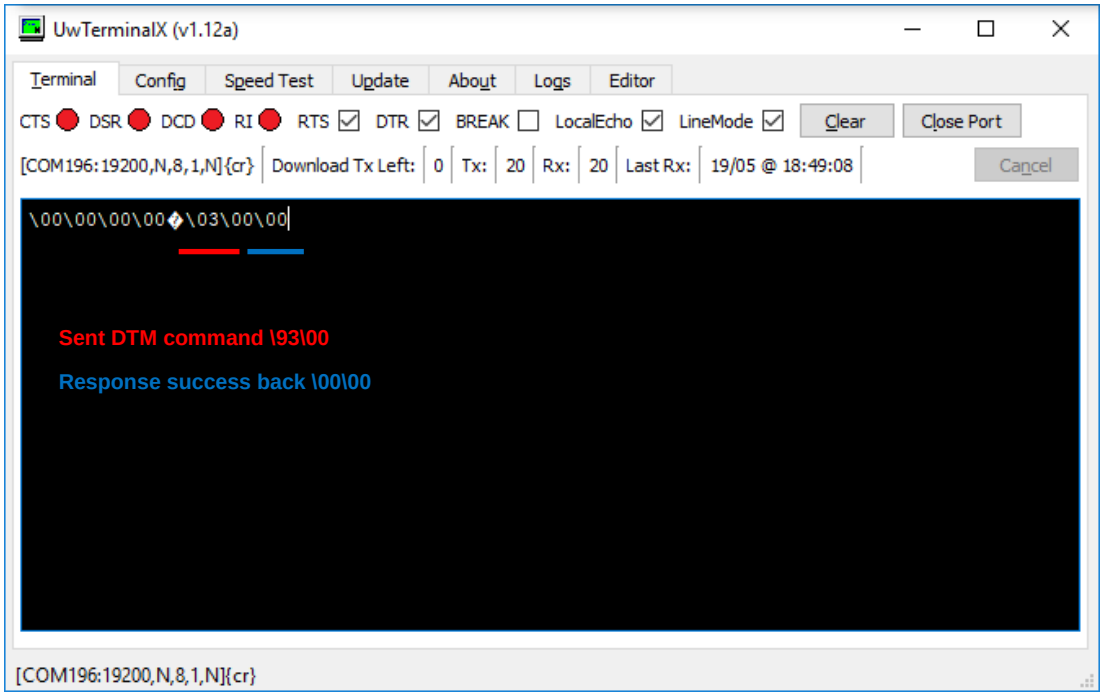

Figure 13: Automation dialogue DTM command \93\00 to produce continuous wave (CW) RF Transmit signal at frequency 2440MHz and response.

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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\00	2430 MHz	\8F\00	2458 MHz	\9C\00
2404 MHz	\81\00	2432 MHz	\90\00	2460 MHz	\9D\00
2406 MHz	\82\00	2434 MHz	\91\00	2462 MHz	\9E\00
2408 MHz	\84\00	2436 MHz	\92\00	2464 MHz	\9F\00
2410 MHz	\85\00	2438 MHz	\93\00	2466 MHz	\A0\00
2412 MHz	\86\00	2440 MHz	\94\00	2468 MHz	\A1\00
2414 MHz	\87\00	2442 MHz	\94\00	2470 MHz	\A2\00
2416 MHz	\88\00	2444 MHz	\95\00	2472 MHz	\A3\00
2418 MHz	\89\00	2446 MHz	\96\00	2474 MHz	\A4\00
2420 MHz	\8A\00	2448 MHz	\97\00	2476 MHz	\A5\00
2422 MHz	\8B\00	2450 MHz	\98\00	2478 MHz	\A6\00
2424 MHz	\8C\00	2452 MHz	\99\00	2480 MHz	\A7\00
2426 MHz	\8D\00	2454 MHz	\9A\00		
2428 MHz	\8E\00	2456 MHz	\9B\00		

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8 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 14.
5. In the first field, enter **\3F\FF**.
6. Tick the box for **De-Escape Strings.**
7. Click **Send**.

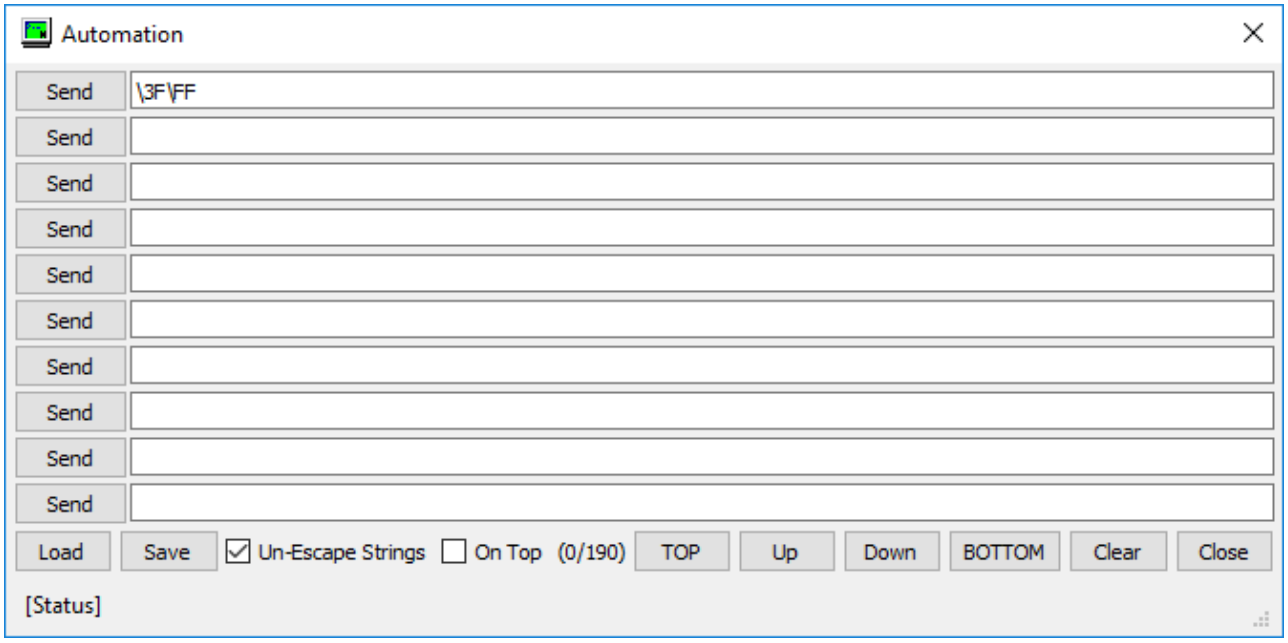

Figure 14: Automation dialogue

8. After this command is complete, close UwTerminalX. Then re-open it and connect to the Pinnacle 100 with the following default parameters:

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

9. Click **OK** to connect.

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10. Check that you get a response by pressing **Enter** in the terminal window. You should the following response:

```
00
```

11. Issue the following command to erase non-volatile data and the module's file system:

```
at&f*4
```

The module erases its DTM configuration and reboots, as shown in Figure 15.

Figure 15: at&f* to erase DTM configuration and reboot module

12. At this point, DTM settings can be changed if required, or if an alternative firmware is to be loaded then the module will need to be restored to factory defaults by following the Restoring to Factory Defaults section. After restoring to factory defaults, a new firmware may be loaded via UwFlashX or SWD.

9 APPENDIX

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

9.1 Configuration of Module GPIO Settings (Optional)

GPIO control enable

Command	AT+DTMCFG 5 *n*
Values for n	0 (Disabled), 1 (enabled)
Default	1

GPIO (0..31) Enable Bitmask

This will be ignored if AT+DTMCFG 5 is set to 0 (which is not 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	0x01006000

GPIO (0..31) Direction Bitmask

This is ignored if AT+DTMCFG 5 is set to 0 (which is not the default). If a bit is set, then the bit number that corresponds to the GPIO number has 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	0x01006000

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GPIO (0..31) State Bitmask

This is ignored if AT+DTMCFG 5 is set to 0 (which is not the default). If a bit is set, then the bit number that corresponds to the GPIO number has the output set to this value if DTMCFG 7 was used to set the direction as output; or enables a pull-up resistor if the bit is set and DTMCFG 7 is used to set the direction as input.

Command	AT+DTMCFG 8 bitmask
Values for n	0x00000000 to 0xFFFFFFFF (bit 0 is the lowest significant bit)
Default	0xFEFF9FFF

GPIO (32..47) Enable Bitmask

This is ignored if AT+DTMCFG 5 is set to 0 (which is not 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	0xE004

GPIO (32..47) Direction Bitmask

This is ignored if AT+DTMCFG 5 is set to 0 (which is not the default). If a bit is set, then the bit number that corresponds to the GPIO number has 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	0xE004

GPIO (32..47) State Bitmask

This is ignored if AT+DTMCFG 5 is set to 0 (which is not the default). If a bit is set, then the bit number that corresponds to the GPIO number has the output set to this value if DTMCFG 7 is used to set the direction as output; or enables a pull-up resistor if the bit is set and DTMCFG 7 is used to set the direction as input.

Command	AT+DTMCFG 18 bitmask
Values for n	0x0000 to 0xFFFF (bit 0 is the lowest significant bit)
Default	0x1FFB

10 Revision History

Version	Date	Notes	Contributor(s)	Approver
1.0	25 Jun 2020	Initial Release	Raj Khatri, Jamie Mccrae	Jonathan Kaye

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