

# Sapphire User Manual V4.0

An RF tester for the *Bluetooth*® 5.2 LE standard, compatible with TLF3000.

January 5, 2021

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## 2 Overview.

*TLF3000* is a wideband, ultra-high dynamic range 2.4GHz software-defined receiver, signal analyser and signal generator. It captures and analyses the entire 2402-2480MHz band simultaneously. It can also generate arbitrary waveforms occupying the band 2395-2485MHz with a maximum peak level of 0dBm. Additionally, it includes a CW signal generator covering 25MHz to 6GHz with an output level of -50dBm to -28dBm

*Sapphire* is a *Bluetooth* 5.2 LE application for the *TLF3000* software-defined receiver, signal analyser and signal generator. The *Sapphire* application can:

1. Perform all Phy level tests as specified in Bluetooth 5.2 LE RF Phy Test Specification (RF-PHY.TS.p15) (with minor restrictions). Testing beyond the limits of the specification is also supported.
2. Act as a signal generator, creating all necessary signals for receiver testing including signals outside the specification as well as continuous tone extension data for AoA/AoD testing. For AoD testing an antenna array can either be simulated by the *TLF3000* or an external array can be switched by the *TLF3000*. In addition, the IQ samples received by the DUT can be displayed. Signals as weak as -120dBm can be generated for testing long range modes.
3. Act as a signal analyser, performing transmitter tests on conducted or off-air signals without knowledge of the payload format or hopping sequence. Test coverage includes AoA/AoD continuous tone extension data.
4. Generate advertising or scan request packets to provoke activity from items on a production line for which there is no direct test mode access and analyse the captured packets.
5. Act as a production tester, supporting the simultaneous testing of up to 32 DUTs. When testing multiple DUTs, the quick transmit tests are performed in series whilst the much longer receiver tests (including AoA/AoD tests) are performed in parallel, thus achieving a dramatic reduction in test time.

The application has been honed for speed. The ability to perform in-band emission tests over the entire 2.4GHz band in just a few milliseconds is particularly impressive. This is possible due to *TLF3000's* unique parallel architecture.

A key feature of the unit is its ability to perform C/I, receiver selectivity and intermodulation tests without the need for additional test equipment. This is possible due to *TLF3000's* ultra-linear wideband signal generator. This permits both wanted and interfering signals to be generated through the same signal path. The high linearity and low noise floor ensure that there is ample dynamic range to encompass both the wanted and interfering signals. Furthermore, high fidelity filtering of the interfering signals ensures that they are correctly bandlimited and that unwanted sidebands are not responsible for test failures; this is frequently overlooked when external test equipment is used to provide these signals. The single signal path also removes the need for time consuming and laborious calibration of signal combiners as well as eliminating the need to ensure that the injected interfering and wanted signals do not generate intermodulation products before arriving at the DUT.

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Unique to *TLF3000* is a 25MHz to 6GHz signal generator. This enables the majority of the receiver blocking performance to be explored prior to committing the DUT for formal inspection at a test house with its associated costs.

The Sapphire application is highly parameterised, permitting it to be configured for different scenarios. For example:

1. The unit will function with arbitrary access addresses, allowing multiple devices to be tested simultaneously without crosstalk.
2. The unit may be controlled directly from a host machine via USB or Ethernet, or operated stand-alone with digital IO used to start, stop and report test results.
3. The DUT may be controlled directly from the unit or via a common host platform.

### 3 Control.

#### 3.1 Overview

Sapphire can be controlled in a number of ways:

Control method	Interface		
	USB	Ethernet	Digital IO
Sapphire GUI	✓	✓	
C dll	✓	✓	
Python API	✓	✓	
LabView	✓	✓	
Standalone			✓

*Table 1: Methods of Controlling Sapphire*

#### 3.2 Sapphire GUI

A GUI is shipped with the developer version of the Sapphire application. This permits the application to be controlled via a host running Windows, Linux or OS X. The GUI connects to the *TLF3000* either over USB or Ethernet. The GUI exposes the majority of the Sapphire functionality.

The GUI may also be used to generate test script files in a format which can be used by the other APIs.

#### 3.3 C dll

A C dll is available which provides the basis for accessing the Sapphire application from a wide range of high-level languages. For example, the dll may be called from C++ for imported into MatLab. Besides low-level access to the Sapphire functionality, the C dll also provides high level calls which will automatically run test scripts and generate results files in html, csv or ascii text formats. Example C++ scripts are available to demonstrate how to control the Sapphire application via the C dll. Both 32bit and 64bit versions of the C dll are supported.

#### 3.4 Python API

A Python API is available for controlling the Sapphire application. This is available in both 32bit and 64bit formats. The Python API can be provided for the customer's choice of Python version. Example scripts are available for running test scripts, controlling the signal generating, working with the signal analyser and using the advertise/scan mode.

#### 3.5 LabView

Example LabView code is available which imports the C dll and uses it to run test scripts which generate reports in either html, csv or ascii text. It provides the ability for the reports to be automatically customised with the customer's logo or other information.

#### 3.6 Standalone

By placing the Sapphire image on a USB memory stick and attaching it to the *TLF3000* USB port, it is possible to run Sapphire without the need for a host computer. In this mode of operation, the test

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script to be executed is contained on the USB memory stick. Control of Sapphire is accomplished by toggling digital IO and pass/fail results are communicated back by Sapphire setting digital IO.

## 4 Operating Modes.

### 4.1 Overview

Sapphire has five operating modes:

Mode	DUT control	Test control	Tx Test	Rx Test
Phy layer	Serial	Script	✓	✓
Signal generator	Serial	User		✓
Signal analyser	Serial	User	✓	
Advertise/Scan	RF	User	✓	✓
Standalone	Serial	Digital IO	✓	✓

*Table 1: Sapphire operating modes overview.*

### 4.2 Phy layer tester

The Phy layer mode executes tests in accordance with the Bluetooth 5.2 LE RF Phy Test Specification. The tests to be performed are entered into a script which is then executed by Sapphire. The DUTs are automatically controlled by Sapphire via a serial interface. Test reports, including graphics, can be generated in html, csv or ascii text format.

All tests are fully parameterised, permitting exploration of margin against the Bluetooth 5.2 LE RF Phy Test Specification or datasheet figures.

### 4.3 Signal Generator

The signal generator mode permits manual control over all the signal sources used in the Bluetooth 5.2 LE RF Phy Test Specification. Any combination of the following signals can be generated simultaneously:

1. Packetised LE test signal, including a CTE
2. GFSK modulated interferer signal which may be either continuous or packetised
3. Up to two in-band CW signals
4. In-band AWGN (2395MHz to 2485MHz)
5. Out-of-band CW signal.

All signal sources are fully parameterised.

The signal generator is also able to control a single DUT over a serial interface. This permits the signal generator to interactively report the PER of the DUT. In addition, the signal generator can read back CTE IQ samples from the DUT and display these to the user.

### 4.4 Signal Analyser

The signal analyser mode monitors all 40 LE channel simultaneously. Any packets which match a specified access address are captured and analysed in accordance with the Bluetooth 5.2 LE RF Phy Test Specification. Tests include the in-band emissions test, which can be completed in as little as 2.5ms.

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If the captured packet is not a standard test packet, then an 'off-air' mode can be selected which performs accurate approximations to the standard Bluetooth 5.2 LE RF Phy tests but which is agnostic to the packet payload. This permits RF test to be performed on live links.

Whilst in signal analyser mode, a single DUT can be controlled over a serial interface. This permits the user to control the transmissions from the DUT, including constant tone extensions, when supported.

The signal analyser mode also permits the capture of raw IQ data.

### **4.5 Advertise/Scan**

The advertise/scan mode permits RF testing of devices when there is no access to either HCI or direct test mode. In this mode of operation, the DUT is provoked by Sapphire issuing advertising or scan request packets. The sensitivity of the DUT can be deduced from the signal level required to provoke a response, whilst the transmitter quality is ascertained by analysing the packets sent by the DUT. Test reports can be generated in html, csv or ascii test format.

### **4.6 Standalone**

The standalone mode permits Sapphire to be run without a USB or Ethernet connection. In this mode of operation, the Sapphire image and test script are held on a memory stick which is attached to the USB port of the *TLF3000*. The supervisor program on the *TLF3000* will automatically launch the Sapphire application which will then execute the test script held on the memory stick. Control of the Sapphire application and signalling of pass/fail are accomplished by the use of digital IO.

## 5 Launching the Sapphire GUI.

In order to communicate with the *TLF3000* unit, it is necessary to attach it to a host computer via USB or Ethernet (or both). An Ethernet connection is only possible if the host computer and *TLF3000* unit reside on the same subnet. The *TLF3000* IP address can be changed by connecting it to a host computer via USB and using the *Application Loader*.

To launch the Sapphire GUI it is first necessary to run *Application Loader*. This should result in the following screen being displayed:

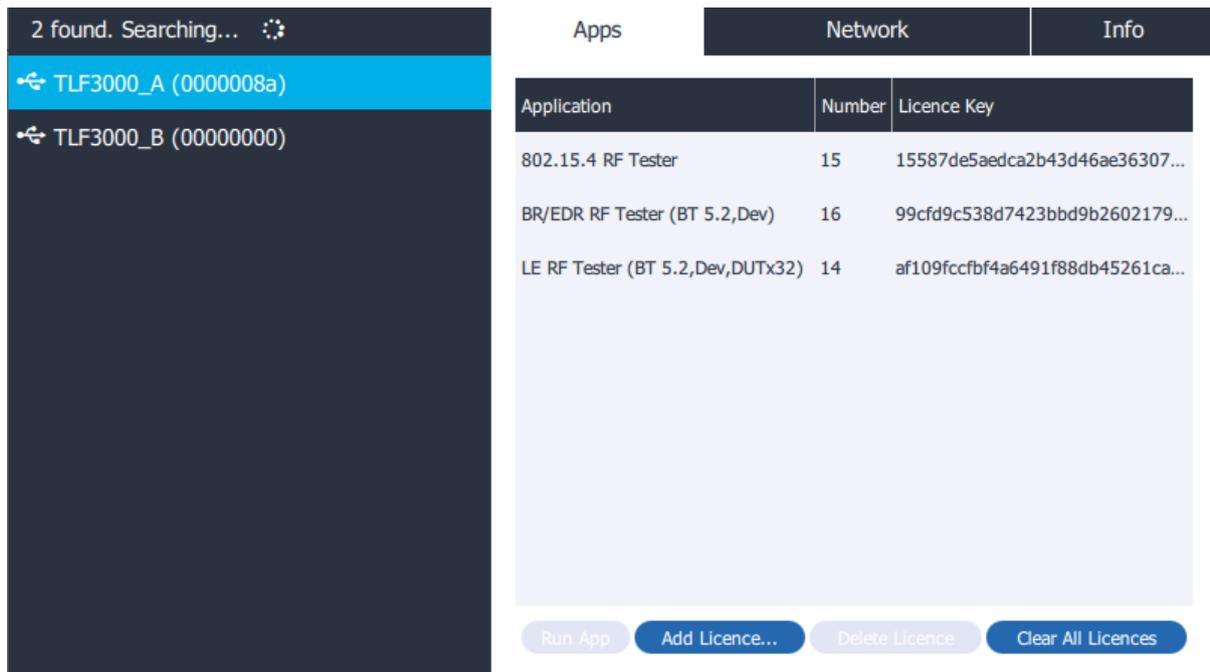


Figure 1: Application Loader main screen.

This screen indicates that the following *TLF3000* devices have been discovered:

1. Serial number 0000008A connected via USB (highlighted)
2. Serial number 00000000 connected via USB

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The right-hand side of the window has three tabs:

1. *Apps*. Shows which applications are licensed to run on this unit. It also permits the loading of new licence keys.
2. *Network*. Shows the current network settings and permits these to be modified.
3. *Info*. Provides more information about the unit and permits the unit's friendly name to be modified. It also provides a means of updating the firmware on the unit.

The selected *TLF3000* unit is shown to hold the following licenses:

1. 802.15.4 RF Tester  
The Cuprite 802.15.4 application
2. BR/EDR RF Tester (BT 5.2,Dev)  
The Zircon application for BT5.2, developer's version
3. LE RF Tester (BT 5.2,Dev,DUTx32)  
The Sapphire application for BT 5.2, developer's version with support for up to 32 DUTs

To launch the Sapphire application open the "*Apps*" tab and then either:

1. Double click on "*LE RF Tester (BT 5.2, Dev,DUTx32)*"
2. Highlight the "*LE RF Tester (BT 5.2,Dev,DUTx32)*" and then click the "*Run App*" button.

On launching the application, the searching cursor should stall, the fan on the *TLF3000* unit will start to spin and after a few seconds the Sapphire GUI will load.

## 6 Anatomy of the Sapphire GUI.

### 6.1 Overview

The Sapphire GUI is composed of the following elements:

1. A toolbar along the top of the window
2. A monitor panel to the right of the window
3. A status bar at the bottom of the window
4. Mode tabs located immediately underneath the toolbar
5. A mode control panel to the left of the window
6. A graphics area
7. A scripting/tabular results area below the graphics area

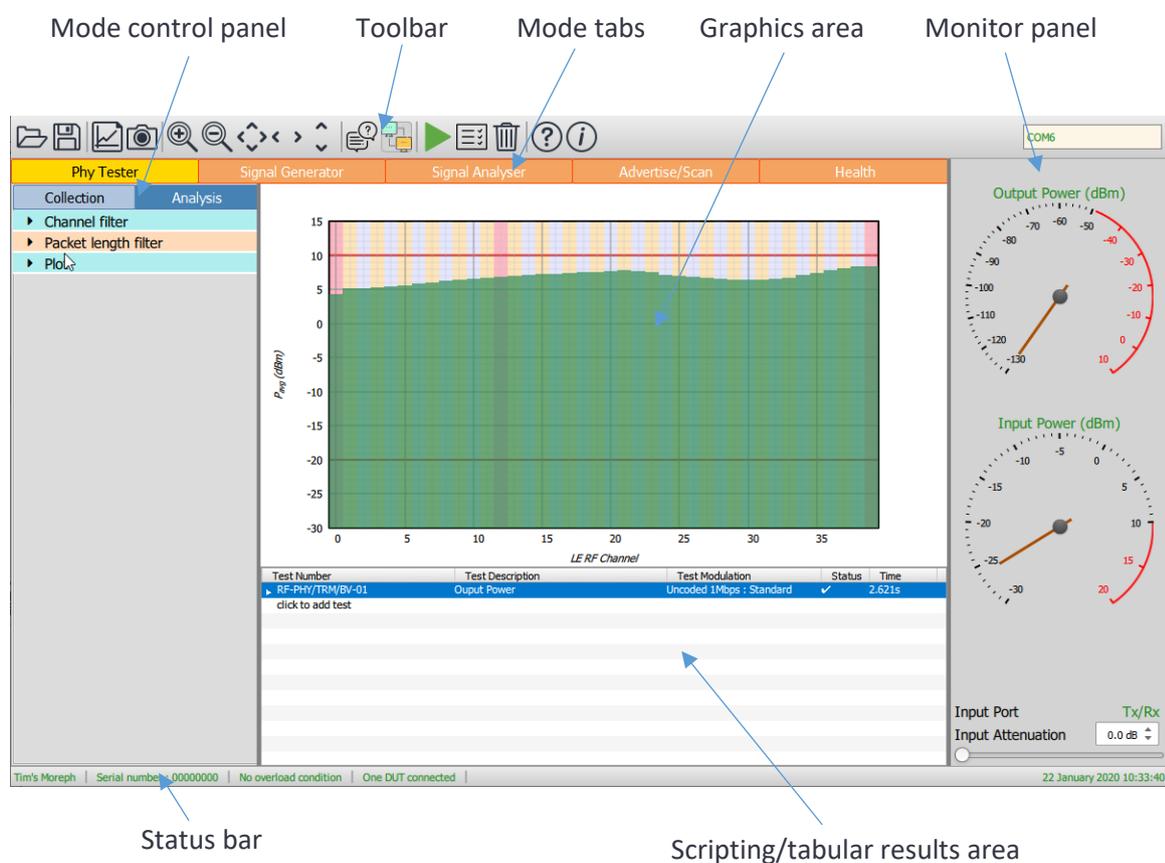


Figure 2: Sapphire GUI.

## 6.2 Toolbar

The toolbar contains the following elements:

### 6.3 Open and save



Opens and loads a settings file. Settings are saved individually for each mode of operation. The appropriate settings file is automatically selected on the basis of the current mode tab.



Saves the settings or results. Settings are saved individually for each mode of operation. The choice as to whether settings or results are saved is determined by the file extension which is selected. This tool can also be used to save test scripts in the format required by the native programming language.

### 6.4 Screen capture



Saves the current graphics area as an image file. A variety of image file formats are supported.



Takes a screen shot of the GUI and saves as an image file. A variety of image file formats are supported.

#### 6.4.1 Zooming



Activates the cross-hair cursor which permits zooming within in the graphics area. Depress the left mouse button whilst dragging the cursor to select the area to be displayed. Clicking the right mouse button within the graphics area will give a list of additional zoom options.



Zooms out within the graphics area. Clicking the right mouse button within the graphics area will give a list of additional zoom options.



Pans within the graphics area. Hold down the left mouse button and drag to pan anywhere within the graphics display.



Pans along the x-axis within the graphics area. Hold down the left mouse button and drag horizontally. This is particularly useful for examining long waveforms.



Pans along the y-axis within the graphics area. Hold down the left mouse button and drag vertically.

#### 6.4.2 DUT control



Causes the Sapphire application to list all the advertising devices which are currently visible. This feature is only available in advertise/scan mode.



Causes the Sapphire application to connect to a DUT if no DUT is currently connected, and then perform a query of the DUT's supported features. The supported features tab under the DUT control menu is automatically expanded to show the results of the query.



Activating this button will attempt to establish serial connections to all of the DUTs which have been selected. The state of the button also indicates if one or more DUTs are currently connected.

### 6.4.3 Run, clear and report



Causes the currently selected mode to run. NOTE: the signal generator will not output energy until this is clicked.



Will cause the signal generator to continuously repeat the programmed operation. Between each repeat the number of packets received by the DUT can be read back by the Sapphire application and the PER displayed. This control is only available in signal generator mode.



Stops the currently selected mode running. A running operation will automatically be aborted if a different mode of operation is selected.



Clicking this button will generate an html report of the current results. The report will be displayed in the default browser. This control is only available in Phy test mode and advertise/scan mode,



Clears the current results history. Not applicable in signal generator mode.



Measure the frequency and amplitude of a CW signal. Only applicable in phy tester mode.

#### 6.4.4 Help



Displays the online documentation in a pop-up window.



Displays version information.

#### 6.4.5 DUT selection



A combination box which allows one of the connected DUTs to be selected. The results displayed in the graphics area will refer to the selected DUT.

### 6.5 Monitor panel

#### 6.5.1 Overview

The purpose of the monitor panel is to permit the user to quickly ascertain whether:

1. There is RF energy being emitted from the unit
2. There is RF energy being received by the unit

Whenever the unit or DUT appears to be unable to receive, the monitor panel should always be the first item to examine. Many problems can be quickly resolved with the information that it displays.

The monitor panel also determines which RF port is being used and provides manual control of the receiver front-end attenuation.

#### 6.5.2 Output power

The output power gauge shows the energy being emitted by the *TLF3000*. The gauge is only approximate and should not be used for accurate measurements.

The red arc indicates the overload region. If an overload does occur, this will be evident by the 'Output Power (dBm)' label turning red and a warning message being displayed in the status bar.

The output power gauge only shows the energy being emitted within the 2.4GHz ISM band. Energy from the out-of-band CW blocker is not included, even if its frequency lies within the 2.4GHz ISM band.

### 6.5.3 Input power

The input power gauge shows the energy incident on the selected *TLF3000* input port. The gauge is only approximate and should not be used for accurate measurements.

The red arc indicates the overload region. If an overload does occur, this will be evident by the '*Input Power (dBm)*' label turning red and a warning message being displayed in the status bar. It may be possible to remove a receiver overload condition by:

1. Adding additional receiver front-end attenuation using the control at the bottom of the monitor panel.
2. Swapping to the '*Tx/Rx*' RF port if the '*Monitor In*' RF port is being used.

The input power gauge only shows energy within the 2.4GHz ISM band. F-bar filters at the front of the receiver chain ensure other energy is eliminated and cannot block the receiver.

### 6.5.4 Input port

The input port switch selects which of the two RF input ports will be used:

1. The '*Monitor In*' port is suitable for off-air monitoring and has a noise figure of 6dB. In benign environments no additional receiver front-end attenuation should be required. However, in environments with strong Wi-Fi activity, it may be necessary to add receiver front-end attenuation to prevent overload conditions.
2. The '*Tx/Rx*' port is suitable for conducted measurements. If the DUT is capable of outputting more than +10dBm, it may be necessary to add receiver front-end attenuation to prevent overloading the receiver.

### 6.5.5 Input attenuation

These controls are used to select the receiver front-end attenuation. The attenuation may be adjusted by:

1. Moving the slider
2. Using the up/down arrows on the spin box
3. Typing a numeric value into the spin box text area

The available attenuation range is 0 to 31.5dB in steps of 0.5dB.

Provided the *TLF3000* unit is not overloading and that the input signal is not attenuated so much that it is driven into the noise floor, changing the input attenuation will have no impact on measured results. The *Sapphire* application automatically compensates for the input attenuator setting.

### 6.5.6 Selection of input port and input attenuation

The following table gives a rough guide of how to select the input port and input attenuation as a function of the received signal level from the DUT:

Input signal level	Attenuation	
	Monitor In Port	Tx/Rx Port
-40	0	0 (Monitor In preferred)
-35	0	0 (Monitor In preferred)
-30	0	0 (Monitor In preferred)
-25	5	0
-20	10	0
-15	15	0
-10	20	0
-5	Do not use	0
0	Do not use	0
+5	Do not use	0
+10	Do not use	0
+15	Do not use	5
+20	Do not use	10
+25	Do not use	15

Table 2: Setting of front-end attenuation.

## 6.6 Status bar

### 6.6.1 Overview

The status bar at the bottom of the window is divided into six areas:

1. Name of *TLF3000* unit
2. Serial number of *TLF3000* unit
3. Overload indicator
4. DUT connection status
5. Error message text
6. Current date and time

### 6.6.2 Name of unit

Displays the friendly name of the connected *TLF3000* unit. This name can be edited within the Application Loader

### 6.6.3 Serial number

Displays the unique serial number of the connected *TLF3000* unit in hexadecimal notation.

#### 6.6.4 Overload indicator

The overload indicator will turn red when an overload condition occurs on either the transmit output or the selected receiver input port. The text of the message will indicate where the overload condition is occurring.

#### 6.6.5 DUT connection status

The DUT connection status message shows the number of DUTs which the Sapphire application believes it currently has communication with via serial interfaces.

#### 6.6.6 Error message text

The error message text reflects the last error detected by the Sapphire application running on the *TLF3000* unit. This message is cleared when either the 'Run' or 'Clear' buttons are pressed, or when a different operating mode is selected.

#### 6.6.7 Current date and time

Displays the current data and time.

### 6.7 Mode tabs

The operating mode is selected by the tabs immediately underneath the toolbar. The following operating modes can be selected:

1. Phy tester
2. Signal generator
3. Signal analyser
4. Advertise/Scan

In addition, it is possible to display a page showing the health of the *TLF3000* unit.

Whenever a new mode of operation is selected, any currently running tests are aborted.

### 6.8 Mode control panel

For each operating mode, a mode control panel is displayed to the left of the window. This panel allows the user to define the parameters for the current operating mode. The contents of the mode control panel are mode specific.

The table below shows which tabs are available for each mode.

Mode	Collection	Analysis	DUT	Generator
Phy Tester		✓	✓	
Signal Generator			✓	✓
Signal Analyser	✓	✓	✓	
Advertise/Scan	✓	✓		

*Table 3: Tabs available on mode control panel.*

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The purpose of each tab is:

1. *Collection*. This tab contains parameters which determine what data will be collected and how it will be collected.
2. *Analysis*. This tab contains parameters which determine how results from the collected data will be displayed.
3. *DUT*. This tab determines the means of communicating with the DUT and also manual control of the DUT.
4. *Generator*. This tab is specific to the Signal Generator mode and controls the signals generated by the *TLF3000* unit.

### 6.9 Graphics area

For the Phy tester, signal analyser and advertise/scan modes of operation, a graphical representation of the results are displayed in the graphics area. The class of results displayed is determined by tabs along the top of the graphics area in signal analyser and advertise/scan modes, and by the selected test in Phy tester mode. The precise details of how the results are displayed is governed by settings in the '*Analysis*' tab on the mode control panel.

For the signal generator mode, the graphics area provides a visual indication of which signals have been programmed. Note that the graphics area only shows what has been programmed; to make the programmed signals appear at the transmitter port, the 'Play' button within the toolbar must be activated. If a DUT is connected via a serial link then further information may be displayed:

1. PER. The packet error rate reported by the DUT. This is available for both HCI and direct test mode connections to the DUT.
2. CTE amplitudes and phases as measured by the DUT. This is only available if the DUT is connected via an HCI interface.

### 6.10 Scripting/tabular results area

In the Phy tester mode, the region below the graphics area is used for constructing and displaying test scripts. This area also indicates whether the tests have been run, and if so, whether they passed or failed. The time taken for each line in the test script is also indicated.

In the signal analyser and advertise/scan modes, the region below the graphics is used to display tabular results. Which results are displayed is determined by settings on the '*Analysis*' tab in the mode control panel. The results tables also contain test limits which can be adjusted by the user. Tests that fail the limits are highlighted. The contents of the graphics display area can also be controlled by highlighting rows within the results table.

The scripting/tabular results area is not used in signal generator mode.

## 7 Communicating with the DUT(s)

### 7.1 Overview

*Sapphire* supports communication with one or more DUTs over a serial interface. The control of this interface is governed by the settings in the ‘*DUT control*’ menu under the ‘*DUT*’ tab in the mode control panel. Up to 32 DUTs can be supported.

The status bar indicates whether the *Sapphire* application currently believes it has communications with a DUT, and if so, how many.

The status of the ‘*Connect*’ button on the toolbar indicates if at least one DUT is connected.

The combo box at the right-hand side of the toolbar shows which DUT the currently displayed results are associated with.

### 7.2 Hardware connections

The serial interface connection can be either

1. via the digital IO connector on the rear of the *TLF3000* unit
2. via a comport accessible from the host

The ‘*DUT(s) attached to host*’ checkbox at the top of the ‘*DUT control*’ menu determines which of these options is selected.

If the DUT is connected to the digital IO connector on the rear of the *TLF3000* unit, then only one DUT can currently be supported. The pinout of the digital IO connector on the rear of the *TLF3000* unit is:

Pin	Signal	Direction
1	Vio	Input/Output
2	Vio	Input/Output
9	RTS	Output
10	TX	Output
17	CTS	Input
18	RX	Input
19	Gnd	-
20	Gnd	-

Table4: Pinout of the digital IO connector on the rear of *TLF3000*.

### 7.3 IO voltage levels

Vio in the above table is the voltage level which is used for all signalling on the digital IO connector on the rear panel of the *TLF3000*. This can either be supplied by the *TLF3000* unit or the DUT. If it is supplied by the *TLF3000* unit, then it is fixed at 3.3 V. If it is supplied by the DUT, then it must be in the range 0.8 V to 3.6 V. Whether Vio is supplied by the *TLF3000* unit or the DUT is determined by the setting of the ‘*External IO voltage*’ checkbox in the ‘*DUT control*’ menu. It is essential that this checkbox is set to the correct state prior to the DUT being attached.

### 7.4 Comport selection

If 'DUT(s) attached to host' has been selected, then 'DUT control' menu shows a list of comports available on the host. If 'DUT(s) attached to host' has not been selected, then the single comport on the rear of the TLF3000 unit is displayed as TLF3000. Future releases of the Sapphire application will extend the number of comports available on the rear of the TLF3000 unit to 8.

Individual comports can be selected from the list. The selected comports will initially be highlighted in red with a cross to indicate that they have been selected but the corresponding DUTs have not yet been connected to. Once the DUTs have been connected, the selected comports will be highlighted in green with a tick.

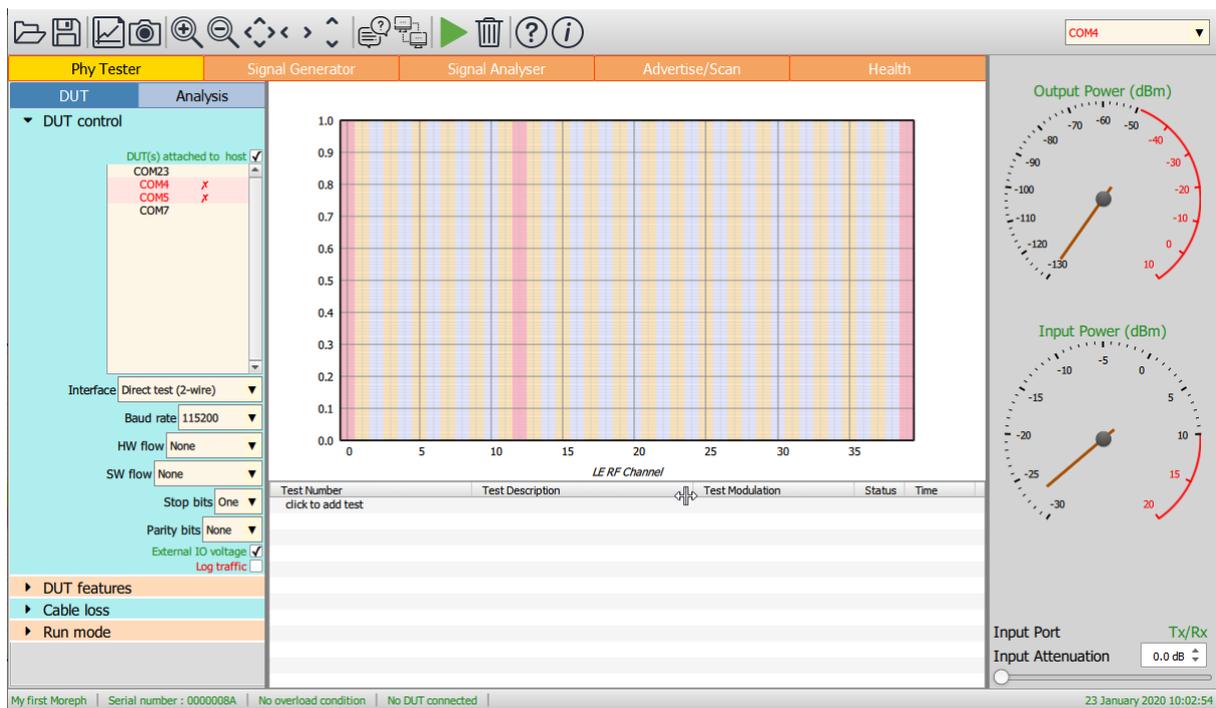


Figure 3: Status prior to connecting to the DUTs.

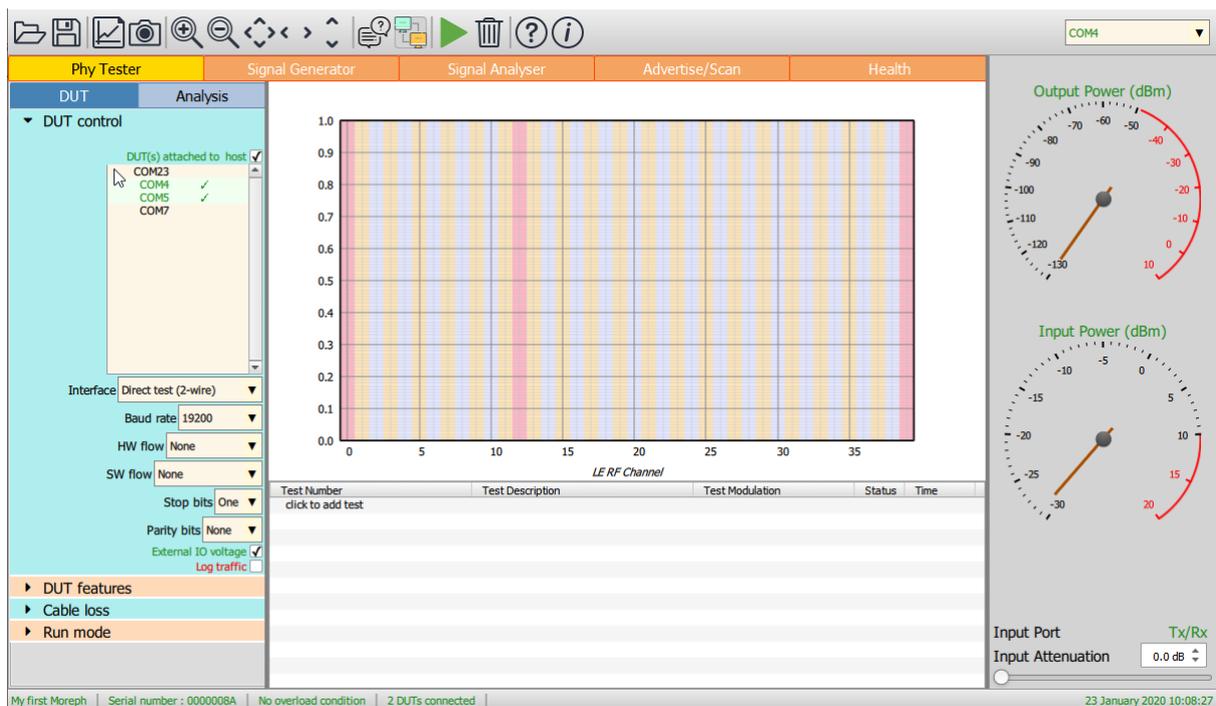


Figure 4: Statis after connecting to the DUTs.

All the selected DUTs must communicate using the same hardware and protocol settings.

## 7.5 Protocol settings

All protocol settings are contained in the 'DUT control' menu under the 'DUT' tab.

The DUT may be communicated with using any one of the following protocols:

1. Direct test mode (also known as 2-wire mode)
2. H4
3. H5 (also known as 3-wire mode)
4. BCSP (a Qualcomm/CSR proprietary mode)
5. SPI BCMMD (a Qualcomm/CSR proprietary mode)

The protocol is selected from the 'Interface' combo box. Selecting the protocol will automatically set appropriate defaults for all other serial link parameters.

Other link parameters which may be set are:

1. Baud rate. Supported baud rates are 50, 75, 110, 134, 150, 300, 600, 1200, 1800, 2400, 9600, 19200, 38400, 57600, 115200 and 230400. An automatic baud rate detection features is also supported. Additional baud rates can be added on request. (This parameter is not relevant for SPI BCMMD.)
2. Hardware handshaking (this parameter is not relevant for SPI BCMMD).
3. Software flow control (not supported for H5, BCSP or SPI BCMMD).
4. Number of stop bits (this parameter is not relevant for SPI BCMMD).

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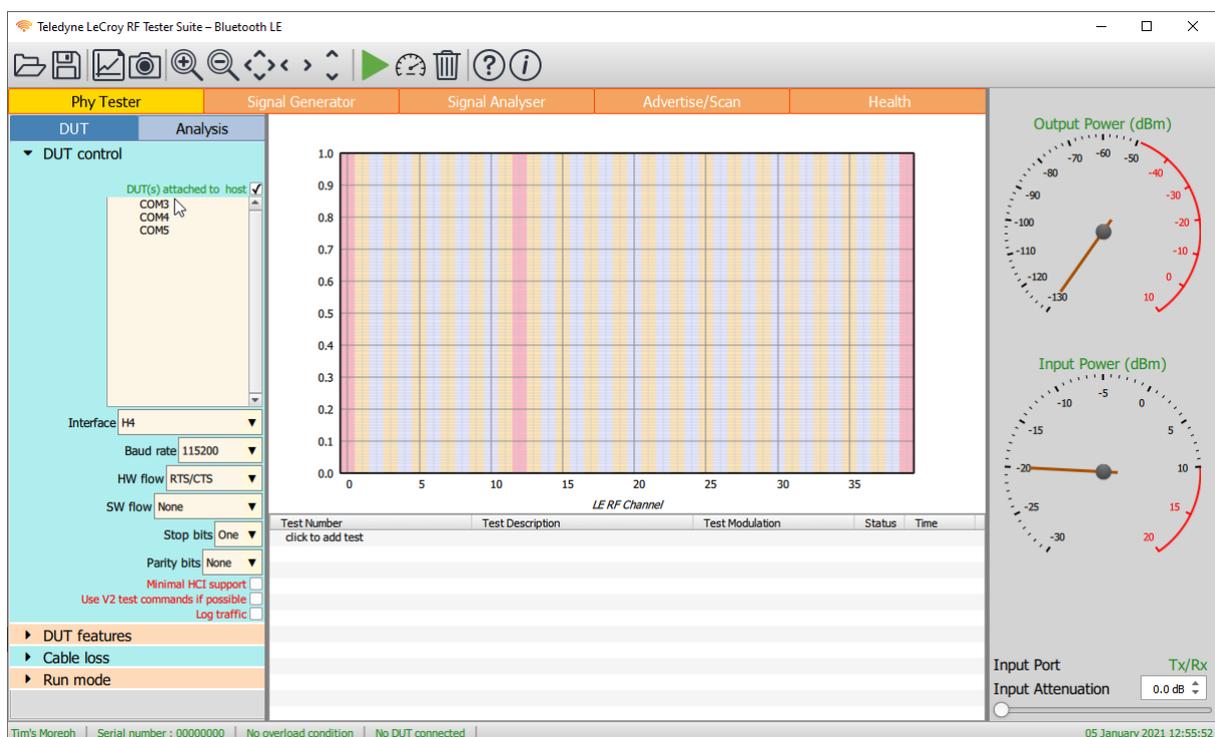
5. Parity bits (this parameter is not relevant for SPI BCMMD).
6. CRC (H5 and BCSP only, not yet supported).

### 7.6 Logging serial traffic

It is possible to log the serial traffic to and from the DUT. This can be useful when it is required to debug DUT communication issues. To enable logging of serial traffic, tick the 'Log traffic' checkbox at the bottom of the 'DUT control' menu. When this checkbox is ticked a dialog will pop-up for the user to select a file where the logged traffic will be saved. The traffic is saved in a simple text format.

### 7.7 Controlling HCI command selection

If the protocol select is an HCI protocol (H4, H5 or BCSP) then additional checkboxes are visible which control which HCI commands are used to communicate with the DUT.



If *Minimal HCI support* is checked, then the Sapphire application will use the smallest subset of HCI commands possible in order to communicate with the DUT. In this mode it will be necessary to set the DUT supported features manually.

If *Use V2 test commands if possible* is checked, then the Sapphire application will attempt to use V2 HCI test commands to control the DUT in preference to V1 commands.

### 7.8 DUT supported features

In order for *Sapphire* to determine which tests are applicable to the DUT, it is necessary to establish which features the DUT supports. The DUT supported features can be entered in the 'DUT features' menu of the 'DUT' tab.

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Parameters which are required are:

1. The role of the DUT. This may be one of:
  - a. Central
  - b. Peripheral
  - c. Broadcaster
  - d. Observer

This information is required to ascertain whether the DUT has both a transmitter and receiver and which channels these operate on.

2. Support for advertising extensions
3. Support for data length extensions
4. Maximum supported octets in an advertising packet. Permissible range is 37 to 255. This is only required if advertising extensions are supported.
5. Maximum supported octets in a receive packet. Permissible range is 27 to 251. This is only required if data length extensions are supported and advertising extensions are not supported.
6. Maximum supported receive time. Minimum permissible value is 328 $\mu$ s. This is only required if data length extensions are supported and advertising extensions are not supported.
7. Maximum supported octets in a transmit packet. Permissible values are 27 to 251. This is only required if data length extensions are supported.
8. Maximum supported transmit time. Minimum permissible value is 328  $\mu$ s. This is only required if data length extensions are supported.
9. Support for 2Mbps Phy.
10. Support for long range (coded) Phys.
11. Support for stable modulation index.
12. Support for AoA reception and supported slot durations
13. Support for AoA transmission and supported slot durations
14. Support for AoD reception and supported slot durations
15. Support for AoD transmission and supported slot durations
16. Maximum supported CTE length
17. Number antenna attached to DUT
18. Maximum supported switching pattern length

The 'Query' button on the toolbar can be used to read back the supported features from the DUT. If not DUT(s) are currently selected, then the first selected DUT will be connected to and the features read back. If DUT(s) are already connected, then the features will be read back from the first selected DUT. All DUTs must have the same supported features.

If the DUT(s) are connected via direct test mode, then there can be ambiguity over the supported features. This arises since legacy devices may not respond to more recent direct test commands.

The DUT features can also be entered manually in the 'DUT features' menu. This menu will also be populated if a saved settings file is read.

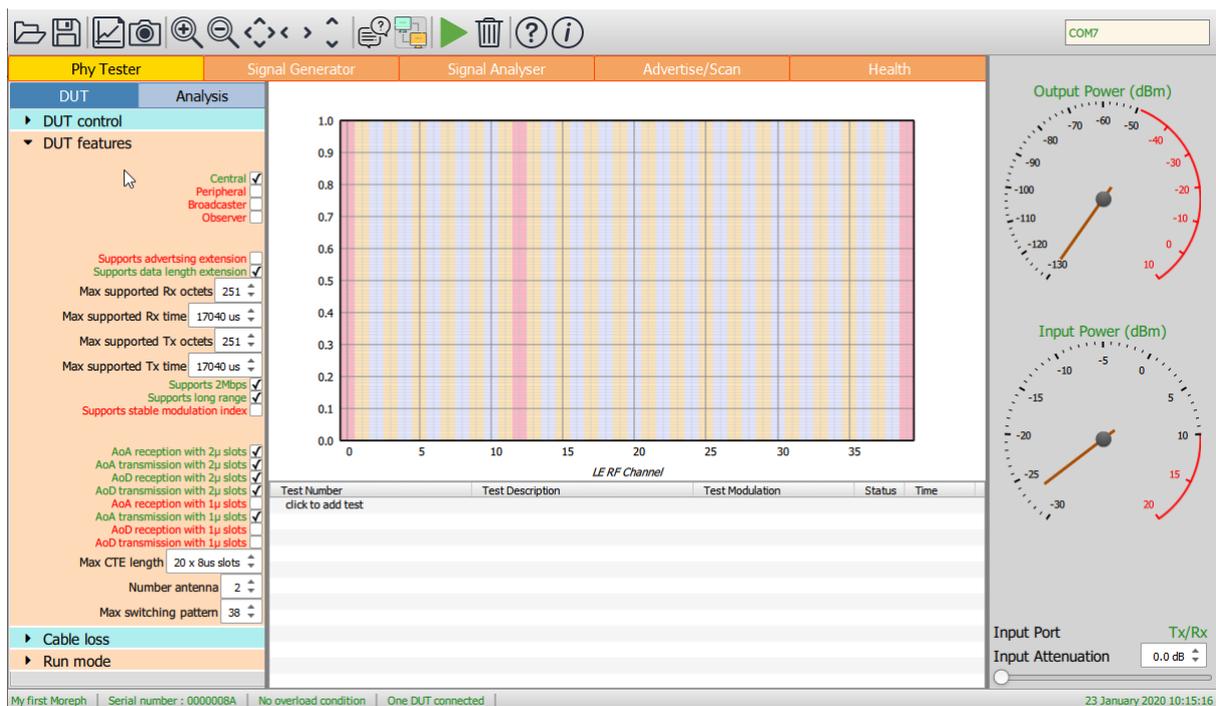


Figure 5: DUT supported features.

## 7.9 Connecting to a DUT

The selected DUT(s) can be connected to by pressing the 'Connect' button on the toolbar. If the DUT(s) are successfully connected to then their status in the list under the 'DUT control' menu will turn from red to green and the item will be ticked. The number of DUT(s) connected to will be shown in the status bar. The status of the 'Connect' button indicates if one or more DUT(s) are currently connected.

If no DUT(s) are connected when the 'Query' button on the toolbar is pressed, then the first selected DUT will be connected to.

In Phy test mode, the selected DUT(s) will automatically be connected when the 'Run' button on the toolbar is pressed.

## 7.10 Disconnecting a DUT

By releasing the 'Connect' button on the toolbar all connected DUTs will be disconnected.

## 7.11 Displaying results from an individual DUT

The combo box on the right-hand side of the toolbar shows which DUT the currently displayed results refer to.

In signal generator mode, altering the selection of the combo box will alter which DUT the received packet count and CTE IQ samples are being read from.

In signal analyser mode, altering the selection of the combo box will alter which DUT is transmitting.

### 7.12 Compensating for cable loss

The cable loss between the DUT and the TLF3000 can be compensated in the measurements made by the Sapphire application. The cable loss must be entered in the 'Cable loss' menu under the 'DUT' tab of the mode control panel.

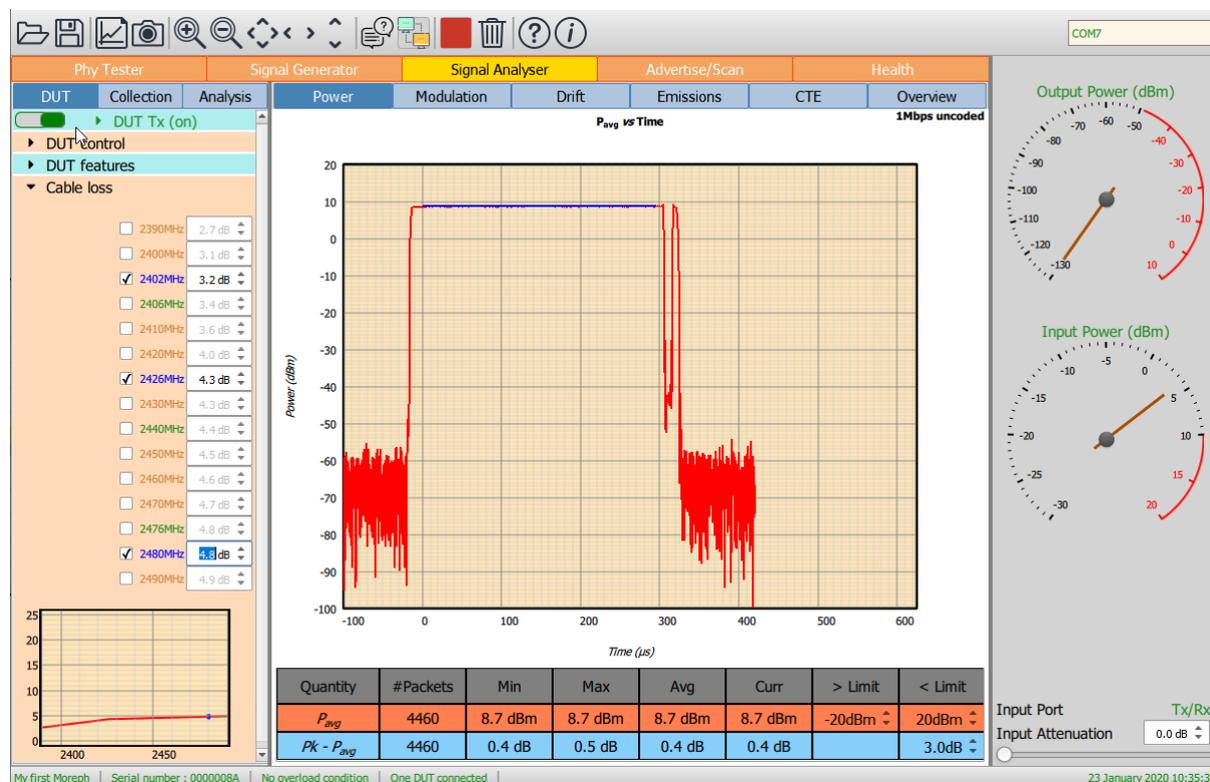


Figure 6: Cable loss.

The cable loss can be specified at a number of frequencies throughout the ISM band. The frequencies to be used are selected by ticking the checkbox to the left of the frequency label. The cable loss at the frequency can then be entered using the spin box to the right of the label.

A graph at the bottom of the 'Cable loss' menu shows the cable loss which will be applied.

If the cable loss is specified at a single frequency, then this value will be used throughout the band.

If the cable loss is specified at two or more frequencies, then linear interpolation will be used between the specified frequencies and linear extrapolation applied outside the range of the specified frequencies.

All interpolated/extrapolated cable loss values will be limited to the range 0dB to 25dB.

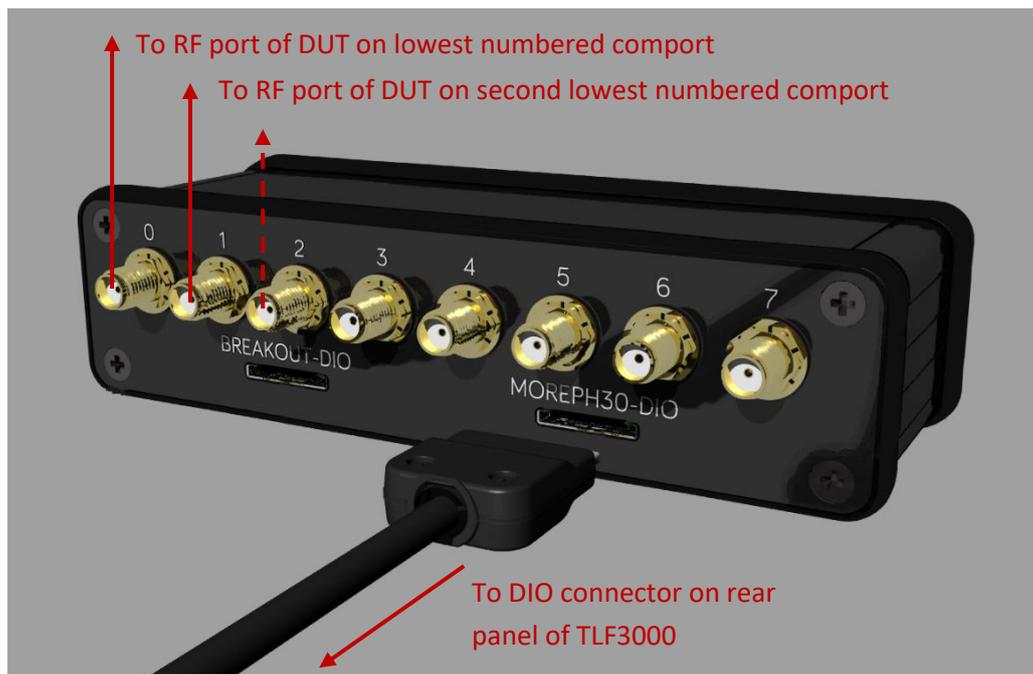
### 7.13 RF Connections to multiple DUTs

The Sapphire application is capable of testing multiple DUTs simultaneously. The short transmitter tests are performed sequentially whilst the much longer receiver tests are performed in parallel. This can result in a dramatic decrease in test time. Up to 32 DUTs can be tested simultaneously.

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When testing multiple DUTs an *N*-way splitter/combiner should be used to connect the 'Tx/Rx' port to the DUTs.

The Teledyne 'Programmable RF 8-Way Switch' can be used to connect up to 8 DUTs to the *TLF3000* unit. This unit is controlled via the digital IO connector on the rear panel of the *TLF3000*. The presence of the programmable switch will automatically be detected by the *Sapphire* application. The *Sapphire* application will program the switch to correctly terminate any unused ports. The DUTs should always be connected such that the DUT on the lowest numbered comport is connect to port 0 on the switch unit, the DUT on the next lowest numbered comport to port 1 on the switch unit, etc.

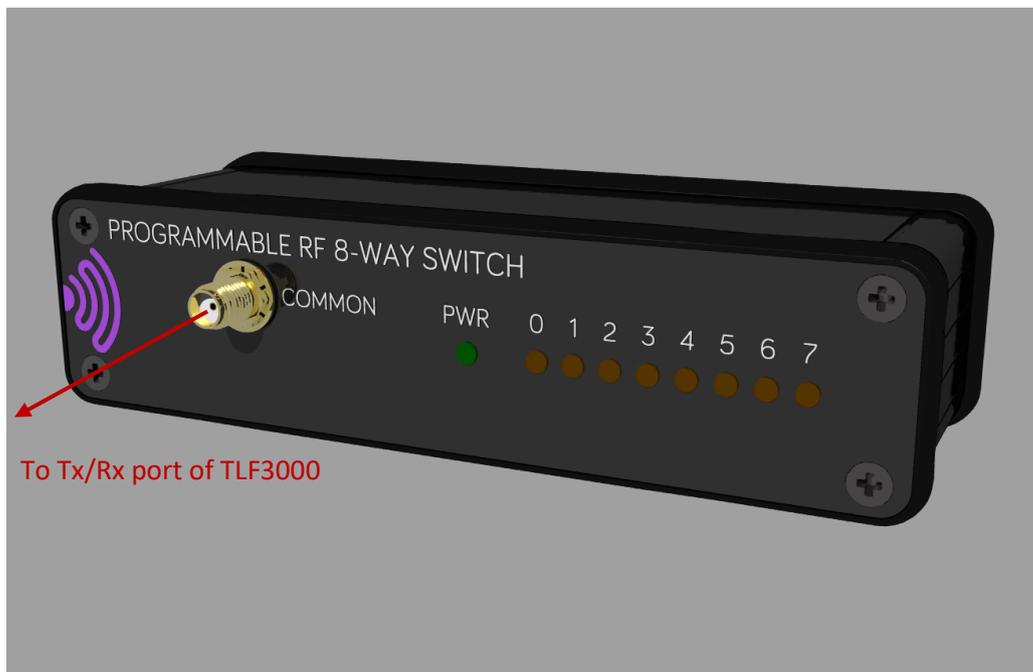
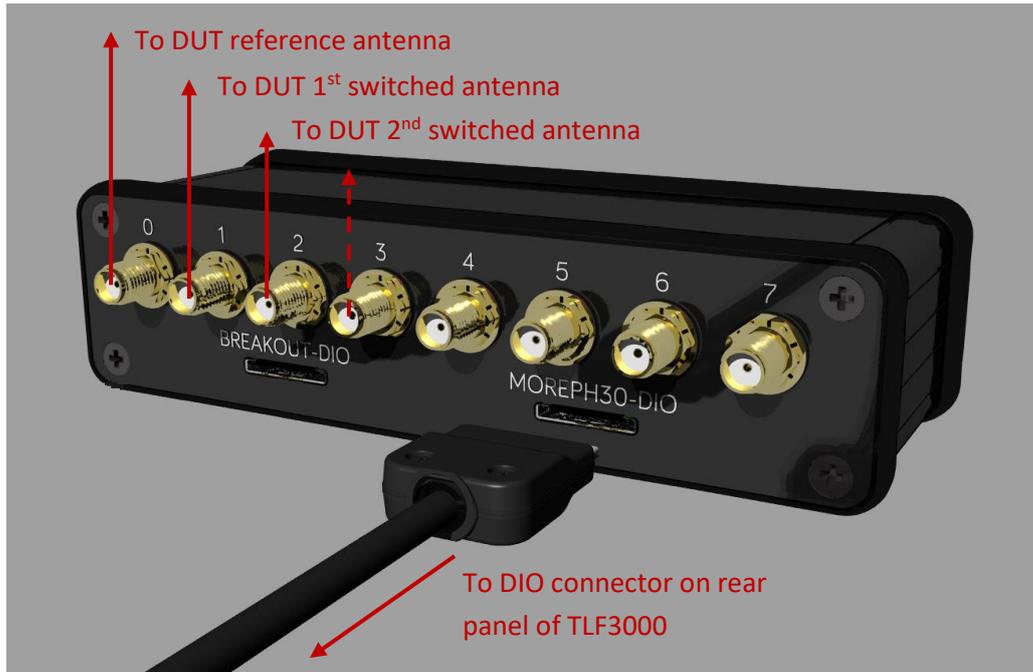




#### 7.14 RF Connections for CTE testing

When performing CTE testing on a DUT with multiple antenna ports, it is necessary to split the output of the *TLF3000* 'Tx/Rx' port to the individual antenna ports on the DUT. This can be done using an *N*-way splitter/combiner.

The Teledyne 'Programmable RF 8-Way Switch' can be used to connect up to 8 antenna ports to the *TLF3000* unit. This unit is controlled via the digital IO connector on the rear panel of the *TLF3000*. The presence of the programmable switch will automatically be detected by the *Sapphire* application. The *Sapphire* application will program the switch to correctly terminate any unused ports. The DUT antennas should always be connected to the lowest numbered ports.



During AoD antenna switching integrity testing it is necessary to connect just one DUT antenna port to the *TLF3000* and to terminate the remaining antenna ports. In normal operation the *Sapphire* application will prompt the user to switch antenna ports as required. The process of switching antenna ports will be performed automatically if the Teledyne ‘Programmable RF 8-Way Switch’ is used to connect the DUT antenna ports to the *TLF3000* unit.

## 8 Signal Generator Mode.

### 8.1 Overview

The signal generator is able to produce any combination of the following signals:

1. Packetised LE test signal, including a CTE
2. GFSK modulated interferer signal, which may be either continuous or packetised
3. Up to two in-band CW signals
4. In-band AWGN (2395MHz to 2485MHz)
5. Out-of-band CW signal.

The 'Generator' tab in the mode control panel on the left-hand side of the screen lists the signals which can be generated. The switch to the left of the signal name programs the signal on or off. Although a signal may be programmed on, **no output is generated from the unit until the 'Play' button in the toolbar is activated.**

When the 'Output' tab at the top of the graphics area is selected then:

1. The top graph in the graphics window shows a symbolic representation of signals generated within the 2.4GHz ISM band. The graphics assume a resolution bandwidth of 100kHz, hence the displayed levels for modulated signals will be slightly lower than their programmed levels. The LE channels are emphasised by alternating colour bars. Advertising channels are further highlighted.
2. The bottom graph in the graphics window shows a symbolic representation of the signals generated between DC and 6GHz. The graphics assume a resolution bandwidth greater than modulation bandwidth, hence all signals appear at their programmed levels.



Figure 7: Sapphire GUI in signal generator mode.

## 8.2 RF connections

The signal generator output is always on the Tx/Rx port.

## 8.3 Programming the packetised LE signal

### 8.3.1 Overview

To turn the packetised LE signal on or off, toggle the switch to the left of the 'Wanted' text.

To program the packetised LE signal, expand the 'Wanted' signal menu by clicking on it:

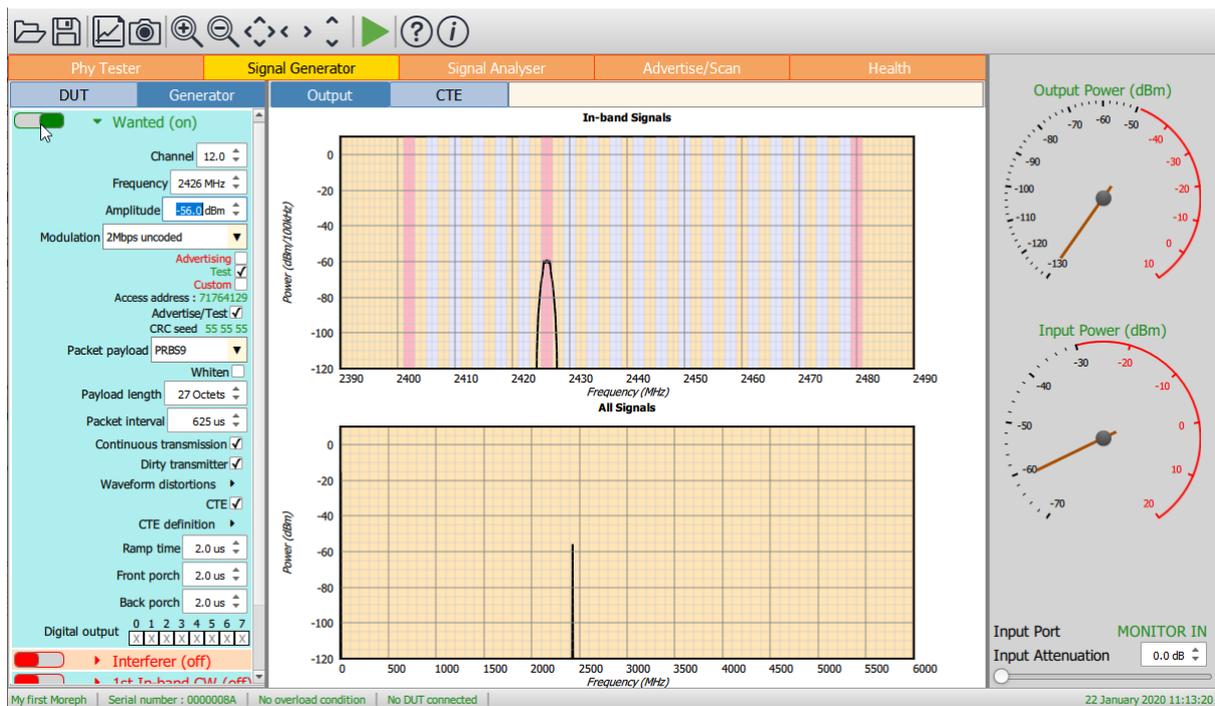


Figure 8: Programming the packetised LE signal.

### 8.3.2 Carrier frequency

The frequency of the carrier can be set to any one of the 40 LE channels either by:

1. Using the channel number spin box
2. Using the frequency spin box

As with all spin boxes, adjustment can be performed either by using the up/down arrows or by entering a numeric value into the text field.

### 8.3.3 Amplitude

The amplitude of the wanted signal can be adjusted from -120dBm to 0dBm. The total combined output power of the unit within the 2.4GHz ISM band is 0dBm. Therefore, if other signals are active, the maximum output power for the wanted signal will be reduced to maintain the peak output power within the 0dBm limit. The amplitude of the signal refers to that of the preamble, access address, header and payload but not the CTE.

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If a CTE is present, then the amplitude of the sampling slots is programmed relative to the level of the payload. If the amplitude of a CTE sampling slot is programmed to be greater than that of the payload, then the maximum output power of the remainder of the packet is correspondingly reduced.

### 8.3.4 Modulation

The modulation may be set to anyone of the Bluetooth 5.2 LE RF Phys:

1. 2Mbps, GFSK
2. 1Mbps, GFSK
3. 500kbps, s=2 spreading, GFSK
4. 125kbps, s=8 spreading, GFSK

The 1Mbps, 500kbps & 125kbps signals are all bandlimited to 2MHz, whilst the 2Mbps signals are bandlimited to 4MHz.

Modulation index, carrier offset, drift, drift rate and symbol timing can all be adjusted by enabling the dirty transmitter mode.

If the modulation scheme is changed to or from 2Mbps, then the packet interval may be automatically updated.

### 8.3.5 Access Address

The access address in use is displayed in the green hexadecimal characters to the right of the 'Access address' label.

Three checkboxes are provided for selecting the advertising address:

1. *Advertising*. Selects the advertising access address of 8E89BED6.
2. *Test*. Selects the test access address of 71764129.
3. *Custom*. Permits the user to enter their own custom access address. The address is entered by typing over the green hexadecimal characters to the right of the 'Access address' label.

### 8.3.6 CRC seed

The CRC seed in use is displayed in the green hexadecimal characters to the right of the 'CRC seed' label.

The 'Advertise/Test' checkbox will set the CRC seed to 555555, which is the default seed for advertising and test packets.

If the 'Advertise/Test' checkbox is unchecked, then the user may enter their own CRC seed by typing over the green hexadecimal characters to the right of the 'CRC seed' label.

### 8.3.7 Payload

The packet payload can be set to any one of the following (least significant bit first):

1. PRBS9 sequence, as defined in the Direct Test Mode section of the Bluetooth 5.2 Core Specification
2. PRBS11 sequence
3. PRBS15 sequence, as defined in the Direct Test Mode section of the Bluetooth 5.2 Core Specification
4. PRBS20 sequence
5. PRBS23 sequence
6. PRBS29 sequence
7. PRBS31 sequence
8. 11110000 repeated
9. 10101010 repeated
10. 11111111 repeated
11. 00000000 repeated
12. 00001111 repeated
13. 01010101 repeated

The choice of payload also defines the first octet of the packet header:

<b>b<sub>7</sub> b<sub>6</sub> b<sub>5</sub> b<sub>4</sub> b<sub>3</sub> b<sub>2</sub> b<sub>1</sub> b<sub>0</sub></b>	<b>Payload</b>
0 0 0 0 0 0 0 0	PRBS9
0 0 0 0 0 0 0 1	11110000
0 0 0 0 0 0 1 0	10101010
0 0 0 0 0 0 1 1	PRBS15
0 0 0 0 0 1 0 0	11111111
0 0 0 0 0 1 0 1	00000000
0 0 0 0 0 1 1 0	00001111
0 0 0 0 0 1 1 1	01010101

*Table 5: Choice of payload defining first octet of the packet header.*

If other payloads are required, then the user should use Tanzanite, a Bluetooth 5.2 LE traffic generator application compatible with *TLF3000*.

### 8.3.8 Whitening

The 'Whiten' checkbox determines whether the transmitted packet should be whitened. The whitening seed is derived from the channel index of the transmission.

### 8.3.9 Payload length

The payload length can be adjusted between 0 and 255 octets. Altering the payload length may result in the packet interval changing. If the packet length exceeds the packet interval, then the packet interval will be rounded up to the next multiple of 625  $\mu$ s.

### 8.3.10 Packet interval

The minimum packet interval is dependent on the payload length, the modulation scheme, the CTE length, the packet ramp time and the length of unmodulated carrier at the start and end of the packet. For a 2Mbps packet with no payload, the minimum packet interval is around 57  $\mu$ s. The maximum packet interval is 100ms.

The packet interval may change automatically if either the payload length, the modulation scheme, CTE, packet ramp time or lengths of unmodulated carrier are changed. If this occurs, then the packet interval will be set the lowest multiple of 625  $\mu$ s which encompasses the entire packet.

### 8.3.11 Packet count

The signal generator can be set to transmit LE packets continuously or a finite number of packets can be specified. The specification of a finite number of packets is useful if it is desired to measure the PER on a receiving DUT.

No packets are transmitted from the unit until the 'Run' button on the toolbar is pressed.

If a finite number of packets have been specified, then the signal generator will stop as soon as the packets have been sent. If a DUT is connected, the signal generator will then read back from the DUT the number of packets received and display the calculated PER at the top of the graphics area. If continuous transmission has been selected, then no PER will be displayed.

If it is desired to get a continuous reading of the PER from the DUT, then select a finite number of packets and depress the 'Repeat' button on the toolbar. The *Sapphire* application will now repeat the selected number of packets, calculating and displaying the PER after each repeat. To exit this mode, uncheck the 'Repeat' button on the toolbar.

The minimum number of packets which can be set is 1. If not in continuous mode, the maximum number of packets which can be sent is 65535.

### 8.3.12 Dirty transmitter

#### 8.3.12.1 Overview

By selecting dirty transmitter mode, it is possible to control:

1. Modulation index
2. Carrier offset
3. Carrier drift magnitude
4. Carrier drift rate
5. Symbol timing error

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The carrier drift is applied in accordance with the Bluetooth 5.2 LE RF Phy Test Specification:

1. The carrier drift at the start of each packet is zero
2. The carrier drift follows a sinusoidal variation whose frequency is determined by the drift rate parameter
3. The magnitude of the sinusoidal variation is determined by the drift magnitude parameter
4. Successive packets have the sign of the carrier drift reversed

The GUI holds two different sets of waveform distortions. One set is applied to 2Mbps modulated waveforms whilst the other set is applied to 1Mbps, 500kbps & 125kbps modulated waveforms.

Clicking on the 'Waveform distortions' button will pop-up the dirty transmitter dialog which displays the waveform distortion table which is currently in use:

Packet group	Carrier offset	Modulation Index	Drift Magnitude	Drift Rate	Symbol Timing Error
0	100 kHz	0.45	50 kHz	1250 Hz	-50 ppm
1	19 kHz	0.48	50 kHz	1250 Hz	-50 ppm
2	-3 kHz	0.46	50 kHz	1250 Hz	50 ppm
3	1 kHz	0.52	50 kHz	1250 Hz	50 ppm
4	52 kHz	0.45	50 kHz	1250 Hz	50 ppm
5	0 kHz	0.48	50 kHz	1250 Hz	-50 ppm
6	-56 kHz	0.46	50 kHz	1250 Hz	-50 ppm
7	97 kHz	0.52	50 kHz	1250 Hz	-50 ppm
8	-25 kHz	0.45	50 kHz	1250 Hz	-50 ppm
9	-100 kHz	0.55	50 kHz	1250 Hz	50 ppm

Figure 8: Dirty transmitter dialogue box displaying the waveform distortion table currently in use.

The transmitted signal is divided into groups of 50 packets. The first 50 packets are transmitted using the distortions defined in the first row of the waveform distortion table, the second 50 packets are transmitted using the distortions defined in the second row of the waveform distortion table, etc. Once all the rows in the waveform distortion table have been exhausted, the first row is reused.

Each individual distortion specified in the waveform distortion table can be adjusted using the associated spin box, either by using the up/down arrows or by entering a numeric value into the text field. The parameters can be varied over the following ranges:

Parameter	2Mbps	1Mbps, 500kbps & 125kbps
Carrier offset	±500kHz	±250kHz
Modulation index	0.4 to 0.6	0.4 to 0.6
Drift magnitude	±150kHz	±78kHz
Drift rate	0 to 2440Hz	0 to 2440Hz
Symbol timing error	±100ppm	100ppm

Table 6. Ranges over which the transmit distortions may be varied.

### 8.3.12.2 Editing the waveform distortion table

A row in the table can be selected by left or right clicking on the packet group number in the first column. Once a row in the packet group table has been selected, an edit menu can be popped-up by right clicking anywhere in the selected row.

The edit row permits the following operation to be performed:

1. *Copy*. The contents of the selected row are copied into the waveform distortion clipboard
2. *Paste*. The contents of the waveform distortion clipboard are copied into the selected row (this option is only available if the waveform distortion clipboard is not empty)
3. *Remove*. The selected row is deleted from the waveform distortion table.
4. *Clear All*. The entire waveform distortion table is deleted. Once the table has been cleared, a new entry can be inserted by clicking immediately underneath the table header.
5. *Insert above*. A new entry is inserted above the selected row. The new entry has no distortions and a modulation index of 0.5.
6. *Insert below*. A new entry is inserted below the selected row. The new entry has no distortions and a modulation index of 0.5.
7. *Duplicate*. The selected row is duplicated.

A new row can be inserted at the end of the waveform distortion table by clicking immediately below the last row. The new entry has no distortions and a modulation index of 0.5.

### 8.3.12.3 Dirty transmitter dialog buttons

The buttons along the bottom of the dirty transmitter dialog perform the following functions:

1. *Reset*. The contents of the waveform distortion table are reset to the values they held when the dirty transmitter dialog was popped up and all edits are discarded.
2. *Restore defaults*. The contents of the waveform distortion table are reset to the values specified in the Bluetooth 5.2 LE RF Phy Test Specification.
3. *Apply*. The current contents of the waveform distortion table will be used for all future transmissions and the dirty transmitter dialog is closed.
4. *Cancel*. Any edits to the waveform distortion table are discarded and the dirty transmission dialog is closed. All future transmissions will use the waveform distortions which were present prior to the dirty transmitter dialog being popped-up.
5. *Open*. The waveform distortion table will be loaded from an XML file.
6. *Save*. The currently displayed waveform distortion table will be saved to an XML file.

### 8.3.13 CTE

#### 8.3.13.1 Overview

If 'CTE' is selected, then a CTE will be added to the end of the packet. For AoD operation, the CTE phase and amplitude can be modulated to simulate the switching between antennas or an external array can be switched using the DIO connector on the rear of the *TLF3000* unit. The IQ samples can be read back from a DUT connected via an HCI interface and displayed in the graphics area.

It is possible to control:

1. CTE length
2. AoA or AoD mode
3. Length of switching slots
4. Antenna switching pattern
5. Number of antenna (AoD)
6. Simulated antenna phases and amplitudes

Abrupt switching between the transmit antenna would result in large sidebands being imposed on the wanted signal. The *Sapphire* application avoids the introduction of sidebands by modulating the amplitude as well as the phase of the signal during the switching slots. As a consequence, a signal which possesses a CTE remains within a 4MHz bandwidth. The *Sapphire* application is able to perform 180° phase shifts between successive transmit antenna whilst maintaining this bandwidth.

Clicking on the 'CTE definition' button will pop-up the CTE antenna programming dialog which displays the current CTE definition. The dialog includes a graph showing how the transmitter phase will be modulated over the length of the CTE.

If a DUT is connected, access to the CTE definition will only be possible if the DUT supports AoA or AoD. This can be set manually in the 'DUT features' menu under the 'DUT' tab or the 'Query' button on the toolbar can be used to read back the supported features from the DUT.

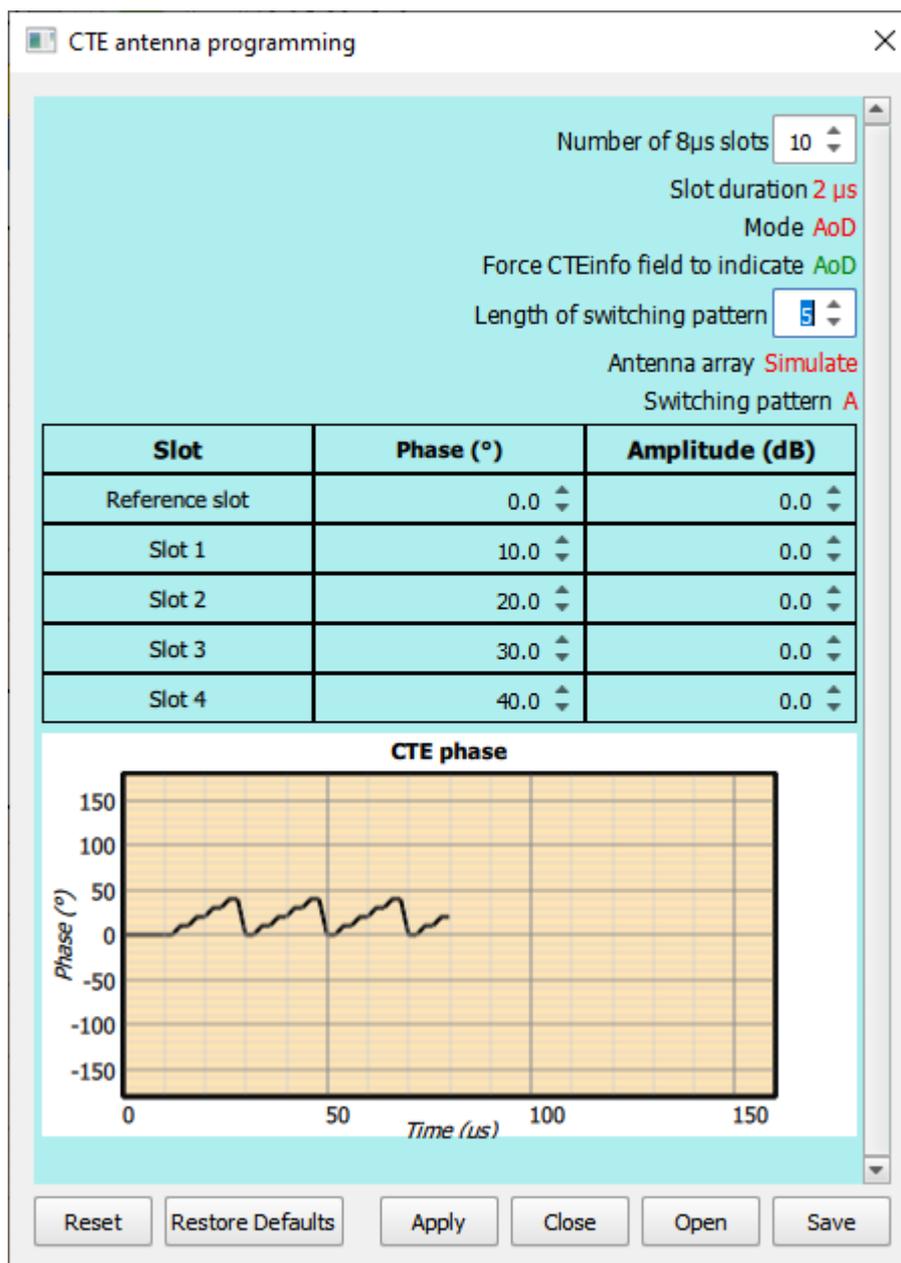


Figure 9: CTE definition.

8.3.13.2 **Editing the CTE parameters**

The length of the CTE is defined by a spin box showing the length in 8 µs slots. The minimum length is 2 x 8 µs slots (guard interval + reference interval + switching/sampling slots) and the maximum length is 20 x 8 µs slots.

The slot duration can be toggled between 2µs and 1µs by clicking on the displayed slot duration.

The mode of operation can be set to either AoA or AoD. Switching between modes is achieved by clicking on the displayed mode.

The CTE info field in the extended packet header is normally set to be the same as the selected mode. However, there are occasions where it is desirable to send an AoA packet with an AoD CTE

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info field or vice versa. The *'Force CTE info field to indicate'* field permits the CTE info to contain a different CTE type to that actually transmitted.

If AoA is selected, then the phase of the supplemental is not modulated and the only relevant parameter is the supplemental length. In this instance all parameters apart from *'Number of 8μs slots'* and *'Force CTE info field to indicate'* are hidden.

In AoD mode, the length of the switching pattern can be selected using a spin box. If a DUT is connected, then the maximum switching pattern length is determined but that supported by the DUT, otherwise the maximum length is determined by the number of switch slots and the switching slot duration.

To maintain consistency with the direct test mode command interface, two types of switching pattern can be selected. The antenna switching pattern can be toggled between 'A' and 'B' by clicking on the *'Switching pattern'* button. Antenna switching pattern 'A' corresponds to the sequence:

1 2 3 4 . . . 1 2 3 4 . . . 1 2 3 4 . . .

whilst antenna switching pattern 'B' corresponds to the sequence:

1 2 3 4 . . n-4 n-3 n-2 n-1 n n-1 n-2 n-3 n-4 . . 4 3 2 1 2 3 4 . .

### 8.3.13.3 AoD modes

When sending an AoD CTE, there are two possible modes of operation:

1. *Simulate*. The amplitude and phase modulations arising from antenna switching are simulated by the *Sapphire* application. The signal output on the *Tx/Rx* connector appears to have come from a switched antenna array.
2. *External*. The output of the *Tx/Rx* port is fed to an external antenna array. The external antenna array is switched using digital signals from the DIO connector on the rear panel of the *TLF3000*.

The user can select which mode of operation to use by toggling the *'Antenna array'* button.

If the antenna array is to be simulated, then the phases and amplitudes for each sample slot can be individually programmed. These are displayed in a table and the phase is plotted in a graph. Each value can be changed either by editing the text or using the up/down arrows of the spinbox. The phases must lie in the range  $-360^\circ$  to  $+360^\circ$ . The amplitudes are relative to the amplitude of the main portion of the packet and must lie within the range  $-10\text{dB}$  to  $+6\text{dB}$ . If the amplitude of a switching slot is made greater than that of the main portion of the packet, then the maximum amplitude of the main portion of the packet will be reduced correspondingly, ie the maximum amplitude anywhere in the packet, including the CTE, cannot exceed  $0\text{dBm}$ .

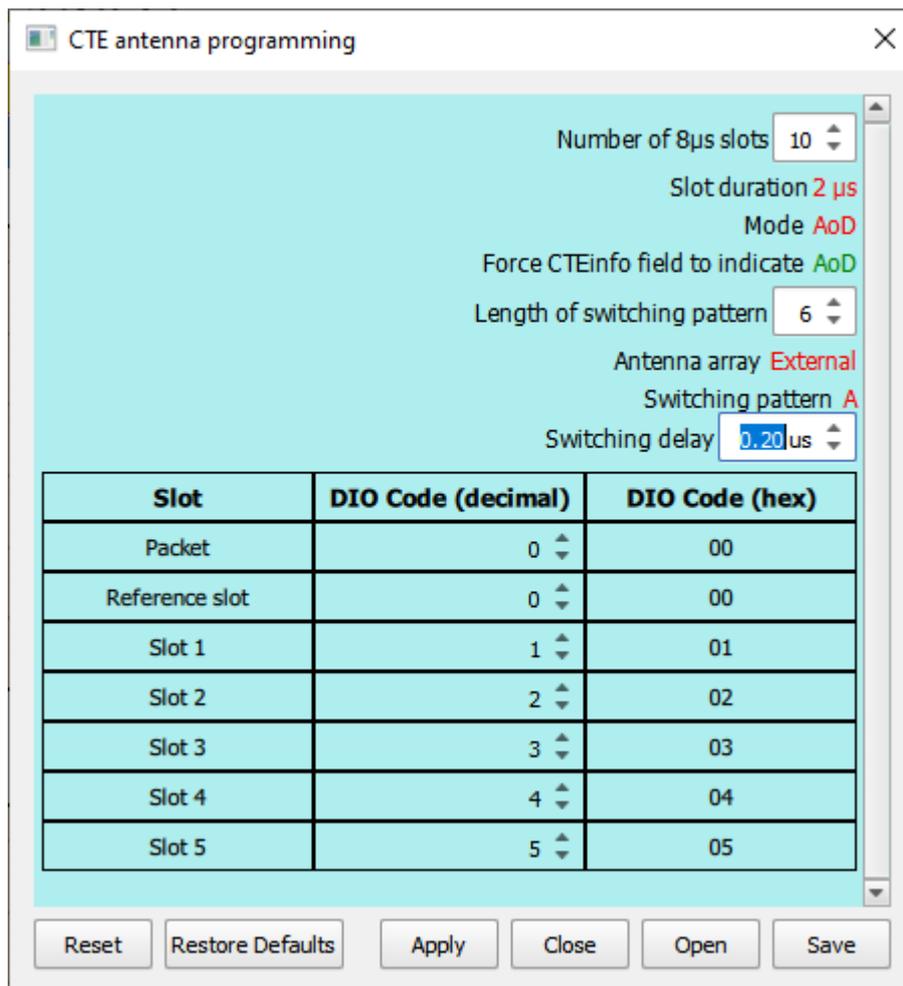


Figure 10: Programming external antenna array.

If an external antenna array is to be used, then a table is displayed showing the digitally generated output on the DIO connector for each sample slot. The DIO connector has 8 output lines. Each line can be individually set high or low for each sample slot. The DIO code displayed in the table is an 8 bit number representing the state of the 8 output lines during the sample slot. The LSB of the DIO code corresponds to the state of digital output line 0 and the MSB of the DIO code corresponds to the state of digital output line 7.

By default, the digital IO lines are switched at the middle of each switching slot. However, it is possible to advance or retard the switching time by using the 'Switch delay' spin box. This permits timing to be advanced or retards by up to 2µs relative to the centre of the switching slots. See [IO voltage levels](#) for how to set the signalling levels.

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### 8.3.13.4 CTE antenna programming buttons

The buttons along the bottom of the CTE antenna programming dialog perform the following functions:

1. *Reset*. All CTE parameters, antenna phases, antenna amplitudes and DIO codes are reset to the values they held when the CTE antenna programming dialog was popped up and all edits are discarded.
2. *Restore defaults*. All CTE parameters, antenna phases, antenna amplitudes and DIO codes are reset to Teledyne default values.
3. *Apply*. The current CTE parameters, antenna phases, antenna amplitudes and DIO codes will be used for all future transmissions.
4. *Close*. The CTE antenna programming dialog is closed. Any edits which have not be applied will be lost.
5. *Open*. The CTE parameters, antenna phases, antenna amplitudes and DIO codes will be loaded from an XML file.
6. *Save*. The currently displayed CTE parameters, antenna phases, antenna amplitudes and DIO codes will be saved to an XML file.

### 8.3.14 Detailed Phy parameters

The following details of the packet can be adjusted:

1. *Ramp time*. Time taken for the power to ramp up and down at the start and end of the packet
2. *Front porch'*. The length of unmodulated carrier inserted between the power ramp and the start of the first bit of the preamble.
3. *Back porch*. The length of unmodulated carrier inserted between the end of the last bit of the CRC or CTE and the start of the power ramp down.

By default, all these parameters are set at  $2\mu\text{s}$ , making the transmitted packets compliant with the reference signal definition of the Bluetooth 5.2 LE RF Phy Test Specification.

The '*Ramp time*' can be set between  $1.1\mu\text{s}$  and  $10\mu\text{s}$ .

The '*Front porch*' and '*Back porch*' can be set between  $0\mu\text{s}$  and  $12.7\mu\text{s}$ .

### 8.3.15 Digital output

To enable other test equipment to be synchronised with Sapphire's transmissions, it is possible to toggle digital output lines when a packet is being transmitted. The selected lines will be low between transmissions and go high during the transmission.

The *TLF3000* unit has 8 digital output lines. Lines are selected by toggling 'X' to '1' in the appropriate box.

If a digital output line is specified to monitor both wanted signal transmissions and modulated interferer transmissions or is also used to switch an external antenna array, then the state of the line is the logical OR of these signals.

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Digital output lines which are used as part of a serial interface to a DUT cannot be used to indicate the state of the *Sapphire* transmissions.

The IO voltage for the lines may be either:

1. An internal 3.3 V generated supply
2. An external supply in the range 0.8 V to 3.6 V

See [IO voltage levels](#) for how to set the signalling levels.

## 8.4 Programming the GFSK modulated interferer signal

### 8.4.1 Overview

Sapphire can generate a GFSK modulated interferer signal which may be either continuous or packetised. This signal is required to perform receiver C/I and intermodulation tests.

To turn the modulated interferer signal on or off, toggle the switch to the left of the *'Interferer'* text.

To program the modulated interferer signal, expand the *'Interferer'* signal menu by clicking on it:

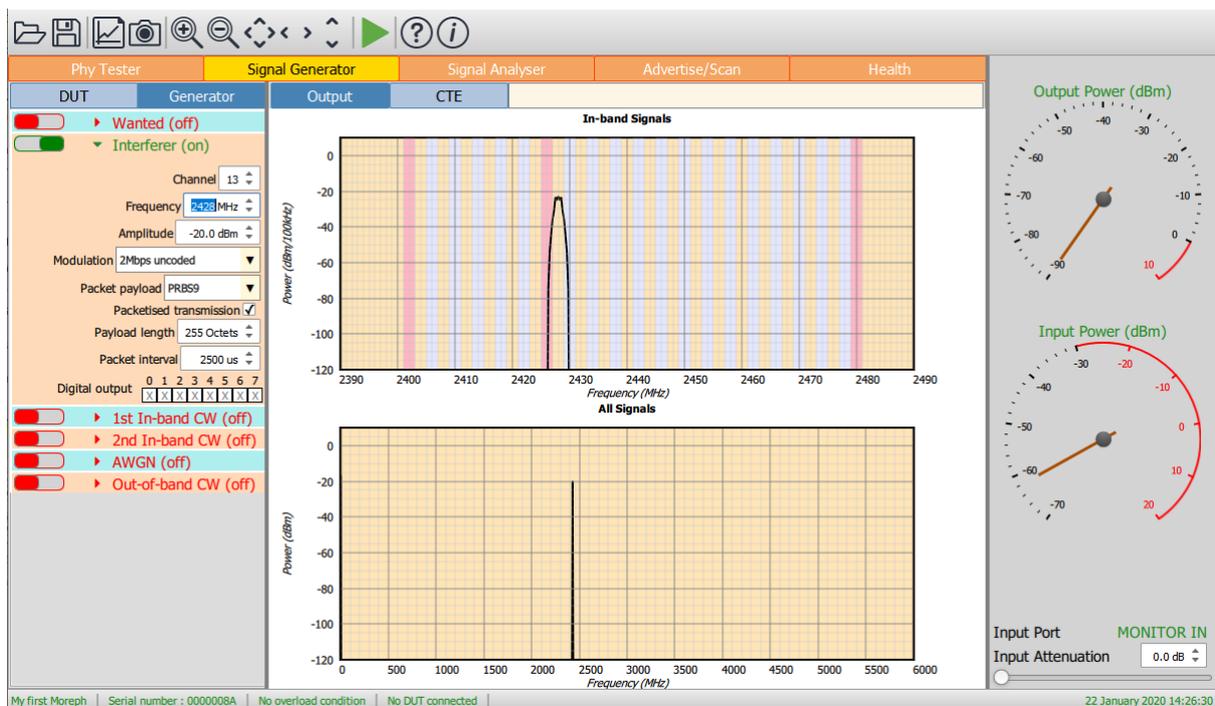


Figure 11: Programming the modulated interferer signal.

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### 8.4.2 Carrier frequency

The frequency of the carrier can be set by:

1. Using the channel number spin box
2. Using the frequency spin box

As with all spin boxes, adjustment can be performed either by using the up/down arrows or by entering a numeric value into the text field.

If 1Mbps, 500kbps or 125kbps modulation is selected, then the carrier frequency can be set to any integer MHz between 2395MHz and 2485MHz inclusive. Odd MHz frequencies do not coincide with LE channels, so are denoted by LE channels plus 0.5. Channel numbers are extended beyond the range 0 to 40 to encompass frequencies outside the range 2402 to 2480MHz.

If 2Mbps modulation is selected, then the carrier frequency can be set to any value between 2396MHz and 2486MHz inclusive, in steps of 2MHz. Channel numbers are extended beyond the range 0 to 40 to encompass frequencies outside the range 2402 to 2480MHz.

If the receiver intermodulation tests are being performed on channels near the band edges, then the required frequency for the modulated interferer signal may fall outside the 2402-2480MHz band. For large values of the frequency separation parameter 'n' (as defined in the Bluetooth 5.2 LE RF Phy Test Specification), the required frequency may also fall outside the 2395MHz to 2485MHz range supported by the *Sapphire* application. Under these circumstances it will not be possible to perform the intermodulation test. This is one of two areas where the test coverage of the *Sapphire* application is not compliant with the Bluetooth 5.2 LE RF Phy Test Specification. However, the intermodulation test has to be performed with the interfering signals both above and below the wanted signal. The *Sapphire* application can always perform the test cases where the interferer signals lie within the 2.4GHz band. When the interfering signals lie outside the 2.4GHz band, it is highly likely that they will suffer some attenuation from the receiver's front-end filtering. Therefore, it is unlikely that a device will pass the intermodulation test when the interfering signals lie within the 2.4GHz band, but fail when the interfering signals lie outside the 2.4GHz band.

### 8.4.3 Amplitude

The amplitude of the modulated interferer signal can be adjusted from -120dBm to 0dBm. The total combined output power of the unit within the 2.4GHz ISM band is 0dBm. Therefore, if other signals are active, the maximum output power for the modulated interferer signal will be reduced to maintain the peak output power within the 0dBm limit.

### 8.4.4 Modulation

The modulation may be set to anyone of the Bluetooth 5.2 LE RF Phys:

1. 2Mbps, GFSK
2. 1Mbps, GFSK
3. 500kbps, s=2 spreading, GFSK
4. 125kbps, s=8 spreading, GFSK

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The 1Mbps, 500kbps & 125kbps signals are all bandlimited to 2MHz, whilst the 2Mbps signals are bandlimited to 4MHz. The suppression of sidebands outside the band limit is extremely high. This is essential to ensure that the wanted signal is not being swamped by sidebands from the modulated interfering signal during C/I tests.

If the modulation is changed to 2Mbps, then the carrier frequency will automatically be altered if it is not a multiple of 2MHz.

No transmitter distortions are applied to the modulated interfering signal. To apply transmitter distortions to the interfering signal, use Tanzanite, the *TLF3000* Bluetooth 5.2 LE traffic generator application.

### 8.4.5 Payload

The packet payload can be set to any one of the following:

1. PRBS9 sequence, as defined in the Direct Test Mode section of the Bluetooth 5.2 Core Specification
2. PRBS11 sequence
3. PRBS15 sequence, as defined in the Direct Test Mode section of the Bluetooth 5.2 Core Specification
4. PRBS20 sequence
5. PRBS23 sequence
6. PRBS29 sequence
7. PRBS31 sequence

For packetised transmissions, the selected PRBS sequence is used to modulate the access code, header, payload and CRC fields.

If other payloads are required, then the user should use Tanzanite, a Bluetooth 5.2 LE traffic generator application compatible with *TLF3000*.

### 8.4.6 Packetisation

The modulated interferer signal can either be continuous or packetised. The Bluetooth 5.2 LE RF Phy Test Specification stipulates that the signal should be continuous. However, the use of a packetised signals can often reveal issues with IP2 performance in low-IF receiver architectures.

To turn the interferer from continuous to packetised, check the "*Packetised transmission*" checkbox. Once this box is checked, the user will have the ability to enter payload length and the packet interval for the packetised transmission. The payload length can be in the range 0 to 255 bytes. The packet interval is the time between the start of one packet and the start of the subsequent packet. Intervals of up to 100ms can be entered. The minimum interval which can be entered is determined by the payload length and modulation scheme.

### 8.4.7 Digital output

To enable other test equipment to be synchronised with Sapphire's transmissions, it is possible to toggle digital output lines when the modulated interferer signal is being transmitted. The selected lines will be low prior to transmission and go high during the transmission.

The *TLF3000* unit has 8 digital output lines. Lines 2 to 7 are available for signalling modulated interferer transmission. Lines are selected by toggling 'X' to '1' in the appropriate box.

If a digital output line is specified to monitor both wanted signal transmissions and modulated interferer transmissions or is also used to switch an external antenna array, then the state of the line is the logical OR of these signals.

Digital output lines which are used as part of a serial interface to a DUT cannot be used to indicate the state of the *Sapphire* transmissions.

The IO voltage for the lines may be either:

1. An internal 3.3 V generated supply
2. An external supply in the range 0.8 V to 3.6 V

See [IO voltage levels](#) for how to set the signalling levels.

## 8.5 Programming the in-band CW signals

### 8.5.1 Overview

Sapphire can generate up to two in-band (i.e. 2395MHz to 2485MHz) CW interferer signals. One of these signals is required to perform receiver intermodulation tests.

To turn an in-band CW interferer signal on or off, toggle the switch to the left of the '*1st In-band CW*' or '*2nd In-band CW*' text.

To program the in-band CW interferer signal, expand the '*1st In-band CW*' or '*2nd In-band CW*' menu by clicking on it:

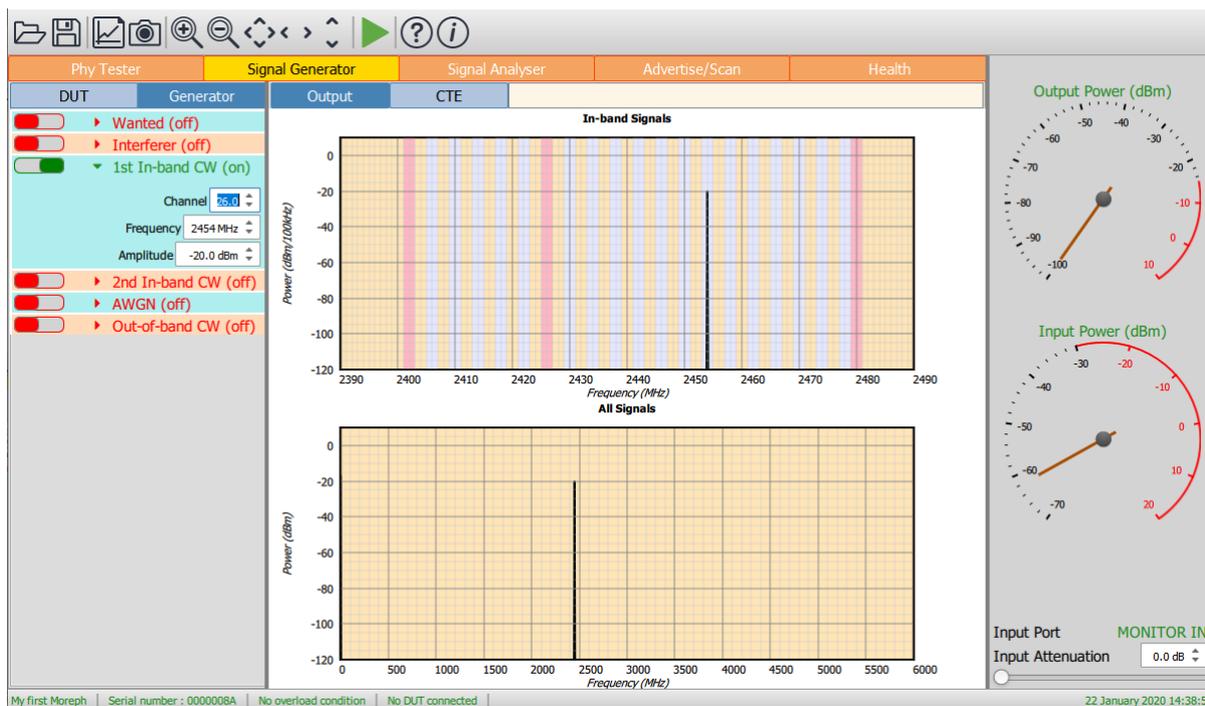


Figure 12: Programming the in-band CW interferer signal.

### 8.5.2 Frequency

The frequency of the in-band CW interferer signal can be set by:

1. Using the channel number spin box
2. Using the frequency spin box

As with all spin boxes, adjustment can be performed either by using the up/down arrows or by entering a numeric value into the text field.

The frequency can be set to any integer MHz between 2395MHz and 2485MHz inclusive. Odd MHz frequencies do not coincide with LE channels, so are donated by LE channels plus 0.5. Channel numbers are extended beyond the range 0 to 40 to encompass frequencies outside the range 2402 to 2480MHz.

### 8.5.3 Amplitude

The amplitude of the in-band CW interferer signal can be adjusted from -120dBm to 0dBm. The total combined output power of the unit within the 2.4GHz ISM band is 0dBm. Therefore, if other signals are active, the maximum output power for the in-band CW interferer signal will be reduced to maintain the peak output power within the 0dBm limit.

## 8.6 Programming the AWGN source

### 8.6.1 Overview

The AWGN source provides uniform output power from 2395MHz to 2485MHz. This source can be used to artificially reduce the signal-to-noise of a signal. The AWGN source can be continuous or pulsed.

To turn the AWGN source on or off, toggle the switch to the left of the 'AWGN' text.

To program the AWGN source, expand the 'AWGN' signal menu by clicking on it:



Figure 13: Programming the in-band AWGN source.

### 8.6.2 Amplitude

The amplitude of the AWGN source can be set in the range -162dBm/MHz to -42dBm/MHz. The total combined output power of the unit within the 2.4GHz ISM band is 0dBm. Therefore, if other signals are active, the maximum output power for the AWGN source will be reduced to maintain the peak output power within the 0dBm limit.

## 8.7 Programming the out-of-band CW signal

### 8.7.1 Overview

Sapphire can generate an out-of-band CW interferer signal. This signal is required to perform receiver blocking tests.

To turn the out-of-band CW interferer signal on or off, toggle the switch to the left of the 'Out-of-band CW' text.

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To program the out-of-band CW interferer signal, expand the 'Out-of-band CW' signal menu by clicking on it:

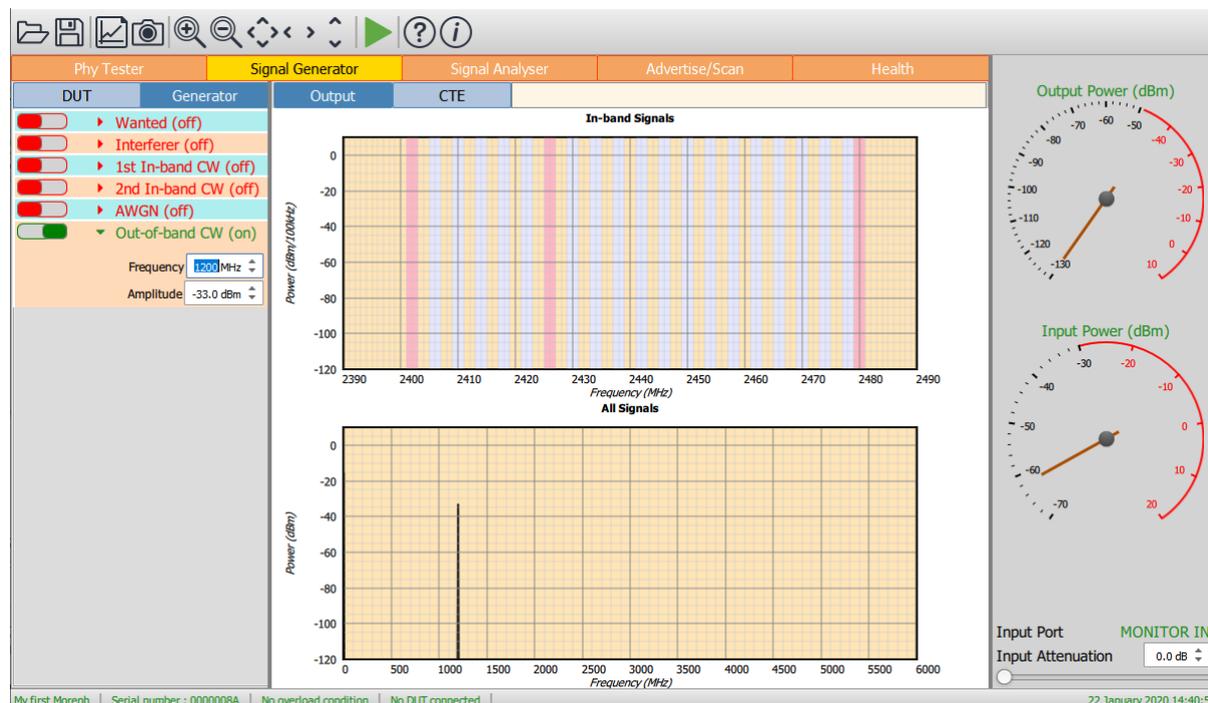


Figure 14: Programming the out-of-band CW interferer signal.

### 8.7.2 Frequency

The frequency of the out-of-band CW interferer signal can be set by using the frequency spin box. The frequency can be set to any integer MHz between 24MHz and 6GHz.

The Bluetooth 5.2 LE RF Phy Test Specification requires that the blocker frequency be swept from 30MHz to 12.75GHz. The *Sapphire* application cannot provide the blocker frequencies above 6GHz. The 6GHz upper limit does encompass the second harmonic of the 2.4GHz band; therefore it is unlikely that a device which passes the blocking test below 6GHz will fail above 6GHz. However, this is one of the two areas where the test coverage of the *Sapphire* application does not meet the full Bluetooth 5.2 LE RF Phy Test Specification.

### 8.7.3 Amplitude

The amplitude of the out-of-band CW interferer signal can be adjusted from -50dBm to -28dBm.

The amplitude of the out-of-band CW interferer signal does not impact the maximum amplitude of the in-band signals. The energy of the out-of-band CW interferer signal is excluded from the power indicated by the 'Output power' gauge in the monitor panel.

## 8.8 Saving and restoring settings

The current collection, analysis and limit settings can be saved by clicking the 'Save' button on the toolbar. Select the 'Signal generator settings (\*.sgs)' file type to save the current settings.

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An existing signal generator settings file (\*.sgs) can be opened using the 'Open' button on the toolbar.

The signal generator settings file (\*.sgs) is an XML file. It is not recommended that this file be edited manually. If it needs to be modified, open it from the signal generator, modify the required parameters and re-save.

### 8.9 Measuring PER with the signal generator

To measure PER directly with the signal generator, a DUT must be connected via a serial interface using either direct test mode or HCI. The DUT receiver should be connected to the Tx/Rx port of the TLF3000 unit.

The wanted signal of the signal generator must have the following properties:

1. Test access address (0x71764129)
2. Advertise/Test CRC seed (0x555555)
3. Whitening disabled
4. PRBS9 payload
5. Continuous transmission must be disabled

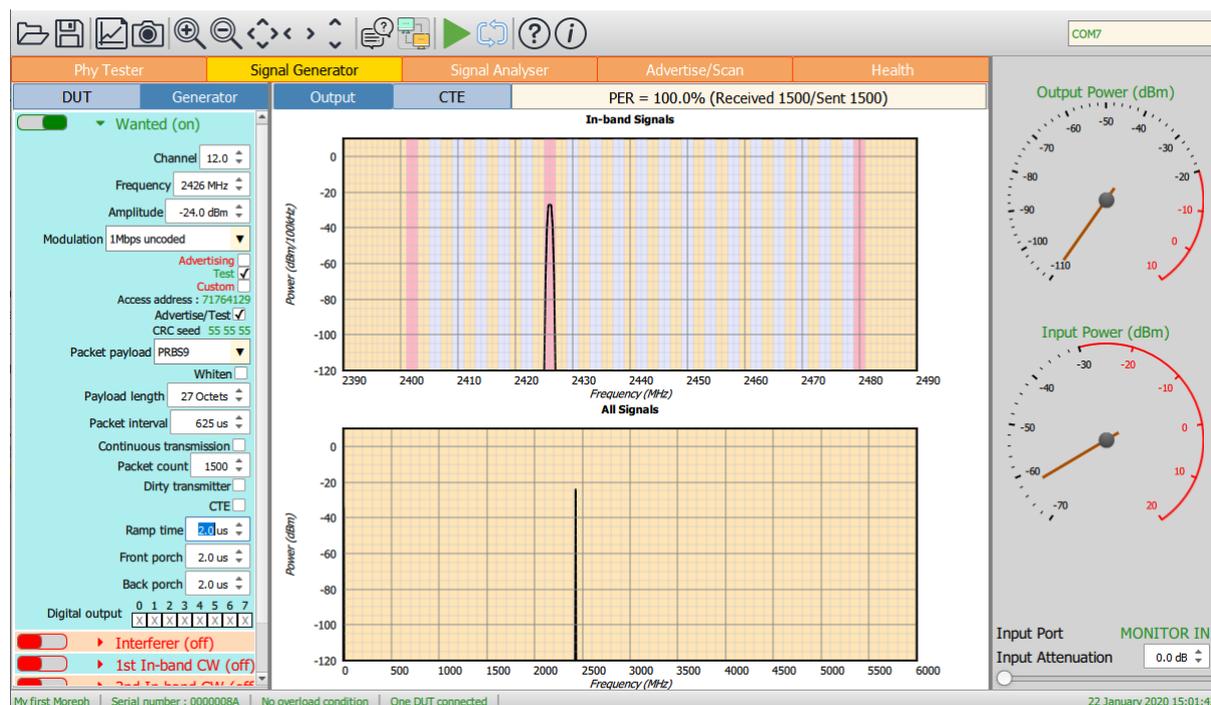


Figure 15: Measuring PER is signal generator mode.

When the 'Run' button is pressed, the signal generator will send the specified number of packets to the DUT. Once these have been sent, the signal generator will ask the DUT how many packets were received. The signal generator will then calculate the PER and display it at the top right of the graphics area.

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For continuous updates of the PER, depress the 'Repeat' button on the toolbar and then the 'Run' button. To exit continuous update mode, release the 'Repeat' button.

Whilst PER measurements are being made it is possible to adjust:

1. Any of the wanted signal parameters, including dirty transmitter and CTE
2. Any of the interferer parameters

A new PER calculation will be started whenever parameters are changed.

### 8.10 Displaying CTE IQ data with the signal generator

#### 8.10.1 Overview

If a DUT is connected via an HCI interface, then it is possible to display the CTE IQ data recorded by the DUT. The 'DUT features' menu must have the appropriate AoA/AoD features set. This can either be done by entering them manually or by using the 'Query' button on the toolbar to read the DUT supported features over HCI.

#### 8.10.2 AoD

In AoD mode, the IQ samples recorded by the DUT should reflect the CTE amplitudes and phases transmitted by the signal generator. To display the IQ amplitudes and phases, select the 'CTE' tab at the top of the graphics area.

The amplitude graph draws a red line in each sample slot to indicate the IQ amplitude.

The phase graph draws a red line in each sample slot to indicate the IQ phase. It also draws a blue dot at the centre of each sample slot to indicate the phase change from the previous sample slot.

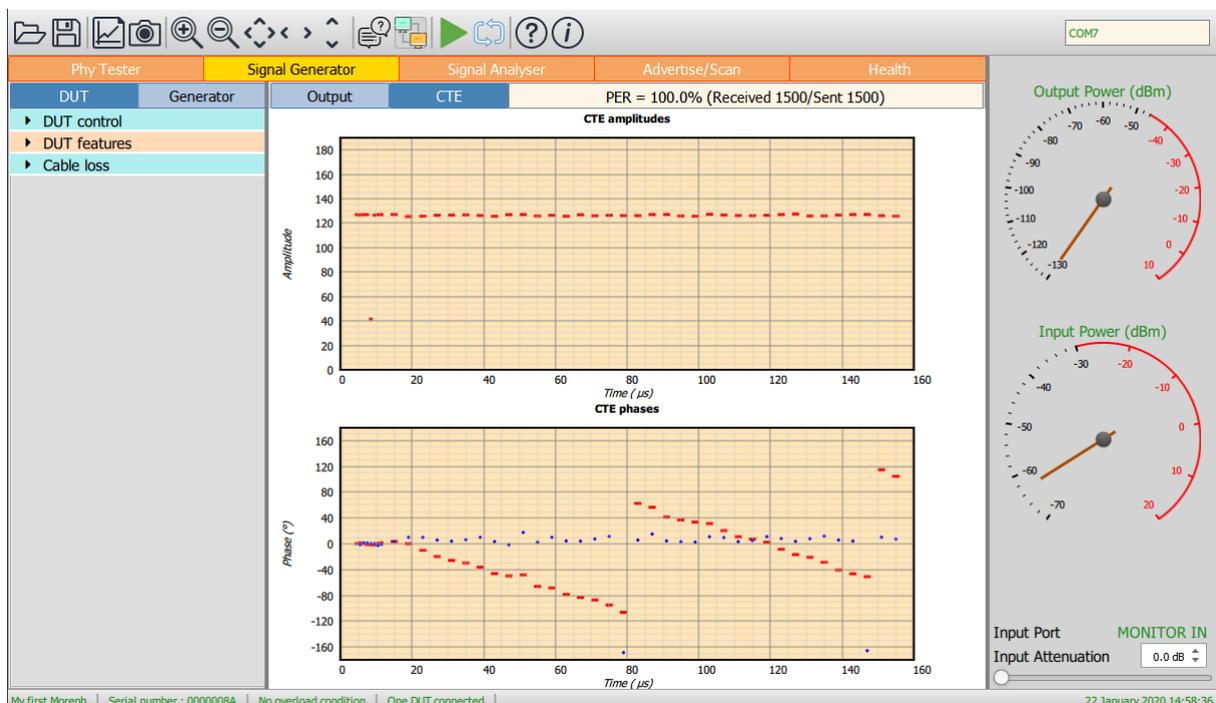


Figure 16: Displaying AoD CTE IQ samples in signal generator mode.

### 8.10.3 AoA

In AoA mode it is necessary to specify the DUT antenna switching parameters. These parameters are located in the 'DUT antenna' menu under the 'DUT' tab of the mode control panel. The range these parameters can take will be limited by the supported features of the DUT.

The CTE switching slot duration can be set at either 2µs or 1µs, provided the DUT supports these rates.

The antenna switching pattern length can be set between 2 and the maximum switching pattern length supported by the DUT.

For each element in the switching pattern, a spin box will be displayed to indicate the antenna ID for that switch slot. The antenna IDs available are specific to the DUT design and cannot be deduced by the Sapphire application.

To display the IQ amplitudes and phases, select the 'CTE' tab at the top of the graphics area.

The amplitude graph draws a red line in each sample slot to indicate the IQ amplitude.

The phase graph draws a red line in each sample slot to indicate the IQ phase. It also draws a blue dot at the centre of each sample slot to indicate the phase change from the previous sample slot.

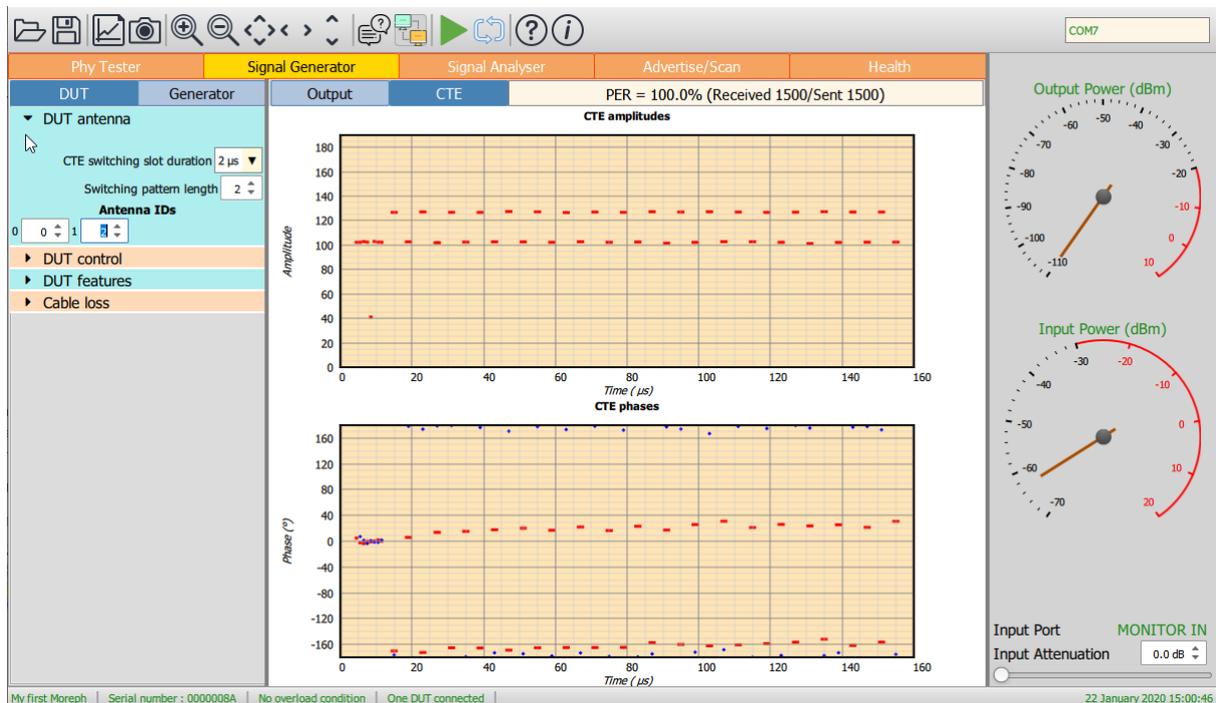


Figure 17: Displaying AoA CTE IQ samples in signal generator mode.

## 9 Signal Analyser Mode.

### 9.1 Overview

In signal analyser mode, the *Sapphire* application is able to analyse incoming signals against the Bluetooth 5.2 LE RF Phy Specification. The application is able to analyse both conducted and off-air signals. If a DUT is generating the packets to be analysed, then this can be controlled directly from the signal analyser. The analysis can be performed on LE test packets or can be payload agnostic. All 40 LE channels are monitored simultaneously, as are all four of the LE RF Phys defined in Bluetooth 5.2. Hence there is no requirement to program the signal analyser to look on a specified channel or to look for a specified Phy. The signal analyser accumulates results separately for each channel, modulation scheme and packet length. This permits the results to be filtered and displayed in a number of different ways. Data is collected from 100µs prior to the preamble until 100µs after the CRC or CTE, permitting the power ramp up and down to be examined.

The left-hand mode control panel is divided into three separate tabs:

1. *DUT*. This tab allows a DUT to be connected to the *Sapphire* application and the transmissions from the DUT controlled.
2. *Collection*. This tab contains the parameters which define which signals will be collected and processed.
3. *Analysis*. This tab contains the parameters which define how the captured results will be displayed.

The central graphics area is used to plot the results. Tabs at the top of the graphics area determine the class of results which will be displayed. Parameters under the '*Analysis*' tab control the details of how the data is displayed.

Below the analysis tab is a results table which displays statistics of the test quantities defined in the Bluetooth 5.2 LE RF Phy Test Specification. The class of results which are displayed is determined by the tabs at the top of the graphics area. The results are filtered by the parameters set under the '*Analysis*' tab in the mode control panel. *If no results are displayed this may be because the analysis filter settings are inconsistent with the packets being received.*

The receiver port and front-end attenuation are set using the controls in the monitor panel on the right-hand side of the window.

Data collection is started/stopped by toggling the '*Play*' button on the toolbar.

The '*Clear*' button in the toolbar will discard all results which have been collected.

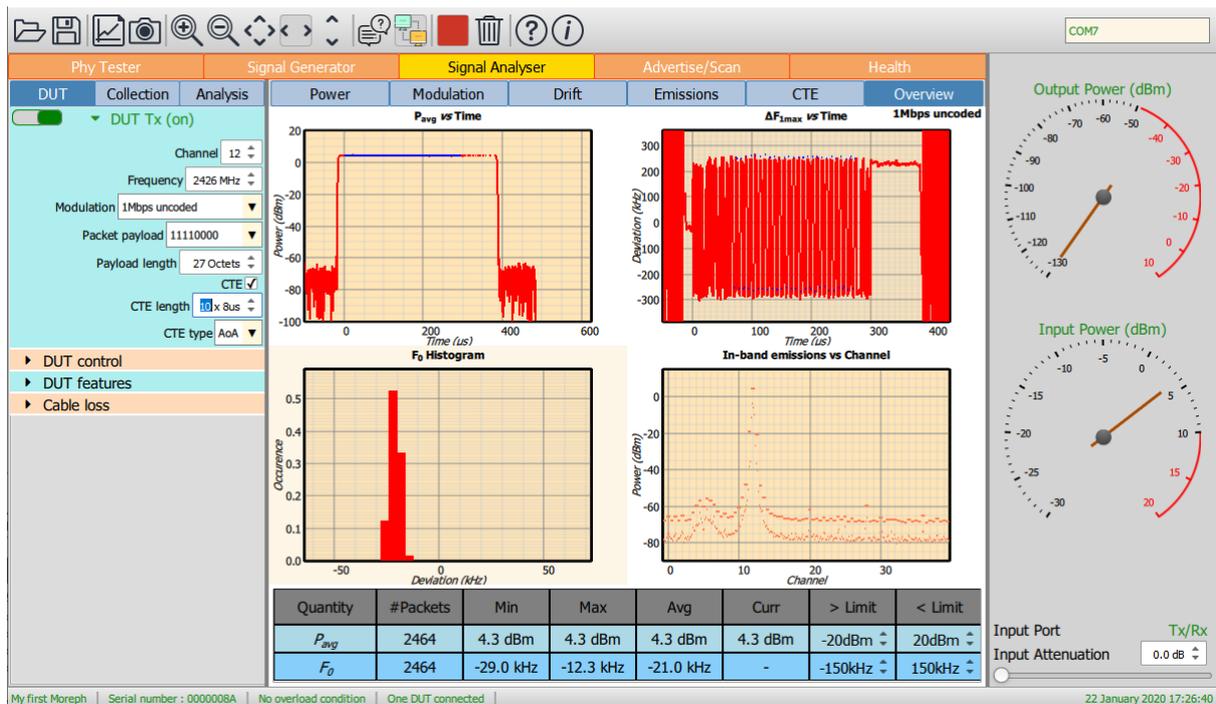


Figure 18: Sapphire GUI signal analyser mode.

## 9.2 RF connections

The signal analyser can monitor signals on either the 'Tx/Rx' port or the 'Monitor In' port. See [Selection of input port and input attenuation](#) on setting the RF input port.

## 9.3 Programming data collection

### 9.3.1 Overview

The data to be collected is determined the settings of the parameters under the 'Collection' tab of the mode control panel on the left-hand side of the window.

It is possible to select:

1. Which Bluetooth 5.2 LE test quantities are to be measured
2. Which Bluetooth 5.2 LE Phys are of interest
3. Which RF channels are of interest
4. Which packet lengths are of interest
5. The access address of the packets to be analysed
6. Whether the packets to be analysed are whitened
7. A minimum RSSI for collected packets
8. When the data analysis should terminate

### 9.3.2 Programming the measurements to be performed

Sapphire divides the Bluetooth LE RF Phy transmitter test measurements into five groups:

1. Power measurements, which includes:
  - a.  $P_{avg}$
  - b.  $P_k - P_{avg}$
2. Modulation characteristics, which includes:
  - a.  $\Delta F1_{max}$
  - b.  $\Delta F1_{avg}$
  - c.  $\Delta F2_{max}$
  - d.  $\Delta F2_{avg}$
  - e.  $\Delta F2_{avg} / \Delta F1_{avg}$
  - f.  $\Delta F2_{max} 99.9\%$
3. Drift and carrier offset measurements, which includes:
  - a.  $F_0$
  - b.  $F_n$
  - c.  $|F_1 - F_0|$  or  $|F_3 - F_0|$  for 125kbps
  - d.  $|F_0 - F_n|$
  - e.  $|F_n - F_{n-5}|$  or  $|F_n - F_{n-3}|$  for 125kbps
4. In-band emissions, which includes:
  - a.  $F_{tx} \pm 2\text{MHz}$  or  $F_{tx} \pm (4,5)\text{MHz}$  for 2Mbps
  - b.  $F_{tx} \pm (3+n)\text{MHz}$  or  $F_{tx} \pm (6+n)\text{MHz}$  for 2Mbps
  - c. Number of exceptions
  - d. Maximum exception
5. CTE measurements, which include:
  - a.  $FS_i$
  - b.  $FS_1 - F_p$
  - c.  $FS_i - F_0$
  - d.  $FS_i - FS_{i-3}$
  - e.  $P_{rev,dev} - P_{ref,ave}$
  - f.  $P_{n,dev} - P_{n,ave}$

Each of these groups of measurements can be individually selected under the 'Collect' menu of the 'Collection' tab.

If the 'waveform' item is selected, then raw IQ data for the last packet analysed is also saved. The raw IQ data is 32x oversampled, as per the Bluetooth 5.2 LE RF Phy Test Specification. Although it is possible to alter the oversampling ratio using the native language, this is currently not supported in the *Sapphire* GUI. If the 'waveform' item is selected, the volume of data which needs to be transferred to the host is large. This may have an impact on the rate at which packets can be analysed. If it is important to analyse packets as fast as possible, then it is advisable to disable collection of raw IQ data.

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The Bluetooth 5.2 LE RF Phy Test Specification requires the use of test packets. These packets have the 0x71764129 access address, a predefined header and one of 8 possible payloads. To enable less restrictive testing, Sapphire supports an ‘Off-air’ analysis mode. The ‘Off-air’ analysis mode is header and payload agnostic, but still provides good approximations to the quantities defined in the Bluetooth 5.2 LE RF Phy Test Specification. The ‘Off-air’ mode also performs analysis of the packet’s preamble, access address, header, payload and CRC. Any LE packet can be analysed in the ‘Off-air’ mode. The ‘Off-air’ mode does impose a greater processing load on the TLF3000 unit.

Results for the ‘Off-air’ mode are held separately from those of the conventional test packet mode. If ‘Off-air’ is selected in the ‘Collection’ menu, then only ‘Off-air’ results will be displayed.



Figure 19: Programming the data to be collected.

### 9.3.3 Programming which RF Phys to collect

The 'Modulation' menu permits selection of which RF Phys are to be collected and processed. One or more of the following can be selected:

- a. 2Mbps, uncoded
- b. 1Mbps, uncoded
- c. 500kbps, s=2 coded
- d. 125kbps, s=8 coded

The results for each RF Phy are accumulated separately.



Figure 20: Programming which RF Phys to collect.

### 9.3.4 Programming which RF channels to collect

The 'Channel' menu permits the RF channels on which data is to be collected and processed to be defined. *Note: these are RF channel numbers, not LE channel indices.*

The required RF channels can be selected by either:

1. Ticking the individual channel boxes
2. Using the quick channel group selection buttons:
  - a. Clear all
  - b. Select all
  - c. Primary advertising
  - d. Data/Secondary advertising
3. Entering a textual description

The textual description must be of the form:

$a_{start}:a_{step}: a_{stop}, b_{start}: b_{step}: b_{stop}, \dots$

This implies that all channels from  $a_{start}$  to  $a_{stop}$  in steps of  $a_{step}$  will be selected, plus all channels from  $b_{start}$  to  $b_{stop}$  in steps of  $b_{step}$ , etc.

If  $a_{step}$  is unity, then  $a_{start}:a_{step}: a_{stop}$  can be abbreviated to  $a_{start}: a_{stop}$ .

If  $a_{step}$  is equal to  $a_{stop}$  then  $a_{start}:a_{step}: a_{stop}$  can be abbreviated to  $a_{start}$ .



Figure 21: Programming which RF channels to collect.

### 9.3.5 Programming which packet lengths to collect

The 'Packet length' menu permits the LE packet lengths for which data is to be collected and processed to be defined.

Due to memory restrictions, individual packet lengths cannot be specified. Instead, the range of possible packet lengths is divided up into 32 groups, each group spanning 8 contiguous packet lengths.

The required packet lengths are selected by ticking the corresponding boxes. If all packet lengths are of interest, then clicking the 'All' box at the bottom of the menu will select all packet length groups.



Figure 22: Programming which packet lengths to collect.

### 9.3.6 Programming which access address to collect

Sapphire’s signal analyser will only collect and process packets with a specified access address. The access address to use is defined under the ‘Access Address’ menu.

Changing the access address can be useful under the following circumstances:

1. When it is necessary to collect and analyse off-air packets
2. When multiple test units are running simultaneously on a production line or characterisation rig and it is desired to minimise cross-interference

Note that *Sapphire* completely decouples the use of the test access address (0x71764129) from the contents of the packet. *Sapphire* can analyse any packet with the test access address or can analyse test packets with access addresses other than the test access address.

The access address menu allows direct selection of either the advertising access address of the test access address through check boxes. It is also possible to enter an arbitrary access address by directly editing the text field at the bottom of the menu. *Sapphire* does not make any checks between the arbitrary access address entered by the user and the constraints on access addresses set out in the Bluetooth 5.2 Core Specification.

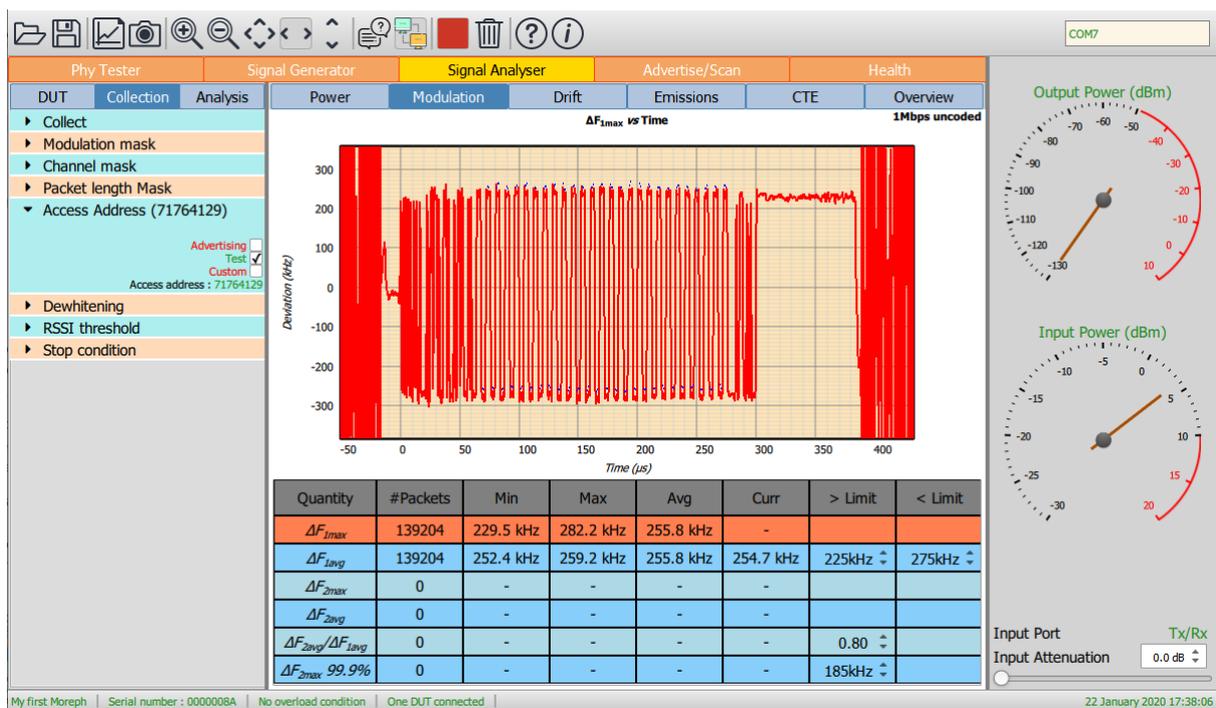


Figure 23: Programming which access address to collect.

### 9.3.7 Programming de-whitening of the packet

The Bluetooth 5.2 RF Phy Test Specification uses un-whitened test packets with the test access address (0x71764129). However, if it is desired to analyse packets off-air, it is likely that these will have had whitening applied. It is therefore necessary to inform the *Sapphire* data collection whether to expect whitened or un-whitened packets.

The selection of whether to process the packets as whitened or un-whitened is done via the single checkbox under the ‘*Dewhitening*’ menu.



Figure 24: Programming de-whitening of the packet.

### 9.3.8 Programming the RSSI threshold

The signal analyser will attempt to capture all signals with the specified access address provided they satisfy both the selected channel and packet length criteria. Without any further selectivity, the TLF3000 is more than capable of capturing signals from distant devices as well as the device under test. To help filter out unwanted devices, an RSSI threshold can be set. Only those packets with signal strengths above the RSSI threshold will be captured and analysed. The RSSI threshold can be set in the range -120dBm to +20dBm. The lower limit effectively disables the RSSI threshold.



Figure 25: Programming the RSSI threshold.

### 9.3.9 Programming the termination criterion

Once the signal analyser has been started by toggling the ‘Play’ button in the toolbar, it will continue to collect, process and display data until either:

1. The ‘Stop’ button in the toolbar is toggled
2. The stop condition has been set to ‘Stop on test failure’ and a test limit is failed

The ‘Stop on test failure’ condition is set by the single checkbox under the ‘Stop condition’ menu.

The test limits are shown in the results table. The penultimate column of the results table displays the lower limit and the final column the upper limit. They can be altered by changing the values in the spin boxes, either by using the up/down arrows or by entering numeric text directly.

Some limit values are shared between different modulation schemes whilst others are specific to a modulation scheme. The table below shows whether limits values are shared or are specific for each test category and modulation scheme:

Test	Modulation			
	2Mbps	1Mbps	500kbps	125kbps
Power	Shared	Shared	Shared	Shared
Modulation	2Mbps specific	Shared	Shared	125kbps specific
Drift & carrier offset	Shared	Shared	LR specific	LR specific
In-band emissions	2Mbps specific	Shared	Shared	Shared
CTE	Shared	Shared	N/A	N/A

Table 7: Table expressing whether limits values are shared or specific for each test category and modulation scheme.

The limit values shown in the results table apply to the modulation scheme currently being received. This is displayed in the top right-hand corner of the graphics area.

When a limit fail is detected, and the stop condition has been set to ‘Stop on test failure’, then the GUI will automatically alter its graphics and tabular display to reflect the quantity that failed. It is possible that a rogue packet will fail more than one test limit, so the data displayed may only partially reflect the reason why the packet failed.

If waveform collection has been enabled under the ‘Collect’ menu, then the IQ data displayed refers to the packet which failed. This provides an invaluable mechanism for catching rogue packets, particularly when monitoring links off-air, and then determining where in the packet the problem occurred.

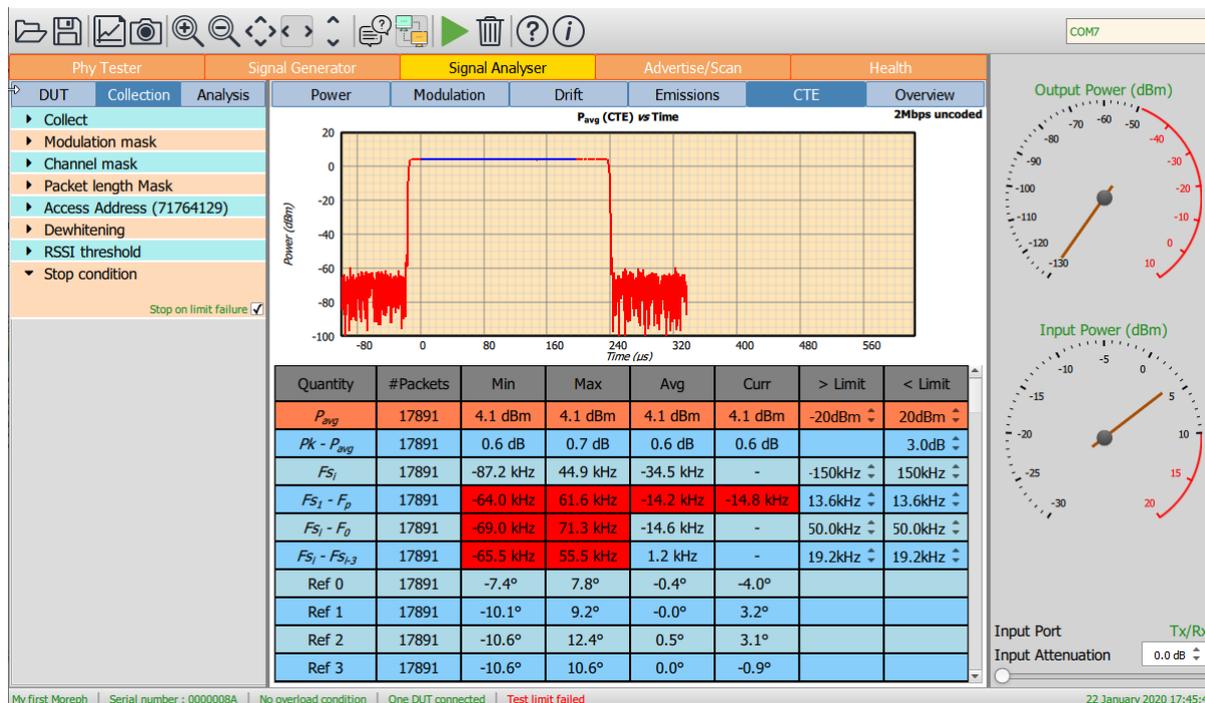


Figure 26: Programming the termination criterion.

### 9.3.10 Selecting the RF input port

The signal analyser can monitor signals on either the '*Monitor In*' RF port or the '*Tx/Rx*' RF port. The selection of which port is used is made clicking the port displayed towards the bottom of the monitor panel.

The '*Monitor In*' port is designed for monitoring signals off-air. The '*Tx/Rx*' port is designed for conducted measurements.

**If the monitor panel shows a lack of RF input energy, check that the DUT is connected to the same RF port as selected by the label at the bottom of the monitor panel.**

### 9.3.11 Adjusting the RF frontend attenuation

The RF frontend attenuation is set via either:

1. The slider at the bottom of the monitor panel
2. The spin box at the bottom of the monitor panel

The RF frontend attenuation can be set between 0dB and 31.5dB in steps of 0.5dB.

To set the RF attenuation, the '*Input Power*' gauge on the monitor panel must be examined. This shows both the current input signal level (the position of the needle) and the point at which saturation of the *TLF3000* receiver will occur (the red arc). The RF attenuation should be adjusted such that the input signal level is just below the saturation level.

If too little attenuation is applied, then there is a danger that the *TLF3000* receiver will be overloaded. An overload condition on the receiver is indicated by:

1. The needle on the '*Input Power*' gauge on the monitor panel entering the region of the red arc (the input power measurement is only approximate, so this is only a rough guide)
2. The title of the '*Input Power*' gauge on the monitor panel turning red
3. The text '*Rx overload*' appearing in red within the status bar at the bottom of the window

If too much attenuation is applied, then the test results may become unreliable. In order to calculate the frequency deviation within a packet, an FM demodulation process is employed. The quality of the output of the FM demodulation process is critically dependent on the signal-to-noise ratio of the signal at the input to the demodulator. If too much attenuation is applied, then the signal to be analysed will be pushed down towards the *TLF3000* receiver noise floor and the accuracy of the test results will be compromised.

## 9.4 Controlling data analysis and presentation

### 9.4.1 Overview

The Sapphire application accumulates results independently for each:

1. LE RF Phy
2. LE RF channel
3. Packet length group

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In addition, results are accumulated separately for the 'Off-air' mode. The 'Analysis' tab in the mode control panel determines how these results are filtered and displayed. ***If no results are displayed, then it is possible that the current analysis filter does not correspond to any of the packets which have been collected.***

The tabs at the top of the graphics area determine which group of measurements will be displayed.

The displayed results are filtered according to the settings of the 'Modulation filter', 'Channel filter' 'Packet length filter' and 'CTE filter' menus. Note that the 'CTE filter' menu will only be displayed when CTE measurements are being viewed and selection of the 'Packet length filter' will no longer be available.

The graphics area shows a plot of one of the test quantities. This may be selected either through the 'Plot' menu or by highlighting a row in the results table. The 'Plot' menu also can also be used to define the format of the plot.

The results table shows the filtered results for the selected measurement group. It also contains the test limits.

### 9.4.2 Selecting the measurement group to display

Sapphire divides the Bluetooth 5.2 LE RF Phy transmitter test measurements into five groups:

1. Power measurements, which includes:
  - a.  $P_{avg}$
  - b.  $P_k - P_{avg}$
2. Modulation characteristics, which includes:
  - a.  $\Delta F1_{max}$
  - b.  $\Delta F1_{avg}$
  - c.  $\Delta F2_{max}$
  - d.  $\Delta F2_{avg}$
  - e.  $\Delta F2_{avg} / \Delta F1_{avg}$
  - f.  $\Delta F2_{max} 99.9\%$
3. Drift and carrier offset measurements, which includes:
  - a.  $F_0$
  - b.  $F_n$
  - c.  $|F1 - F_0|$  or  $|F3 - F_0|$  for 125kbps
  - d.  $|F_0 - F_n|$
  - e.  $|F_n - F_{n-5}|$  or  $|F_n - F_{n-3}|$  for 125kbps
4. In-band emissions, which includes:
  - a.  $F_{tx} \pm 2\text{MHz}$  or  $F_{tx} \pm (4,5)\text{MHz}$  for 2Mbps
  - b.  $F_{tx} \pm (3+n)\text{MHz}$  or  $F_{tx} \pm (6+n)\text{MHz}$  for 2Mbps
  - c. Number of exceptions
  - d. Maximum exception

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5. CTE measurements, which include:
  - a.  $FS_i$
  - b.  $FS_1 - F_p$
  - c.  $FS_i - F_0$
  - d.  $FS_i - FS_{i-3}$
  - e.  $P_{rev,dev} - P_{ref,ave}$
  - f.  $P_{n,dev} - P_{n,ave}$
  - g. *Sample slot phases*

The *Sapphire* GUI displays the results from just one of these measurement groups at any one time. The selection of which measurement group to display is accomplished through the tabs at the top of the graphics area. An 'Overview' of the key parameters is also available.

The *Sapphire* application stores results separately for the 'Off-air' mode. The 'Off-air' check box in the 'Collect' menu under the 'Collection' tab is used to select results which were collected in the 'Off-air' mode.

***If no results are displayed, then it is possible that no packets have been received or that the analysis measurement group selected is incompatible with the choice of collection measurement group(s).***

### 9.4.3 Filtering the displayed results by RF phy

The displayed results are filtered by the RF Phy. Only packets which match one of the Phys in the filter will be displayed. Separate results tables are maintained for each Phy. The currently displayed results table is for the last Phy successfully received which matched the Phy filter. This Phy is shown in the top right-hand corner of the graphics area.

The RF Phy filter is accessible from the 'Modulation filter' menu under the 'Analysis' tab. There is a separate checkbox for each RF Phy and a checkbox to allow all Phys to be selected.

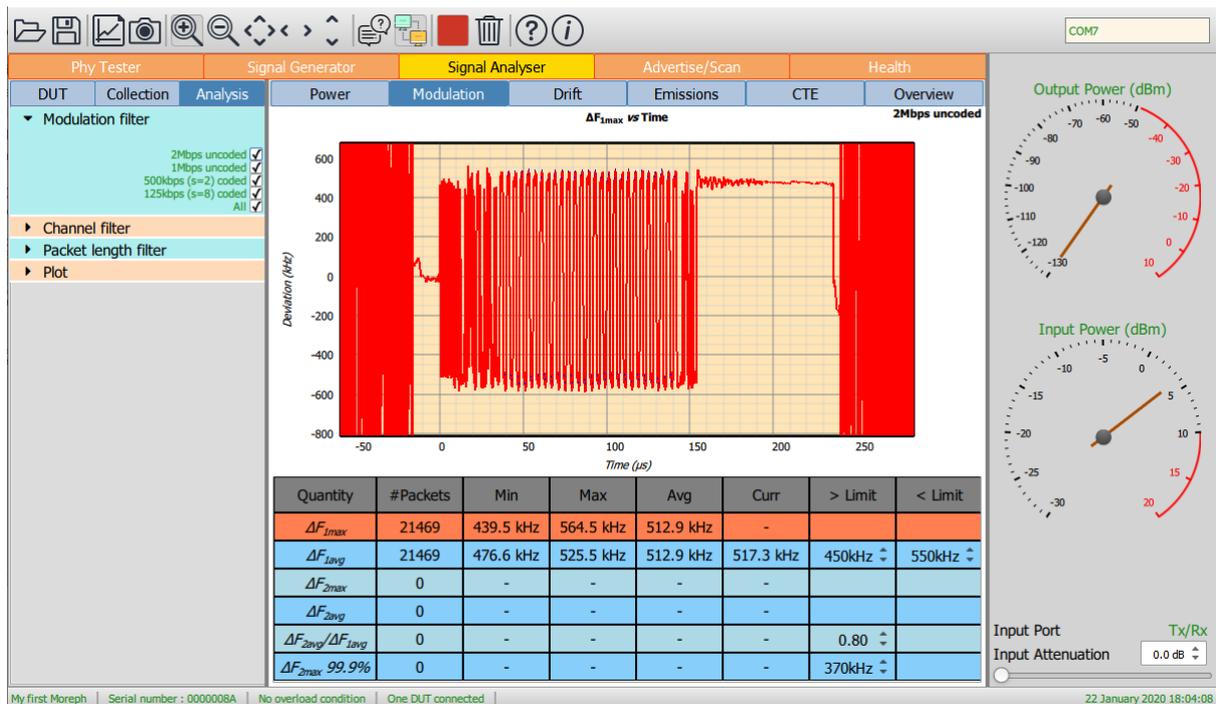


Figure 27: Filtering displayed results by RF Phy.

### 9.4.4 Filtering the displayed results by RF channel

The displayed results can be filtered by RF channel number. This facility may be useful when monitoring a live link and it is suspected that there is a problem with packet transfer on a particular RF channel. It also provides a simple means of comparing test results on different RF channels.

The RF channels used to filter the results are selected via the 'Channel filter' menu under the 'Analysis' tab. Note that the filtering is by RF channel number and not LE channel index.

The required RF channels can be selected by either:

1. Ticking the individual channel boxes
2. Using the quick channel group selection buttons:
  - a. Clear all
  - b. Select all
  - c. Primary advertising
  - d. Data/Secondary advertising
3. Entering a textual description

The textual description must be of the form:

$$a_{start}:a_{step}:a_{stop}, b_{start}:b_{step}:b_{stop}, \dots$$

This implies that all channels from  $a_{start}$  to  $a_{stop}$  in steps of  $a_{step}$  will be selected, plus all channels from  $b_{start}$  to  $b_{stop}$  in steps of  $b_{step}$ , etc.

If  $a_{step}$  is unity, then  $a_{start}:a_{step}:a_{stop}$  can be abbreviated to  $a_{start}:a_{stop}$ .

If  $a_{step}$  is equal to  $a_{stop}$  then  $a_{start}:a_{step}:a_{stop}$  can be abbreviated to  $a_{start}$ .



Figure 28: Filtering displayed results by RF channel.

### 9.4.5 Filtering the displayed results by packet length

The displayed results can be filtered by packet length. This provides a simple facility for monitoring transmitter quality as a function of packet length. Filtering by packet length is not available when CTE results are being displayed.

Due to memory restrictions, individual packet lengths cannot be specified. Instead, the range of possible packet lengths is divided up into 32 groups, each group spanning 8 contiguous packet lengths.

The packet length filtering is specified via the 'Packet length filter' menu under the 'Analysis' tab. The required packet lengths are selected by ticking the corresponding boxes. If all packet lengths are of interest, then clicking the 'All' box at the bottom of the menu will select all packet length groups.



Figure 29: Filtering displayed results by packet length.

### 9.4.6 Filtering the displayed results by CTE length

CTE results can be filtered by the contents of the CTE info field. This option is only available when displaying CTE results.

The CTE filtering is specified via the 'CTE filter' menu under the 'Analysis' tab.

If the 'AoA' box is checked, then CTE packets which have a CTEtype value of 0 in the CTE info field will be analysed.

If the 'AoD 1µs slots' box is checked, then CTE packets which have a CTEtype value of 1 in the CTE info field will be analysed.

If the 'AoD 2µs slots' box is checked, then CTE packets which have a CTEtype value of 2 in the CTE info field will be analysed.

It is also possible to filter on the basis of CTE length. The required CTE lengths are selected by ticking the corresponding boxes. If all CTE lengths are of interest, then clicking the 'All' box at the bottom of the menu will select all CTE lengths.

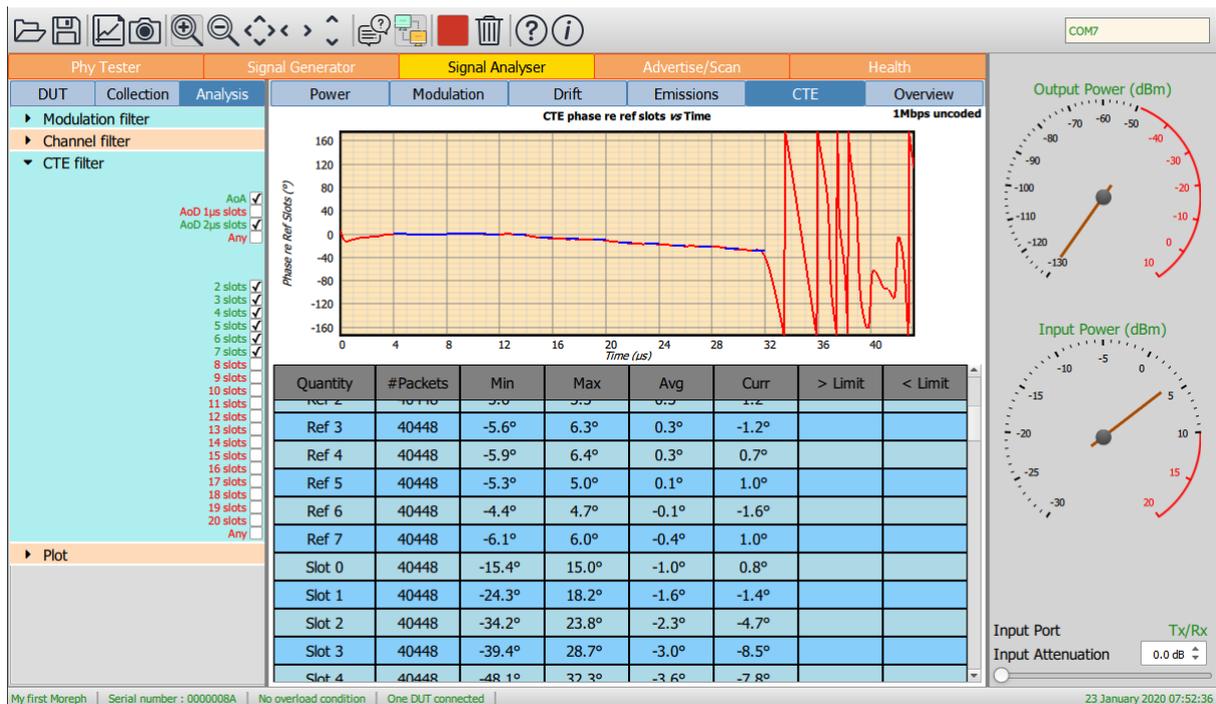


Figure 30: Filtering displayed results by CTE parameters.

### 9.4.7 Understanding the results table

The results table contains a summary of the results obtained from the selected measurement group when filtered by the selected RF Phy, RF channel, packet length and CTE fields.

The first column in the table contains the quantities defined in the Bluetooth 5.2 LE RF Test Specification which are members of the currently selected measurement group.

The second column in the table contains the number of packets which have contributed to the results for each measured quantity.

The third and fourth columns contain the minimum and maximum values which have been observed for each measured quantity.

The fifth column contains the average value of the measured quantity overall packets. If the units of the measured quantity are dBm or dB, then the average is the average of the dB values, not an average of the powers or linear ratios.

If the measured quantity is a scalar quantity, i.e. it has a single value per packet, then the last measured value is displayed in the sixth column.

For scalar quantities with test limits, the lower limit is contained in column seven and the upper limit in column eight.

Quantity	#Packets	Min	Max	Avg	Curr	> Limit	< Limit
$\Delta F_{1max}$	557204	478.2 kHz	530.6 kHz	504.6 kHz	-		
$\Delta F_{1avg}$	557204	500.9 kHz	502.6 kHz	499.8 kHz	501.5 kHz	450kHz ↕	550kHz ↕
$\Delta F_{2max}$	557204	413.0 kHz	499.8 kHz	458.4 kHz	-		
$\Delta F_{2avg}$	557204	455.5 kHz	458.5 kHz	459.9 kHz	456.3 kHz		
$\Delta F_{2avg}/\Delta F_{1avg}$	557204	0.907	0.914	0.907	0.910	0.80 ↕	
$\Delta F_{2max}$ 99.9%	557203	409.6 kHz	409.6 kHz	411.6 kHz	409.6 kHz	370kHz ↕	

Figure 31: The results table.

When the selected filters include more than one RF channel or packet length group, then the displayed values of minimum, maximum and average are the minimum, maximum and average over all packets which satisfy the selected filtering parameters.

Separate tables are held for each different modulation scheme and CTE type/length. The displayed table will be relevant to the modulation scheme and CTE type/length of the last received packet which matched the current filters. The modulation scheme of the last received packet which matched the current filters is displayed in the top right-hand corner of the graphics area. The CTE type/length of the last received packet which matched the current filters can be deduced from the contents of the results table.

If no measurement is available, then the symbol '-' is used to fill the corresponding table cell.

If a cell exceeds one of its test limits, then that cell is highlighted in red.

It is possible to select a row in the table by clicking on it. Once a row has been selected, the corresponding quantity will be plotted in the graphics areas. The format of the plot is controlled by the 'Plot' menu under the 'Analysis' tab.

## 9.4.8 Controlling the graphical data

### 9.4.8.1 Overview

The format of the graphical data being displayed is controlled by the 'Plot' menu under the 'Analysis' tab. The left-hand combo box lists all the quantities which are measured for the current measurement group (which is selected from the tabs at the top of the graphics area). These are the same quantities as displayed in the first column of the results table. The quantity to be plotted can be selected either through the combo box or by highlighting the appropriate row in the results table.

If the 'Overview' tab at the top of the graphics area has been selected, then the current measurement group is selected by clicking and highlighting one of the four graphs displayed.

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The right-hand combo box under the 'Plot' menu determines how the measured quantity is to be plotted. Options may include:

1. vs channel
2. vs RF Phy
3. vs packet length group
4. as a histogram
5. vs time (not available for in-band emission measurements)
6. vs frequency (only available for in-band emission measurements)

The screen update period can also be altered via the 'Plot' menu.

### 9.4.8.2 vs channel:

The quantity to be plotted is shown as a function of the RF channel number. For each RF channel the following quantities are displayed:

1. minimum observed value (bottom of pink bar)
2. average value (junction of green and pink bars)
3. maximum observed value (top of green bar)



Figure 32: Results vs channel.

### 9.4.8.3 vs RF Phy:

The quantity to be plotted is shown as a function of the RF Phy. For each RF Phy the following quantities are displayed:

1. minimum observed value (bottom of pink bar)
2. average value (junction of green and pink bars)
3. maximum observed value (top of green bar)

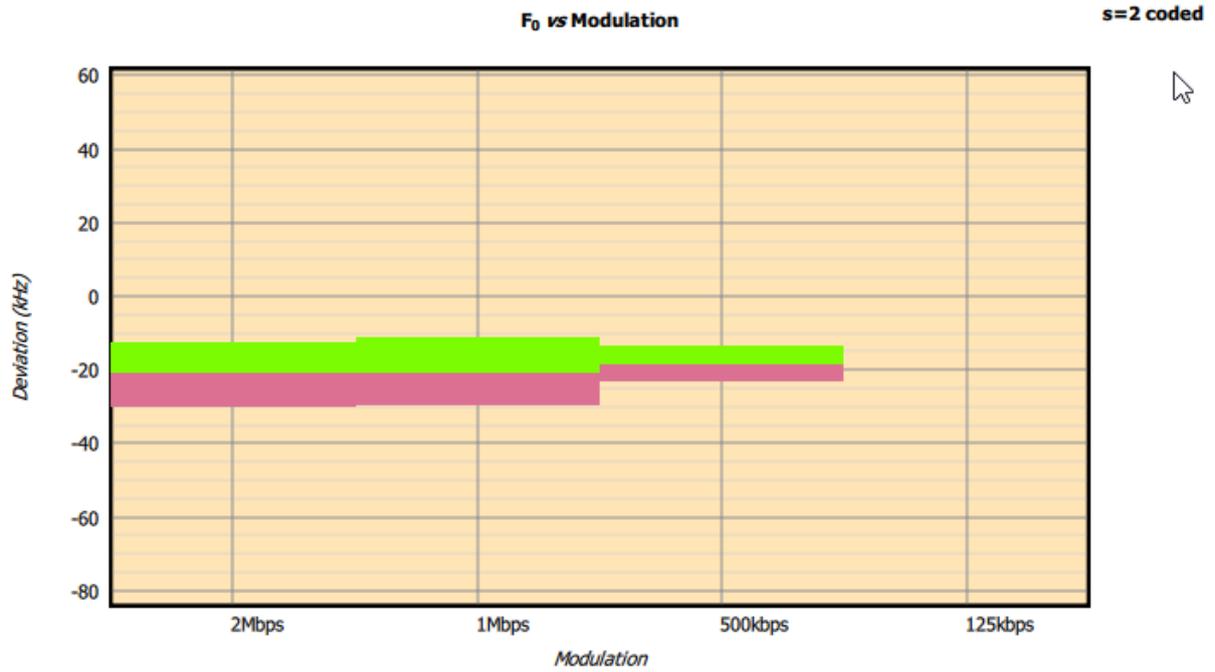


Figure 33: Results vs RF Phy.

9.4.8.4 vs packet length group:

The quantity to be plotted is shown as a function of the packet length group. For each packet length group the following quantities are displayed:

1. minimum observed value (bottom of pink bar)
2. average value (junction of green and pink bars)
3. maximum observed value (top of green bar)

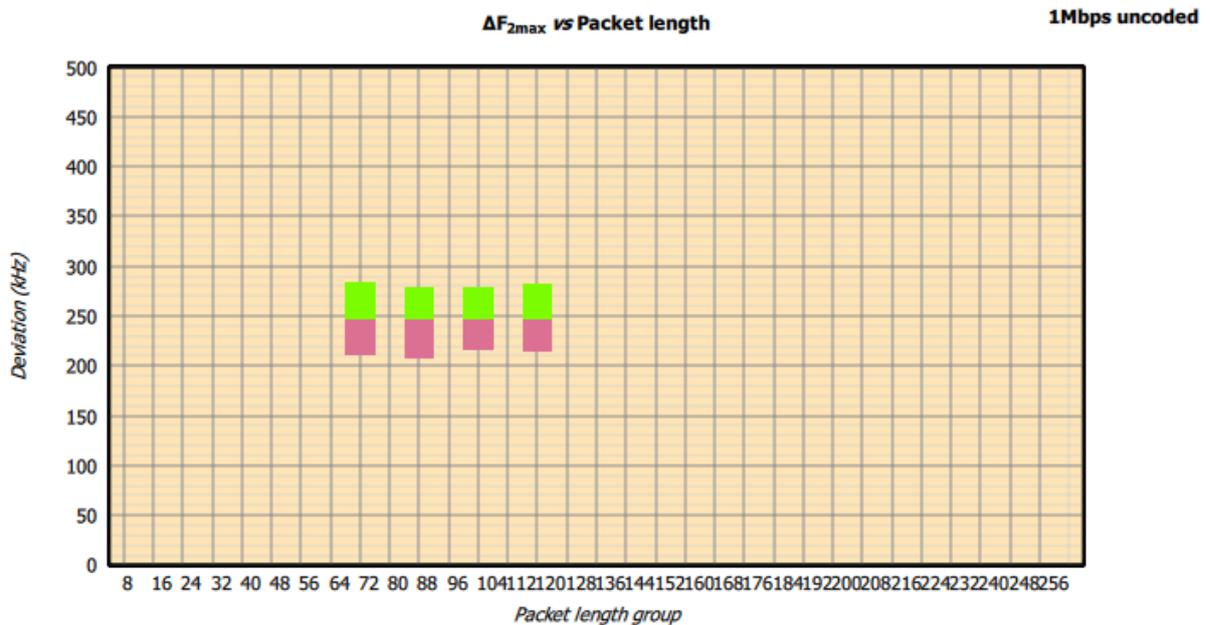


Figure 34: Results vs packet length group.

9.4.8.5 *Histogram*

A histogram of the plotted quantity is displayed.

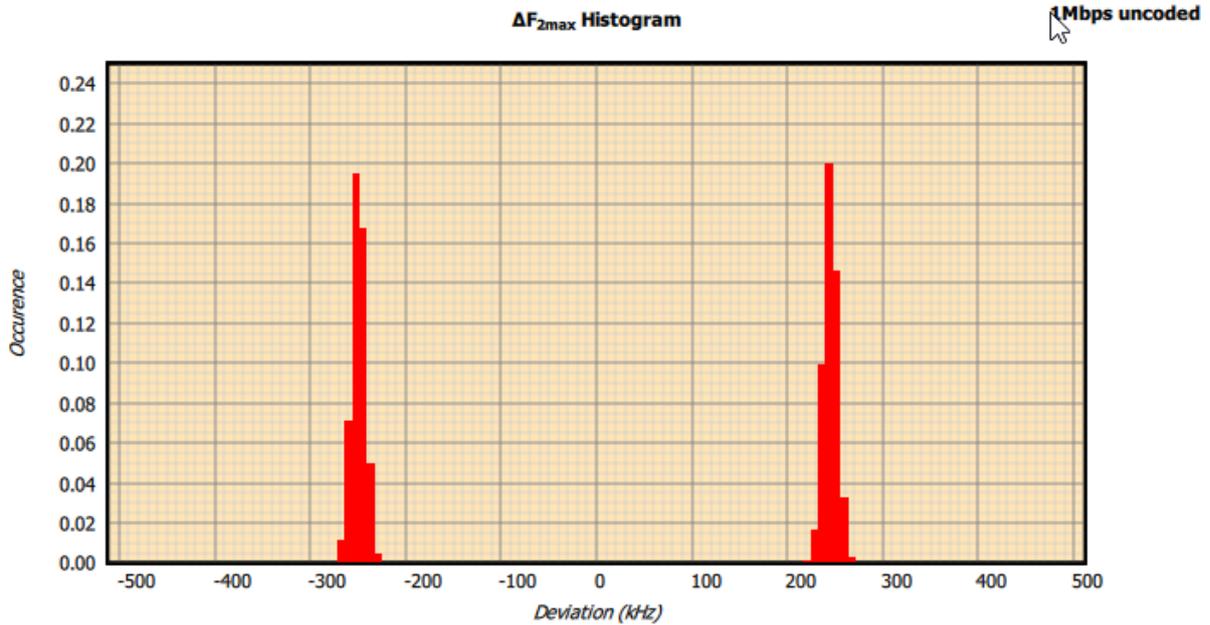


Figure 35: Results plotted as a histogram.

9.4.8.6 *vs time*

This option is not available for in-band emission tests.

**Non-CTE phase measurements**

The measured quantity is shown by the blue lines on the plot. The plot corresponds to the value(s) obtained from the last packet on which the selected quantity was measurable. If waveform collection has been enabled ('Collect' tab, 'Collect' menu) then either the frequency deviation or the packet power will also be displayed in red. ***The waveform data will only be displayed if the quantity to be plotted was measurable on the last received packet.***

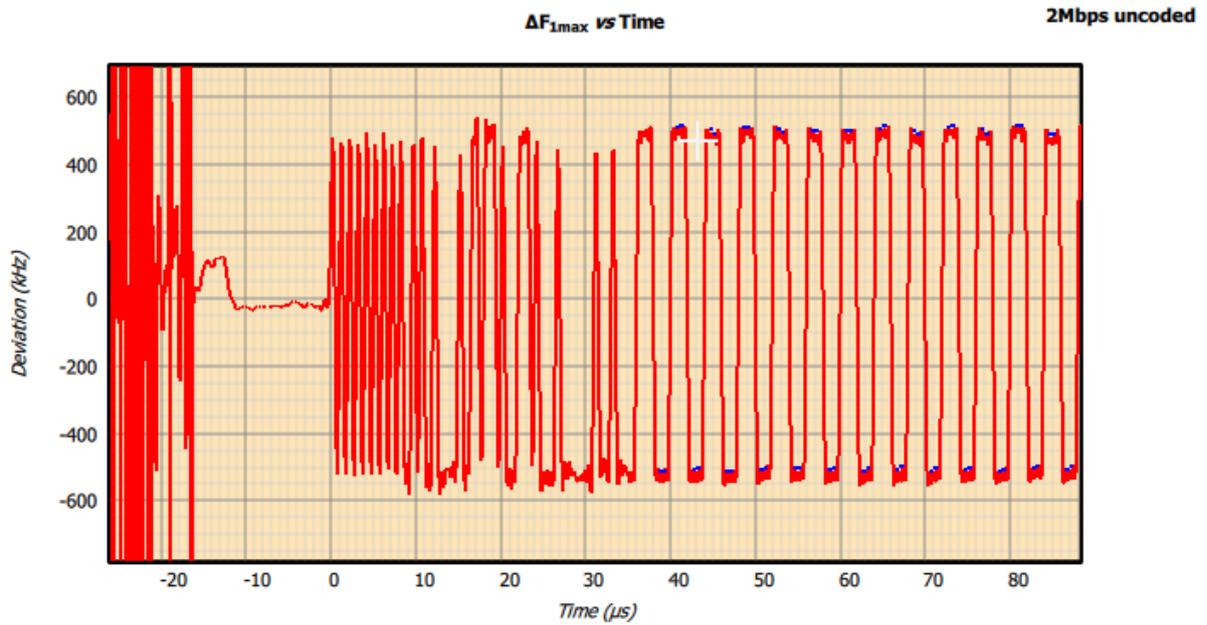


Figure 36: Results plotted vs time.

### CTE phase measurements

If CTE phase measurements are being displayed, then the phases within the reference and sample slots are plotted in blue and the remaining phases plotted in red. Within the 'Plot' menu under the 'Analysis' tab there is now the option for 'Show phase difference between slots'. If this box is checked, then the blue lines on the graph show the phase difference between adjacent slots and not the absolute phase.

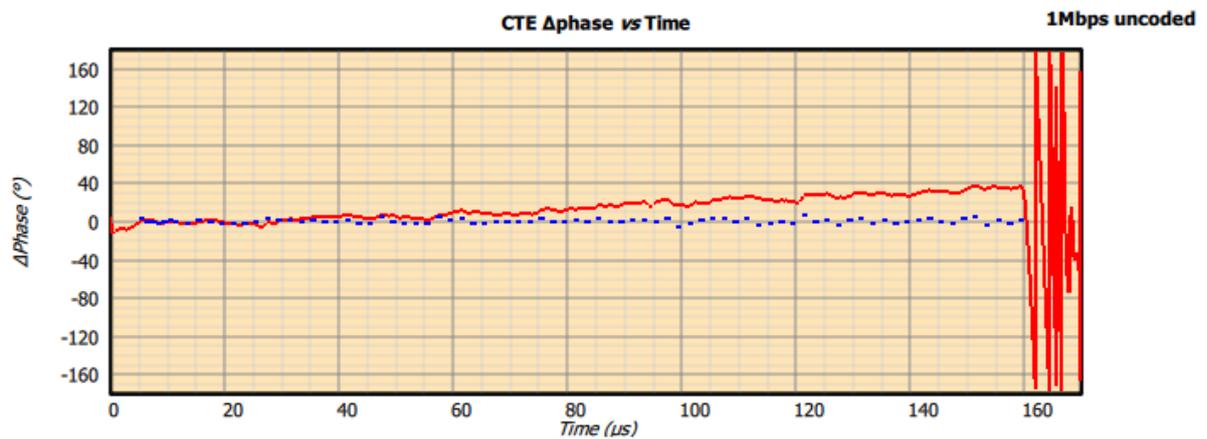


Figure 37: CTE phases vs time

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## 9.4.8.7 vs frequency

This option is only available for in-band emission tests.

When the vs frequency option is selected for in-band emission tests, additional options become available:

1. Plotting of the in-band emission results for every MHz in the 2.4GHz ISM band (1MHz spectrum)
2. Plotting of the 100kHz resolution measurements which were summed to yield the in-band emission results at every 1MHz (100kHz spectrum)

For each spectrum it is possible to plot:

1. Current in-band emission results (orange line)
2. Maximum in-band emission results (red line)
3. Minimum in-band emission results (green line)



Figure 38: In-band emissions vs frequency.

## 9.4.9 Screen update period

The 'Plot' menu contains a slider which can be used to alter the rate at which the results table and graphics are updated.

The fastest update period possible is around 50ms, typically limited by the host screen refresh rate. However, if substantial processing is required by *Sapphire* – for example, the transfer of raw IQ data at 32x oversampling for a 256 byte 125kbps packet – then the specified update rate may not be achievable.

The slowest update rate is 2 seconds. This gives the user time to assimilate the displayed results and waveform data before the next update.

## 9.5 Adjusting test limits

The test limits are shown in the results table. The penultimate column of the results table displays the lower limit and the final column the upper limit. They can be altered by changing the values in the spin boxes, either by using the up/down arrows or by entering numeric text directly.

Some limit values are shared between different modulation schemes whilst others are specific to a modulation scheme. The table below shows whether limit values are shared or are specific for each test category and modulation scheme:

Test	Modulation			
	2Mbps	1Mbps	500kbps	125kbps
Power	Shared	Shared	Shared	Shared
Modulation	2Mbps specific	Shared	Shared	125kbps specific
Drift & carrier offset	Shared	Shared	LR specific	LR specific
In-band emissions	2Mbps specific	Shared	Shared	Shared
CTE	Shared	Shared	N/A	N/A

*Table 8: Table showing whether limit values are shared or are specific for each test category and modulation scheme.*

The limit values shown in the results table apply to the modulation scheme currently shown at the top right-hand corner of the graphics area.

## 9.6 Controlling a DUTs transmissions

In signal analyser mode it is possible to control a DUT whose transmissions are being analysed. The DUT being controlled can be selected using the combo box at the right-hand side of the toolbar. Control of the DUT is via the 'DUT Tx' menu under the 'DUT' tab of the mode control panel. The menu toggle button can be used to turn the DUT transmissions on and off.

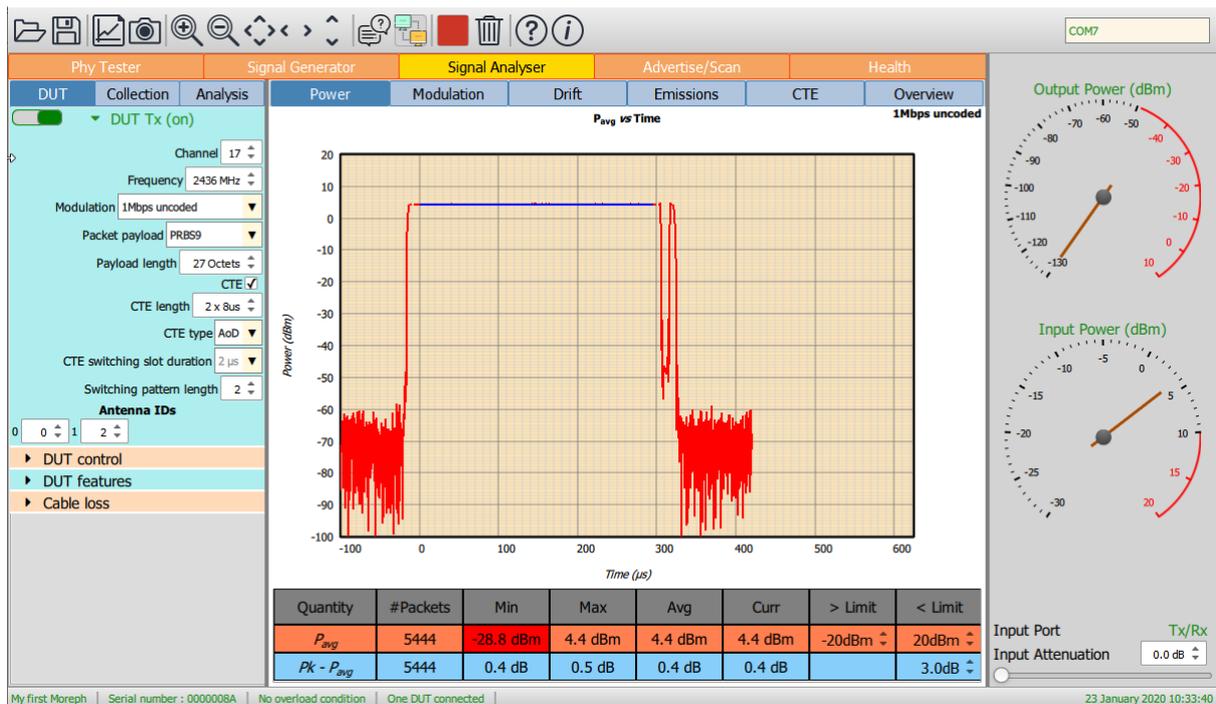


Figure 39: Controlling DUT transmissions from signal analyser.

The 'DUT Tx' menu permits the following parameters of the transmission to be changed:

1. Transmission frequency
2. RF Phy of transmission
3. Packet payload
4. Payload length

The range of all of these parameters will be limited by the current settings in the 'DUT features' menu. It is therefore essential that these settings are correctly populated. The settings can either be populated manually or by using the 'Query' button on the toolbar to read the settings back from the DUT.

The choice of packet payloads will also be dependent on whether a direct test mode connection or HCI connection is used to communicate with the DUT. If a direct test mode connection is used, then the following packet payloads are available:

1. PRBS9
2. 11110000
3. 10101010
4. Vendor specific

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If an HCI connection is used, then the following payloads are available:

1. PRBS9
2. PRBS15
3. 11110000
4. 10101010
5. 11111111
6. 00000000
7. 00001111
8. 01010101

If the DUT supports AoA or AoD, then additional options are available if the 'CTE' checkbox is ticked. This will permit the selection of CTE length and whether it is an AoA or AoD CTE.

If an AoD CTE is selected, then the following parameters can also be defined:

1. CTE switching slot duration
2. CTE switching pattern length
3. The antenna IDs corresponding to each slot in the CTE switching pattern

The antenna IDs will be specific to the DUT design.

### 9.7 Saving and restoring settings

The current collection, analysis and limit settings can be saved by clicking the 'Save' button on the toolbar. Select the 'Signal analysis settings (\*.sas)' file type to save the current settings.

An existing signal analysis settings file (\*.sas) can be opened using the 'Open' button on the toolbar.

The signal analysis settings file (\*.sas) is an XML file. It is not recommended that this file be edited manually. If it needs to be modified, open it from the signal analyser, modify the required parameters and re-save.

### 9.8 Saving current results table and graphics

The current graph and results table can be saved as an image by clicking the 'Graph' button on the toolbar. The range of possible graphics formats includes:

1. Windows bitmap files (\*.bmp)
2. Joint photographic expert group files (\*.jpg)
3. Portable network graphics files (\*.png)
4. Portable bitmap files (\*.pbm)
5. Portable graymap files (\*.pgm)
6. Portable pixmap files (\*.ppm)
7. X11 bitmap files (\*.xbm)
8. X11 pixmap files (\*.xpm)

## 9.9 Notes on measured quantities

### 9.9.1 Power measurements

<b>Bluetooth 5.2 RF Phy Test Specification</b>	<b>Sapphire</b>
Output power tests are only specified for 1Mbps packets	Output power tests are available for all Bluetooth 5.2 RF Phys
Tests should be performed on a spectrum analyser with a 3MHz RBW	Tests are performed using the same filters as specified for the modulation and drift tests
$P_{avg}$ should be measured over at least the central 60% of the packet	$P_{avg}$ is measured over the entire packet

Table 9: Power measurements compared between Bluetooth test specification and Sapphire.

### 9.9.2 Modulation measurements

<b>Bluetooth 5.2 RF Phy Test Specification</b>	<b>Sapphire</b>
Modulation tests are only specified for 2Mbps, 1Mbps & 125kbps	Modulation tests are available for all Bluetooth 5.2 RF Phys
Oversampling rate at least 32x	Oversampling rate 32x
Filter shape for 1Mbps & 125kbps should be at least: ±650kHz @ -3dB ±1MHz @ -14dB ±2MHz @ -44dB	
Filter for 1Mbps & 125kbps to have less than 0.5 dB peak-to-peak ripple between ±550kHz	

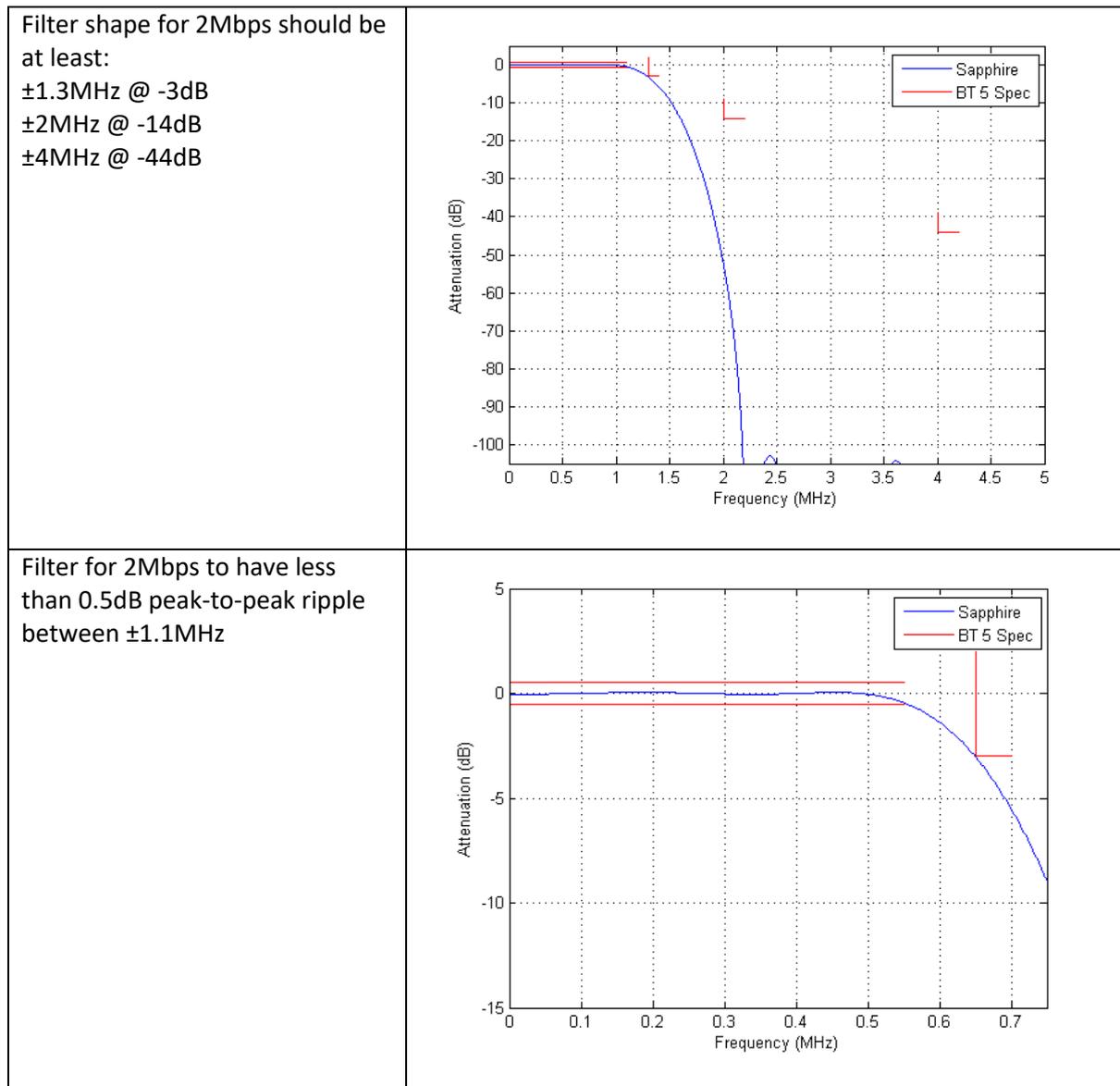


Table 10: Modulation measurements compared between Bluetooth 5.2 test specification & Sapphire.

The  $\Delta F2_{avg} / \Delta F1_{avg}$  current entry in the results table shows the ratio of  $\Delta F2_{avg}$  for the last packet on which this quantity could be calculated to  $\Delta F1_{avg}$  for the last packet on which this quantity could be calculated, with the restriction that both packets had the same RF Phy, RF channel and lay in the same packet length group. The maximum, minimum and average values of  $\Delta F2_{avg} / \Delta F1_{avg}$  are updated whenever a new value of  $\Delta F2_{avg} / \Delta F1_{avg}$  can be calculated.

The  $\Delta F2_{max99\%}$  current entry in the results table shows the frequency corresponding to the 99.9 percentile for all  $\Delta F2$  measurements made over all packets collected. The maximum, minimum and average values are updated at the end of each packet. The  $\Delta F2_{max99\%}$  value will only be displayed once at least 100  $\Delta F2$  measurements have been made.

9.9.3 Drift and carrier offset measurements

<b>Bluetooth 5.2 RF Phy Test Specification</b>	<b>Sapphire</b>
Drift and carrier offset tests are only specified for 2Mbps, 1Mbps & 125kbps	Drift and carrier offset tests are available for all Bluetooth 5.2 RF Phys
Specifications for measurement filters	See filters defined for modulation measurements.

Table 11: Drift and carrier offset measurements compared between Bluetooth test specification and Sapphire.

9.9.4 In-band emission measurements

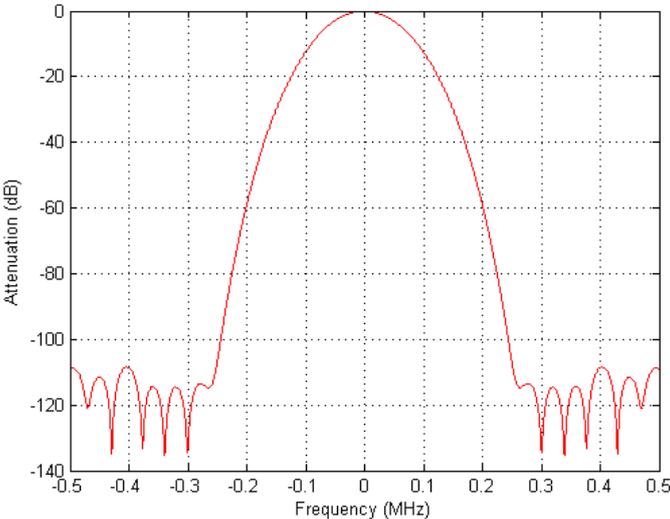
<b>Bluetooth 5.2 RF Phy Test Specification</b>	<b>Sapphire</b>
Modulation tests are only specified for 2Mbps & 1Mbps	Modulation tests are available for all Bluetooth 5.2 RF Phys
RBW of 100kHz	Accurate Gaussian response with 3dB bandwidth of 100kHz 
Average detector Sweep time of 100ms	Assuming 400 points per sweep for a spectrum analyser typical of the period when the Bluetooth 5.2 specification was first written, this gives an averaging time of 2.5ms per point
Maximum hold over 10 sweeps	Maximum hold starts prior to the packet power ramp up and continues until the end of the packet power ramp down or 2.5ms, whichever is longer.

Table 12: In-band emission measurements compared between Bluetooth 5.2 test specification & Sapphire.

The maximum exception row in the results table will only indicate exceptions that exceed the -20dBm absolute limit.

9.9.5 CTE measurements

<b>Bluetooth 5.2 RF Phy Test Specification</b>	<b>Sapphire</b>
Power tests should be performed on a spectrum analyser with a 3MHz RBW	Tests are performed using the same filter as for 2Mbps modulation and drift measurements.

Table 13: CTE measurements compared between Bluetooth 5.2 test specification & Sapphire

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The carrier frequency is estimated using the 8 samples slots in the reference period. This is then used to compensate the phases for the remainder of the CTE.

## 10 Phy Tester Mode.

### 10.1 Overview

In Phy tester mode, the *Sapphire* application directly controls the DUT(s) and executes an editable test script which define which of the Bluetooth 5.2 LE RF Phy Test Specification tests are to be performed.

The *Sapphire* application can communicate with up to 32 DUTs simultaneously. When multiple DUTs are being tested, the short transmit tests are performed sequentially but the much longer receiver tests are performed in parallel. This results in a dramatic reduction in test time.

Communication to the DUT(s) is via one of the following protocols:

1. Direct test mode (2-wire)
2. H4
3. H5 (3-wire)
4. BCSP
5. SPI BCCMD

The application is capable of running all of the Bluetooth 5.2 LE RF Phy Test Specification tests, with the following caveats:

1. Blocking tests cannot be performed above 6GHz. The Bluetooth 5.2 LE RF Phy Test Specification states that blocking frequencies up to 12.75GHz should be used. Since this limit includes the second harmonic of the 2.4GHz ISM band, it is unlikely that a DUT which passes at frequencies below 6GHz will fail at frequencies above 6GHz.
2. The CW blocker has a relatively high harmonic content. A notch filter is used to reduce the harmonic content falling within the 2.4GHz ISM band. However, care should be exercised to ensure that blocking failures are not due to harmonics of the blocker landing on the wanted signal. Such care should always be exercised with blocking tests, irrespective of the test equipment being used.
3. Some intermodulation tests require the interferers to be placed a significant distance outside the 2.4GHz ISM band. The *TLF3000* unit is not always capable of generating these interferers. However, the Bluetooth 5.2 LE RF Phy Test Specification requires that the intermodulation test be performed with the interferers both above and below the wanted signal. The *TLF3000* unit can always generate the interferer signals for the case where they lie within the 2.4GHz ISM band. When they are switched to lie outside the 2.4GHz band they will become attenuated by the frontend filtering of the DUT. It is therefore unlikely that a DUT will pass the intermodulation test with the interfering signal inside the 2.4GHz ISM band but fail when the interfering signals are placed outside the 2.4GHz ISM band.

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The *Sapphire* application allows the Bluetooth 5.2 LE RF Phy Test Specification tests to be expanded to include:

1. Testing on different RF channels
2. Testing with different packet lengths
3. Testing over a different number of packets
4. Testing with a different wanted signal level or over a sweep of wanted signal levels
5. Testing with different interferer signal levels or over a sweep of interferer signal levels
6. Testing with different blocker frequencies
7. Testing with different CTE lengths
8. Testing with different numbers of antenna

Test termination criteria can be set allowing PER searches to be performed.

### 10.2 RF connections

If a conducted link to the DUT is available, then it should be connected to the 'Tx/Rx' port. The 'Tx/Rx' port should also be selected as the receive port in the monitor panel.

For over-the-air measurements where the DUT is adjacent to the *TLF3000* unit, then an antenna should be connected to the 'Tx/Rx' port and the 'Tx/Rx' port selected as the receive port in the monitor panel. When using this configuration check that the received power from the DUT is sufficient to perform accurate modulation measurements. If it is not, it will be necessary to use the configuration described below.

For over-the-air measurements the DUT is not close to the *TLF3000* unit, then antenna should be connected to both the 'Tx/Rx' port and the 'Monitor In' port. The 'Monitor In' port should be selected as the receive port in the monitor panel. It may be necessary to add front-end attenuation using the controls on the monitor panel to prevent the receiver overloading. See [Selection of input port and input attenuation](#) .

The loss between the DUT and the *TLF3000* should be entered using the 'Cable loss' menu under the 'DUT' tab in the mode control panel.

The cable loss value is also used to compensate the blocker level. Since the cable loss value is only applicable at 2.4GHz and the blocker frequency can be anywhere from 24MHz to 6GHz, the compensation is extremely rough. However, given the accuracy of the blocker signal level and the relatively low levels of cable attenuation, this is not normally an issue. The cable loss used for the blocker is that specified at the centre of the ISM band.

### 10.3 Run modes and termination criteria

The operation of the Phy layer tester can be modified by using the options available in the 'Run mode' menu under the 'DUT' tab. Available options are:

1. *Only test against limits.* When performing receiver tests a number of packets are sent to the DUT and then the DUT queried to determine how many arrived uncorrupted. The test limit is typically around 30% PER. In many cases it is not necessary to send the full number of packets to determine whether the 30% PER test limit will be exceeded or passed. If 'Only test against limits' is checked, I will attempt to minimise test time by only sending the minimum number of packets required to determine whether the test will pass. However, in doing so, the accuracy to which the true PER can be determined is compromised.
2. *Run to completion.* If the 'Run to completion' option is checked, then *Sapphire* will always perform all the tests which have been specified. If this option is not checked, then *Sapphire* will terminate execution of the test script as soon as a test failure is detected. An exception to this rule is when PER searches are being performed, either by sweeping the level of the wanted signal or the interfering signals. In these instances, as soon as the test fails *Sapphire* will move to the next test item.
3. *Loop tests.* If 'Loop tests' is checked, then once the test script is exhausted it will be re-run. This facility is useful for tracking down errors which occur infrequently.
4. *Show results.* If selected then a browser window will pop-up at the end of the test run providing a summary of the test results.
5. *Include graphs in results.* If selected then spectral emission plots will be included in the displayed results, provided these tests were run.

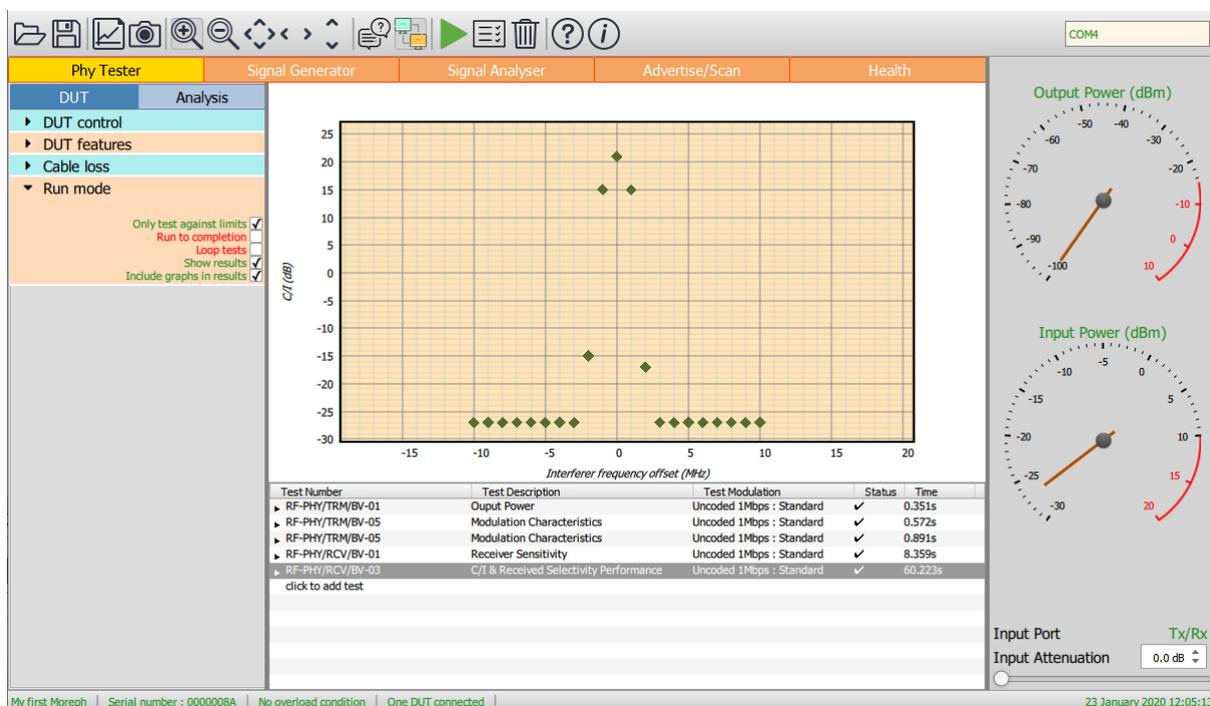


Figure 40. Run modes and termination criteria.

## 10.4 Building a test script

### 10.4.1 Overview

The test script will be displayed at the bottom of the window below the graphics area. On entering the Phy layer tester the script will be empty. To commence building a test script, click on 'click to add test'. This will open up a pop-up window where the test contents can be defined.

### 10.4.2 Test definition window

The pop-up test definition window permits any one of the Bluetooth 5.2 LE RF Phy Test Specification tests to be selected. Various parameters for each test can also be modified.

The test definition window consists of:

1. A yellow bar containing drop down menus which can be used to select the test to be performed.
2. A list of expandable menus which can be used to alter parameters defining the test.
3. A 'Restore Defaults' button which can be used to reset the test parameters to the values defined in the Bluetooth 5.2 LE RF Phy Test Specification.
4. An 'Apply' button which will add a new test to the end of the test script or save the edits to an existing test.
5. A 'Cancel' button which will discard all information which has been entered into the test definition window. If a new test was being created, then it will be discarded. If an existing test was being edited, then the edits will be discarded.
6. A 'Discard' button which will remove the test from the test script.

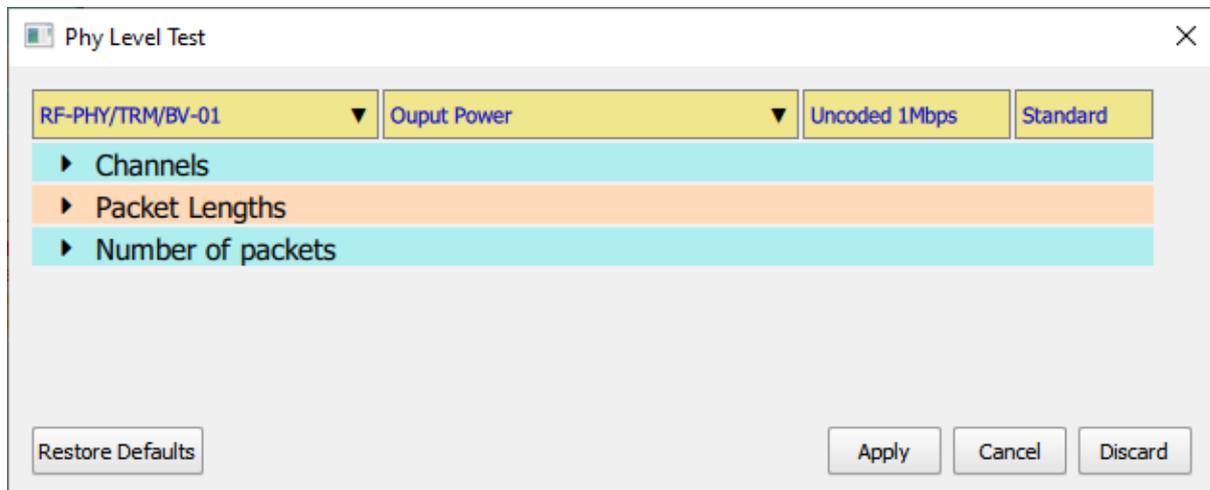


Figure 41: Test definition window.

### 10.4.3 Selecting the test type

The test type is selected by using the drop-down menus in the yellow bar at the top of the test definition pop-up window.

If the test number is known, then it may be selected directly by using the left-hand drop-down menu. The number and type of tests which are displayed in the menu will be dependent on what features the DUT supports. It is therefore essential to ensure that the DUT properties are set correctly prior to creating a test script.

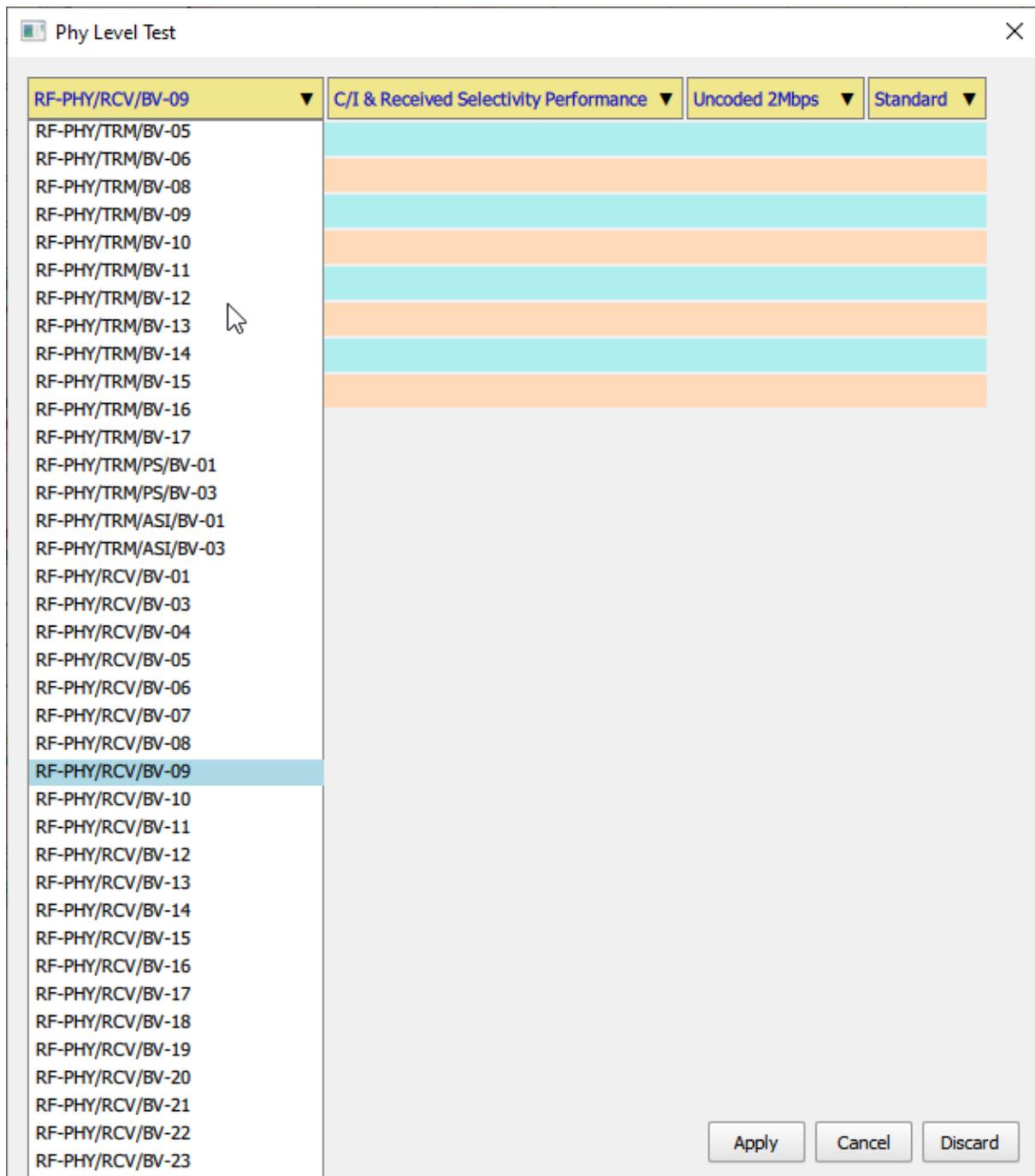


Figure 42: Selecting test by test number.

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If the test number is not known, then the second drop down menu may be used to select the test by its name.

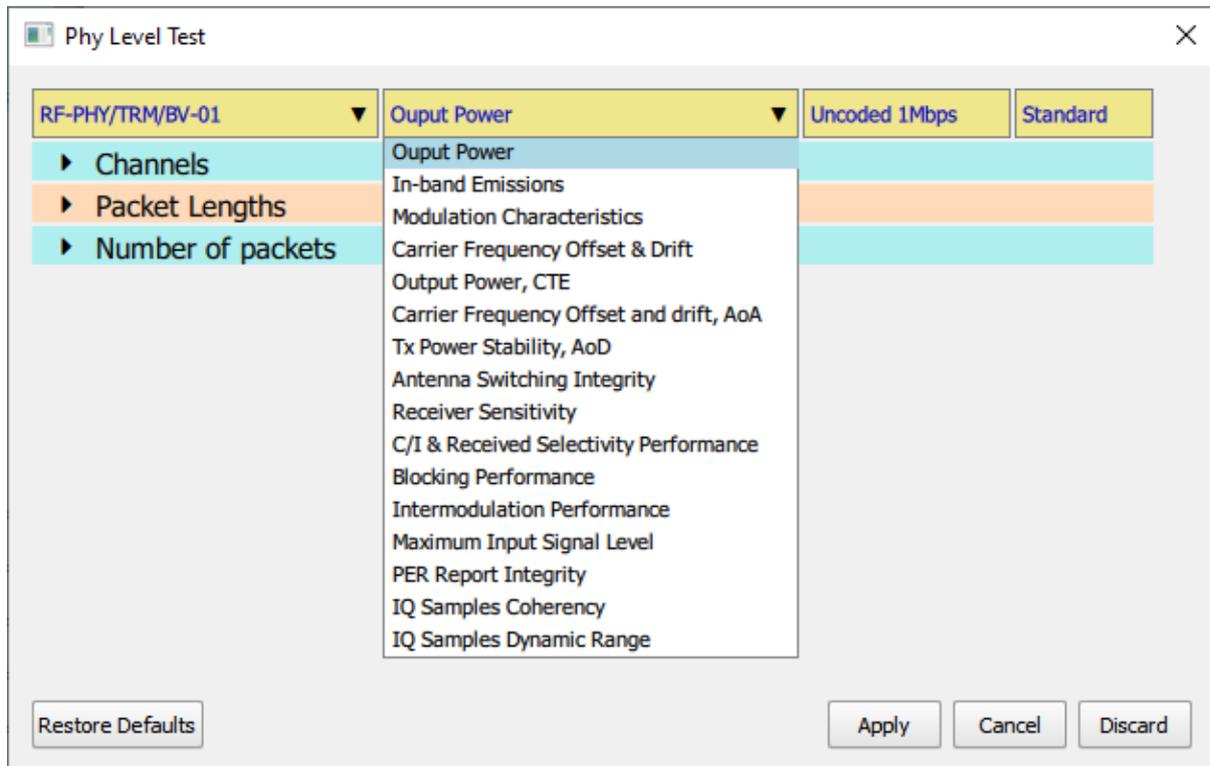


Figure 43: Selecting the test type if the test number is not known.

Having selected a test by its name, it may be necessary to refine the test selection by specifying the modulation scheme using the two remaining menus:

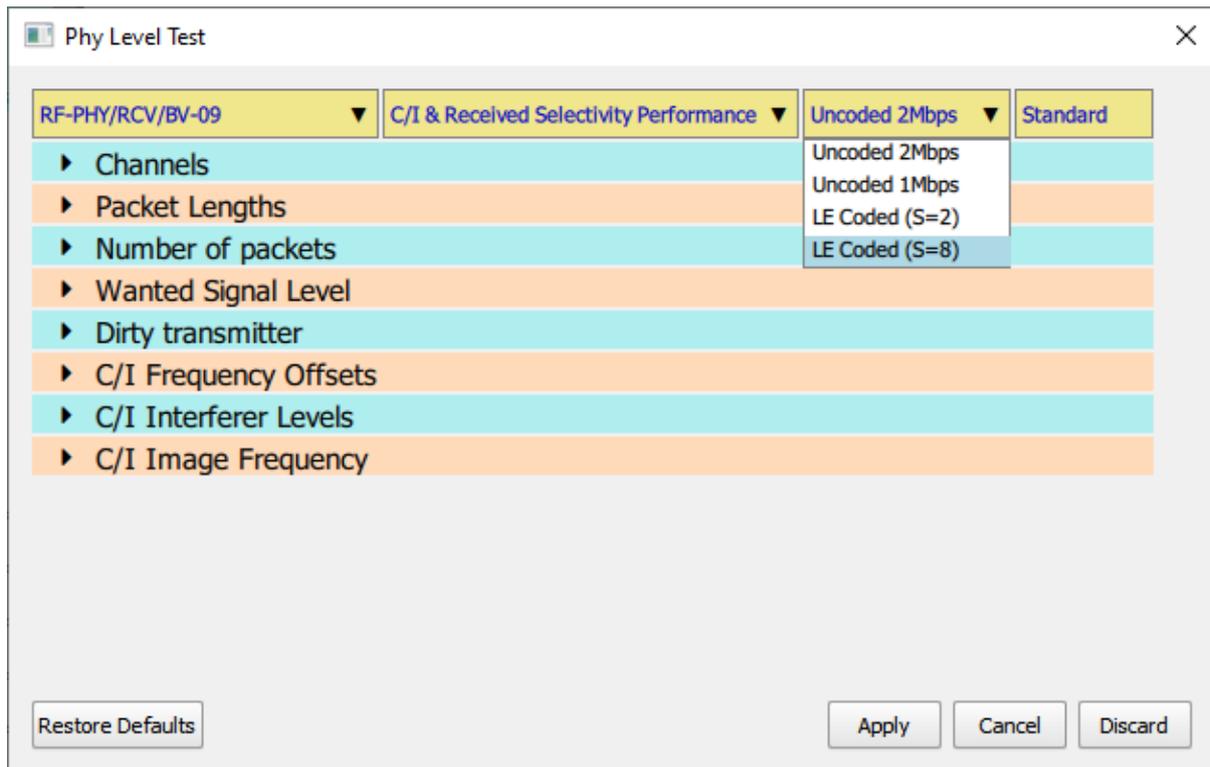


Figure 44: Refining the test selection by specifying the modulation scheme, 1.

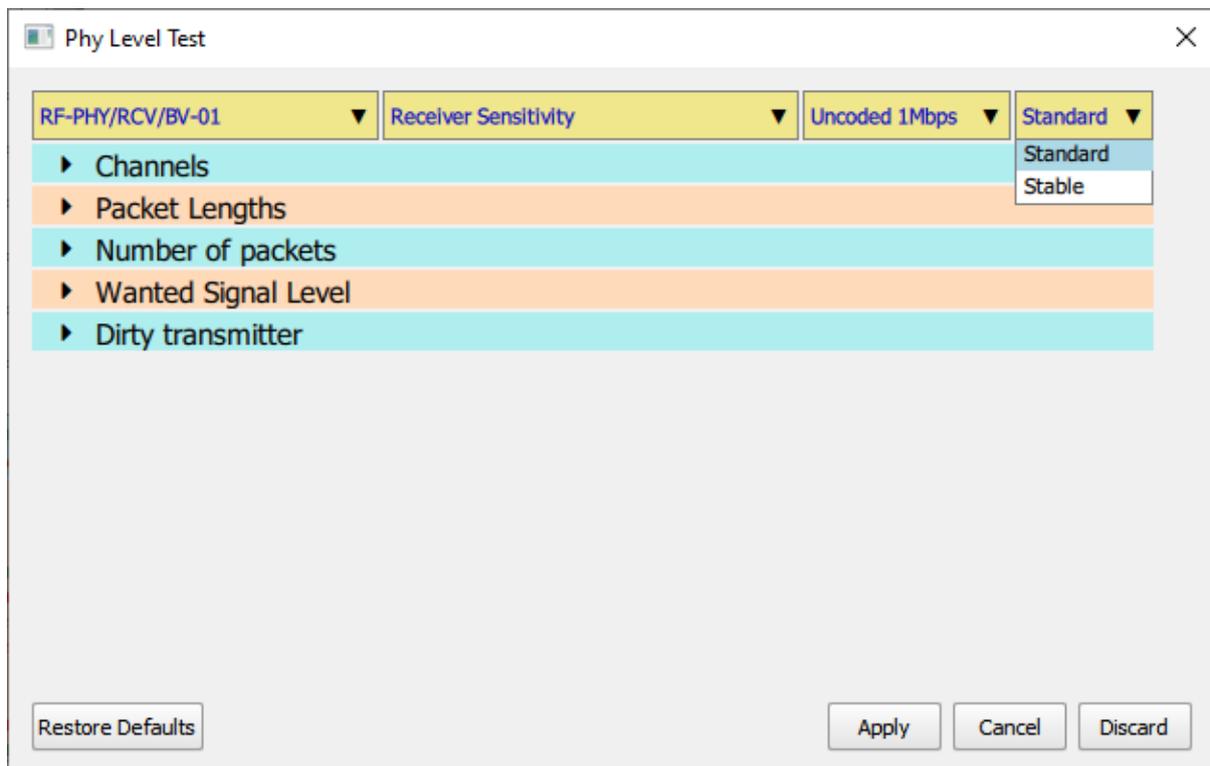


Figure 45: Refining the test selection by specifying the modulation scheme, 2.

### 10.4.4 Selecting which channels are tested

To select which RF channels the test is to be performed on, expand the 'Channels' menu.

The RF channels can be selected by clicking on the checkboxes.

Groups of RF channels can be selected using the toggle buttons at the bottom left:

1. *Clear all.* All RF channels will be deselected.
2. *Select all.* All RF channels which are supported by the DUT will be selected.
3. *Primary advertising.* The primary advertising channels will be selected.
4. *Data/Secondary advertising.* The data and secondary advertising channels supported by the DUT will be selected.
5. *Specification channels.* The RF channels defined for the test in Bluetooth 5.2 LE RF Phy Test Specification will be selected.

It is also possible to select the RF channels by entering text into the text field at the bottom of the menu. The required format for the text is described in [Textual input of test parameters](#).

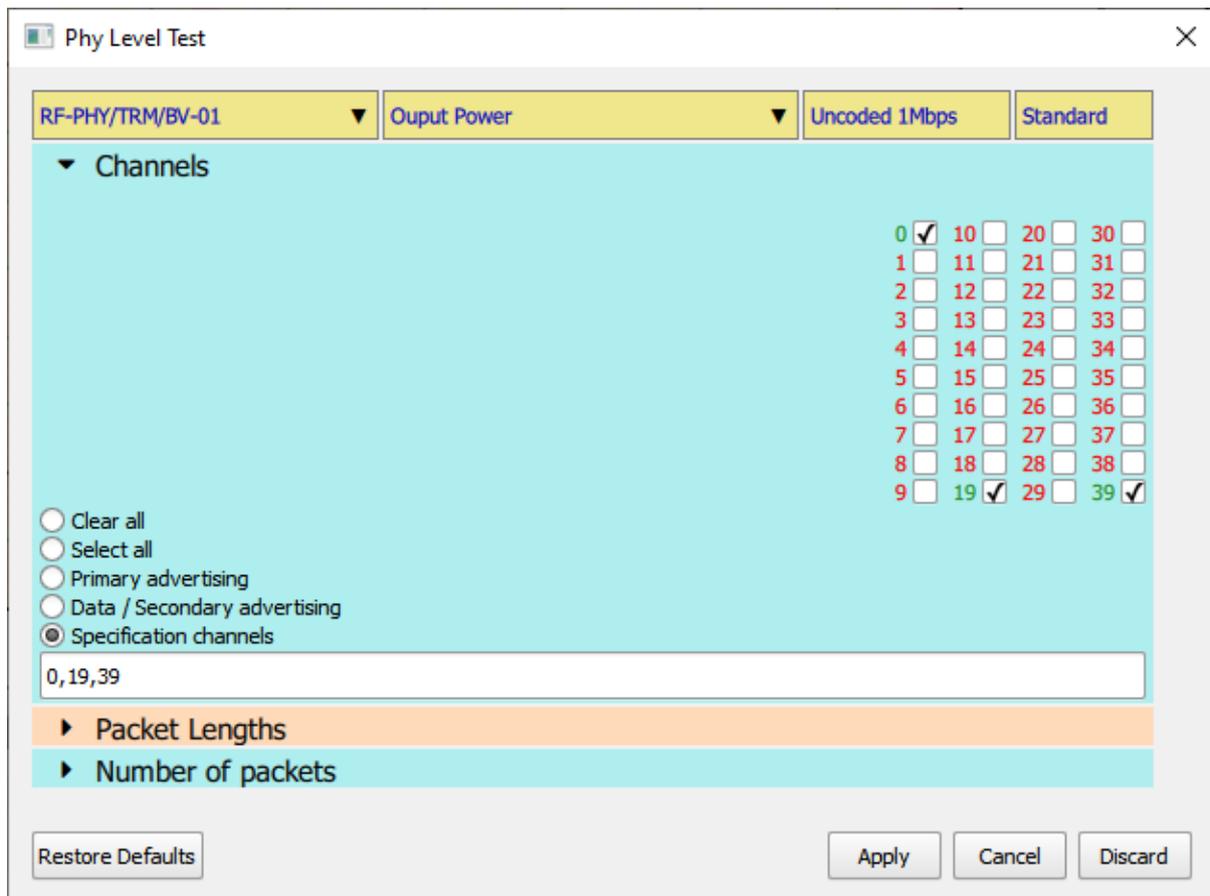


Figure 46: Selecting which channels are tested.

### 10.4.5 Selecting which packet lengths are tested

To select which packet lengths the test is to be performed on, expand the 'Packet Lengths' menu.

The wanted packet lengths can be selected by clicking on the checkboxes.

Groups of packet lengths can be selected using the toggle buttons at the bottom left:

1. *Clear all.* All packet lengths will be deselected.
2. *Select all.* All packet lengths which are supported by the DUT will be selected.
3. *Specification.* The packet lengths specified for the test in Bluetooth 5.2 LE RF Phy Test Specification will be selected.

It is also possible to select the packet lengths to be used by entering text into the text field at the bottom of the menu. The required format for the text is described in [Textual input of test parameters](#).

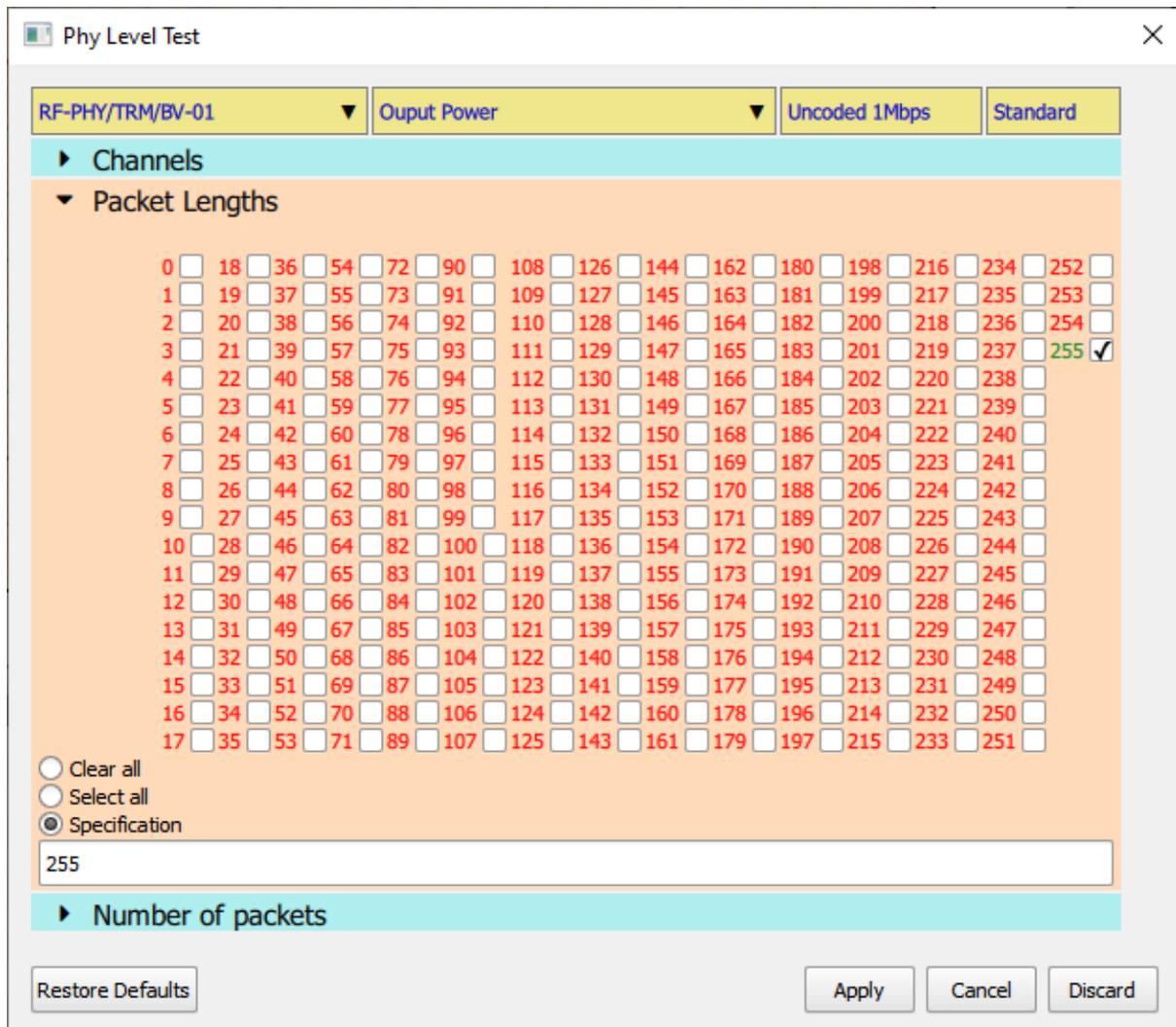


Figure 47: Selecting which packet lengths are tested.

### 10.4.6 Selecting how many packets are used in the test

To select how many packets are used in the test, expand the 'Number of packets' menu.

If the 'Specification' checkbox is ticked, then the number of packets as defined in the Bluetooth 5.2 LE RF Phy Test Specification will be used. This value will be shown in the spin box. The spin box will not be editable whilst the 'Specification' checkbox is ticked.

If the 'Specification' checkbox is cleared, then the number of packets can be entered into the spin box, either by using the up/down arrows or by entering a numeric value directly into the text field.

When performing 'quick look' receiver tests, it is frequently useful to reduce the number of packets from the 1500 specified in the Bluetooth 5.2 LE RF Phy Test Specification. By using a reduced number of packets, it becomes possible to explore a greater range of other parameters.

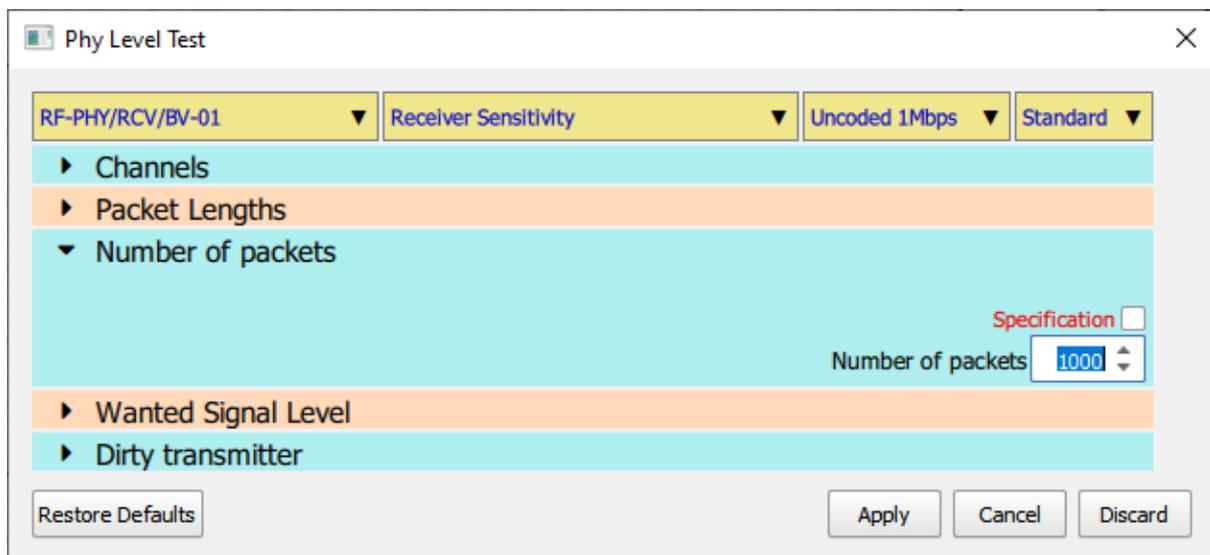


Figure 48: Selecting how many packets are used in the test.

### 10.4.7 Selecting the wanted signal level for receiver tests

To select the wanted signal level to be used for receiver tests, expand the 'Wanted Signal Level' menu.

If the 'Specification' checkbox is ticked, then the wanted signal level as defined in the Bluetooth 5.2 LE RF Phy Test Specification will be used. This value will be shown in the spin box. The spin box will not be editable whilst the 'Specification' checkbox is ticked. The wanted signal level will also be shown on the signal level gauge at the bottom of the menu.

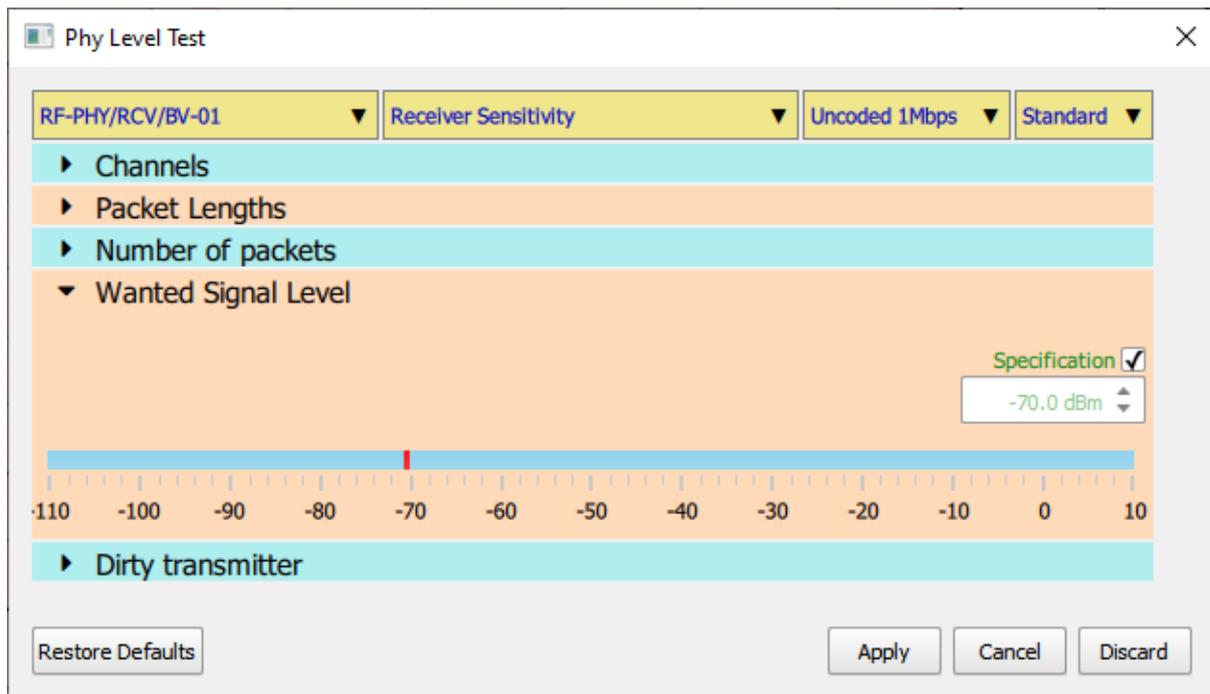


Figure 49: Displaying wanted signal level.

If the 'Specification' checkbox is cleared, then the wanted signal level can be entered into the spin box, either by using the up/down arrows or by entering a numeric value directly into the text field. If the cursor is placed directly over the red bar in the signal level gauge, then a '→' will appear adjacent to the cursor. By holding down the left mouse button it is then possible to drag the red bar to set the wanted signal level. Wanted signal levels must be in the range -110dBm to 0dBm. The resolution of the wanted signal level is 0.1dBm.

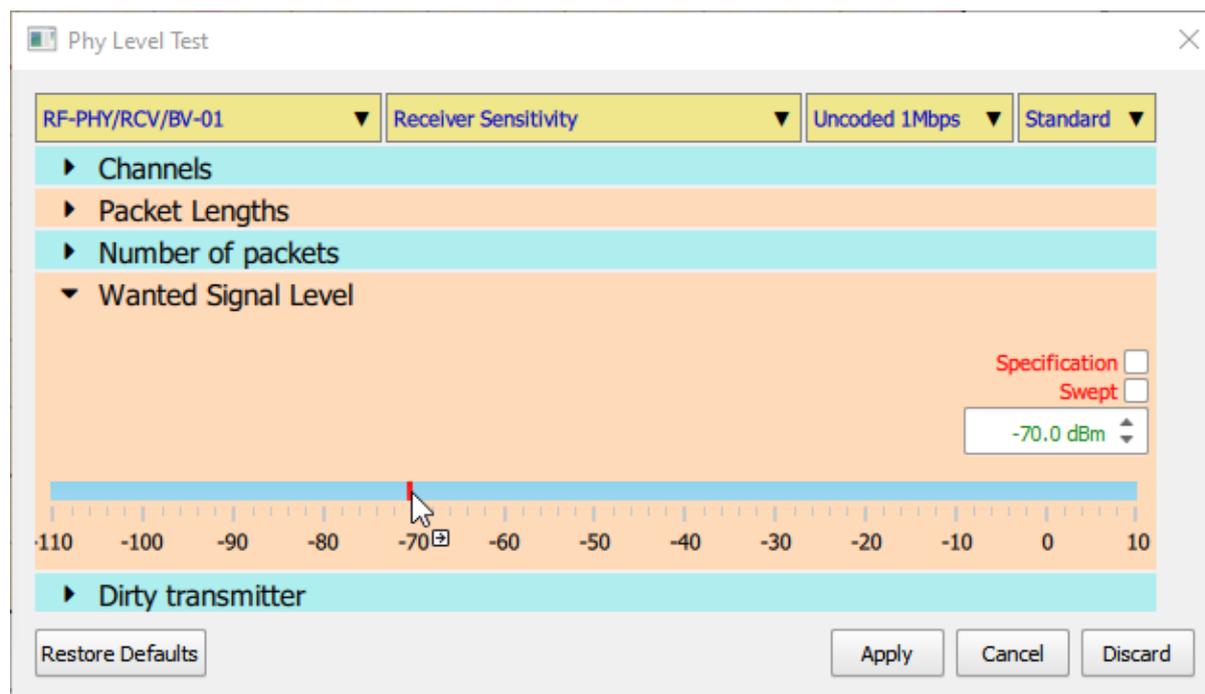


Figure 50: Setting the wanted signal level.

If it is desired to sweep the wanted signal level over a range of values, for example, to perform a PER search, then tick the 'Swept' checkbox. *If interfering signals have been programmed to have swept levels, then it is not possible to sweep the wanted signal level.*

The wanted signal level power sweep is defined by the numbers displayed in the three spin boxes:

1. *Maximum Power*. This indicates the power level at which the sweep will start. The sweep will be from the maximum wanted signal power towards the minimum wanted signal power. The maximum power cannot be above 0dBm and must be greater than or equal to the minimum power. The resolution of the maximum power is 0.1dBm.
2. *Power Step*. This is the step size that the sweep will take from the maximum power towards the minimum power. The step size cannot be less than 0.5dB. The resolution of the step size is 0.1dB.
3. *Minimum Power*. This indicates where the power sweep should terminate. The last wanted signal power to be test will be greater than or equal to the minimum power. The minimum power cannot be below -110dBm and must be less than or equal to the maximum power. The resolution of the minimum power is 0.1dBm.

**If maximum input signal level tests are being performed, the direction of the sweep is reversed, and the roles of maximum power and minimum power are swapped.**

The red bar in the signal level gauge indicates the range selected by the maximum and minimum powers. This entire range may not be explored during the sweep since the actual values tested are dependent on the selection of the step size.

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If the cursor is placed over one of the limits of the red bar, then it will change to a double headed cursor. It is then possible to hold down the left mouse button and drag the edge of the red bar to adjust either the minimum or maximum power.

If the cursor is placed over the body of the red bar, then a '→' will appear adjacent to the cursor. It is then possible to hold down the left mouse button and drag the entire sweep range up or down the gauge.



Figure 51: Setting a wanted signal level range.

### 10.4.8 Selecting the dirty transmitter for receiver tests

For each receiver test it is possible to individually select whether the dirty transmitter is enabled. The control of the dirty transmitter is through the 'Dirty transmitter' menu.

The dirty transmitter can take on one of three values:

1. *Off*. No dirty transmitter is applied during the test.
2. *On*. The dirty transmitter is on and uses the parameters specified in the Bluetooth 5.2 LE RF Phy Test Specification.
3. *Single value*. The dirty transmitter is on but uses constant values for the carrier offset, modulation index, drift magnitude, drift rate and symbol timing error.

When 'Single value' is selected, the various dirty transmitter parameters can be adjusted via spin boxes.

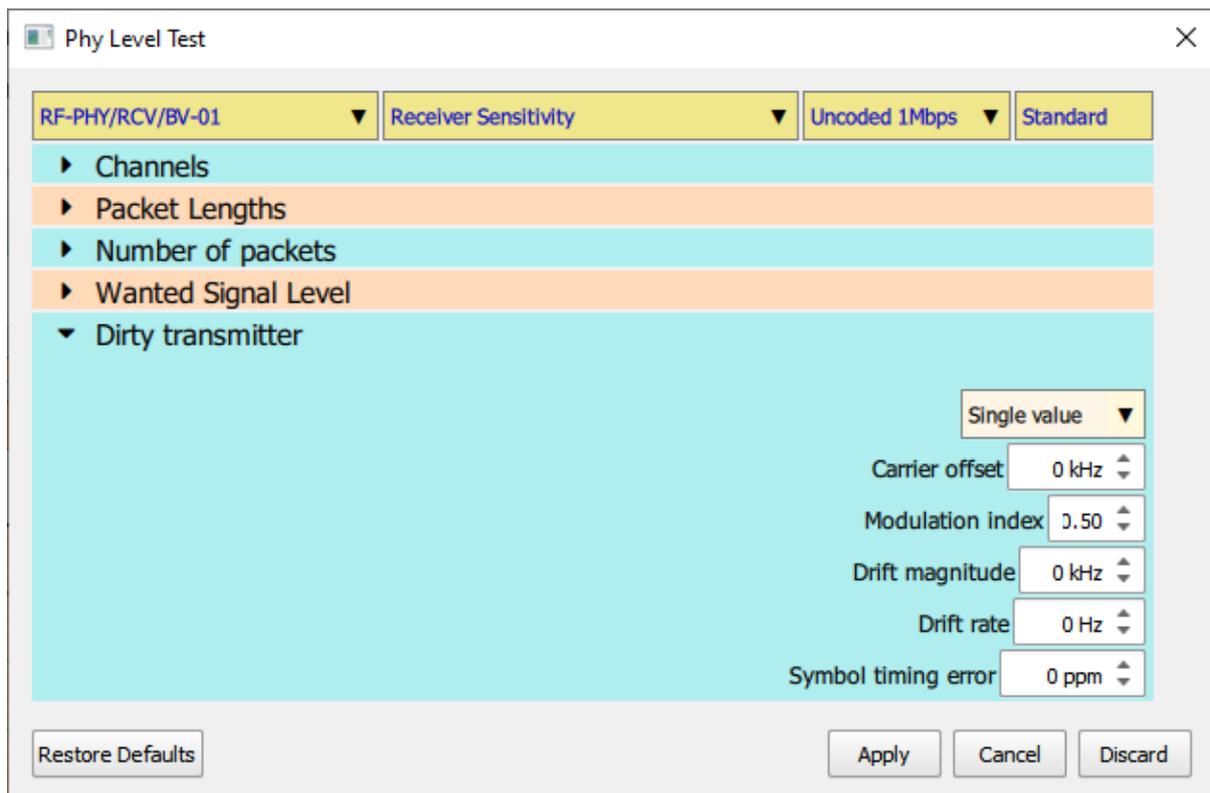


Figure 52: Setting dirty transmitter to a single value.

## 10.4.9 Configuring C/I receiver tests

### 10.4.9.1 Overview

In order to perform C/I receiver tests, it is necessary for *Sapphire* to know where the image frequency of the DUT receiver lies. The location of the image frequency alters the level of the interfering signals which must be generated.

The C/I receiver tests can take a long time to perform. Frequently it is only a few offsets of the interferer signal from the wanted signal that are interest. It is possible to individually select which interferer offset frequencies are used.

Most LE devices will greatly exceed the Bluetooth 5.2 LE RF Phy Specification C/I test. *Sapphire* therefore contains the ability to adjust the interferer signal level as well as the ability to sweep it over a range of values.

### 10.4.9.2 Specifying the DUT image frequency

To set the DUT image frequency, expand the 'C/I Image Frequency' menu.

The spin box labelled 'Image frequency' determines the offset of the DUT's image frequency. The image frequency can be set to any value from 0MHz to 100MHz in steps of 1MHz. The step size is limited to a resolution of 1MHz to be compatible with the resolution of the interfering signal offset. *Sapphire* implicitly assumes that the image frequency offset is the same for all LE RF channels.

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For each of the LE RF channels it is possible to specify whether high-side or low-side mixing is employed by the DUT. With high-side mixing the image will appear above the wanted signal, whilst with low-side mixing the image will appear below the wanted signal. The choice between high- and low-side mixing can be made by:

1. Toggling the individual checkboxes for each LE RF channel
2. Using the toggle buttons are the bottom left of the window:
  - a. 'All channels low-side mix' will set low-side mix for all LE RF channels
  - b. 'All channels high-side mix' will set high-side mix for all LE RF channels
3. By entering a text string into the text field at the bottom of the window. The format of this text string is defined in [Textual input of test parameters](#).

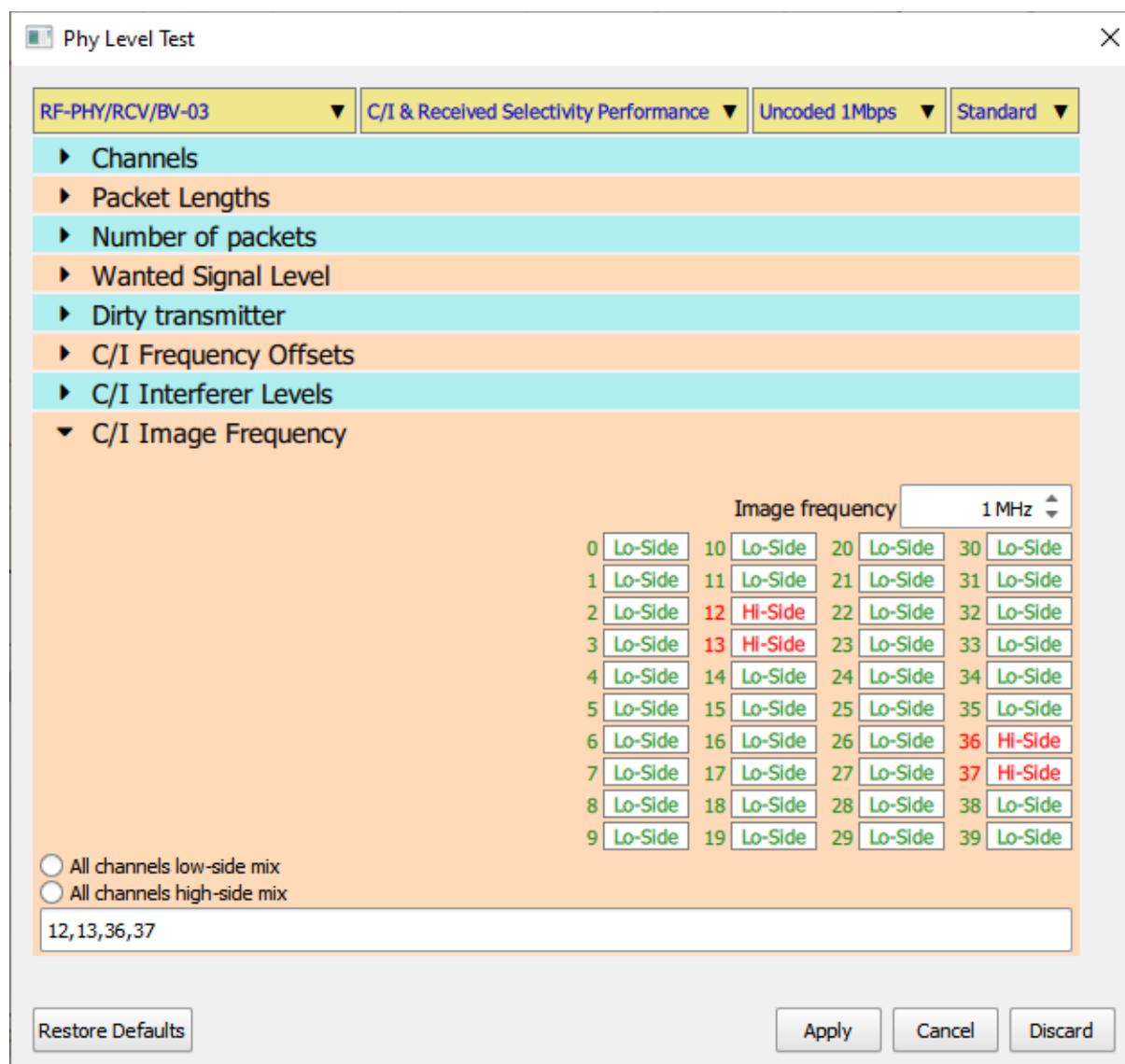


Figure 53: Specifying DUT image frequencies.

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### 10.4.9.3 *Selecting the C/I receiver test offset frequencies*

To select which offsets of the interferer from the wanted signal are to be explored, expand the 'C/I Frequency Offsets' menu.

The interfering signal can be placed up to 81MHz from the wanted signal with a resolution of 1MHz. If the interferer signal is placed outside the range 2395MHz to 2485MHz then the test will be silently ignored.

The C/I interferer signal frequency offsets can be set by:

1. Individually ticking the checkboxes for each frequency offset
2. Using the toggle buttons located at the bottom left of the window:
  - a. *Clear All*. Removes all C/I interferer offset frequencies
  - b. *Select All*. Ticks all C/I interferer offset frequencies
  - c. *Force symmetry*. Ensures that the interferer frequency offsets that lie below the wanted signal are an image of the interferer frequency offsets that lies above the wanted signal.
3. Entering a text string directly into the text field at the bottom of the window. The format for this text string is described in [Textual input of test parameters](#).

Positive C/I frequency offsets correspond to the interferer being at a higher frequency than the wanted signal. Negative C/I frequency offsets correspond to the interferer being at a lower frequency than the wanted signal.

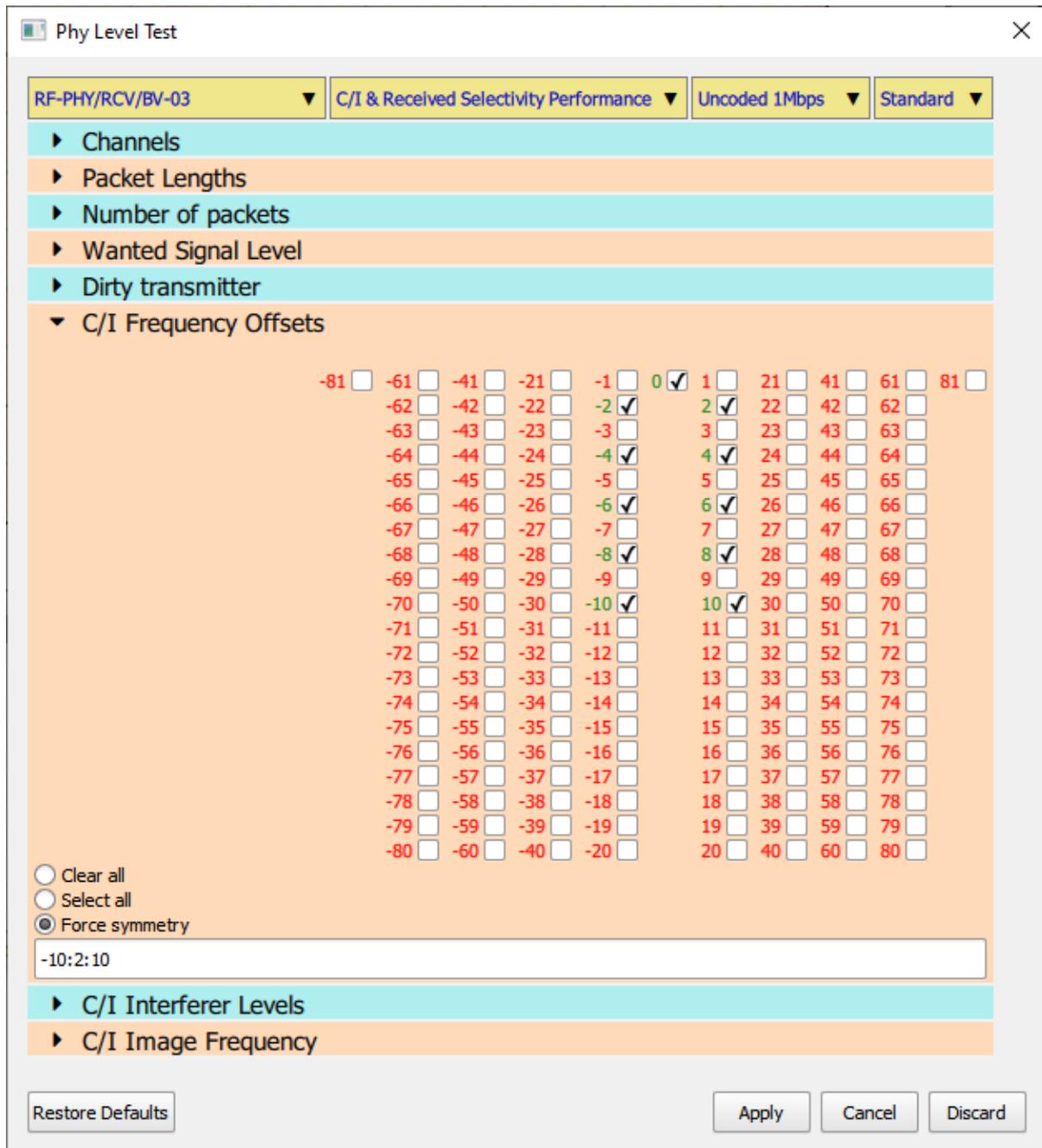


Figure 54: Selecting the C/I receiver test offset frequencies.

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### 10.4.9.4 *Selecting the interferer signal level for C/I receiver tests*

To select the interferer signal levels to be used in the C/I receiver tests, expand the '*C/I Interferer Levels*' menu.

At the top of the window is graphical display of the C/I levels which have been selected. This has been provided so that the plausibility of the selected parameters can be seen at a glance.

Below the graphical display, the C/I levels are shown in a tabular form, similar to that of the Bluetooth 5.2 LE RF Phy Test Specification.

Below the table is a '*Specification*' checkbox. If this check box is ticked, then the C/I values in the table and displayed on the graph are those defined in the Bluetooth 5.2 LE RF Phy Test Specification. The spin boxes within the table are disabled when the '*Specification*' checkbox is ticked.

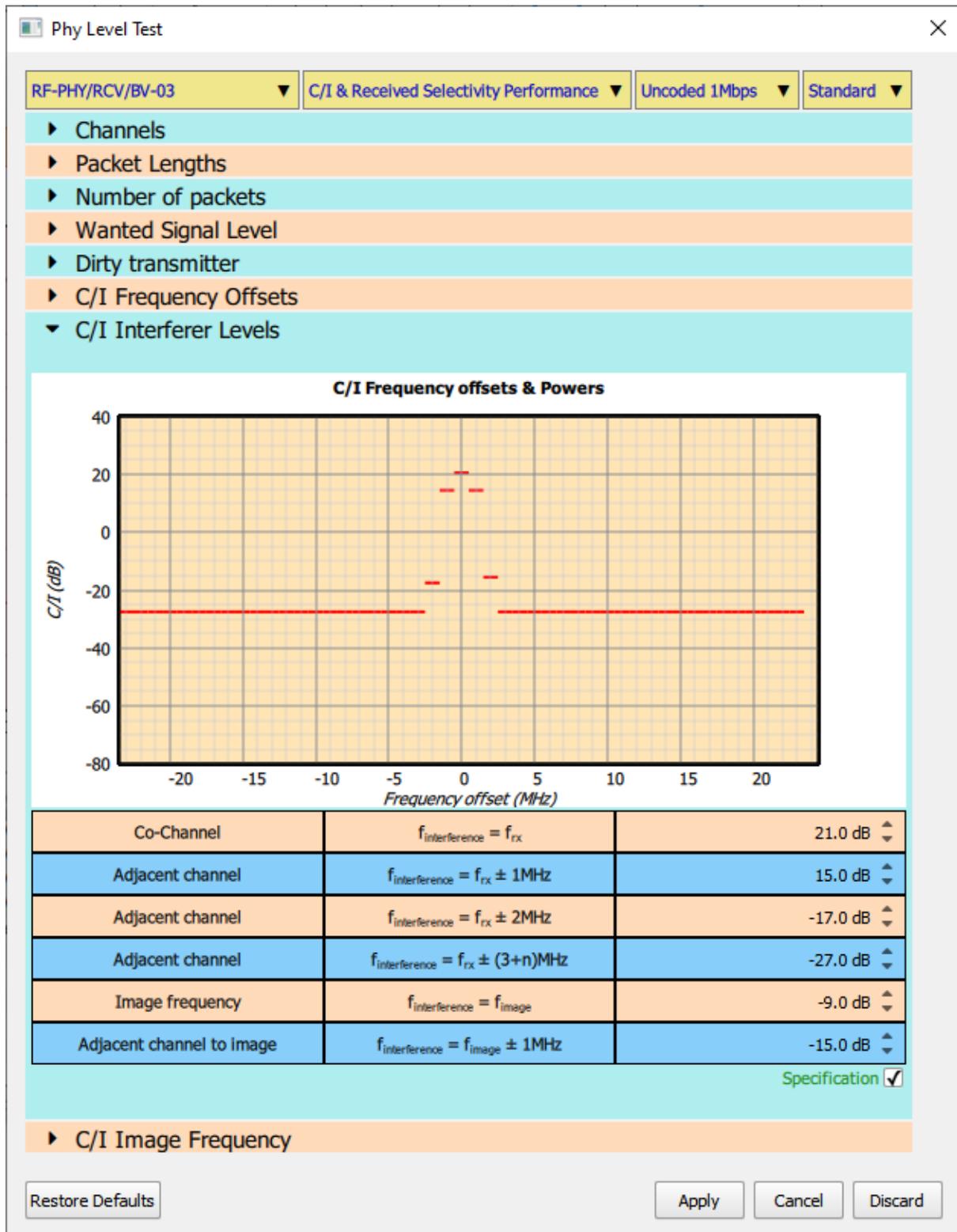


Figure 55: Displaying interferer signal level for C/I receiver tests.

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To enable the *C/I* levels to be adjusted, the '*Specification*' checkbox must be cleared. Once the checkbox has been cleared, the following controls are accessible:

1. The individual spin boxes in the last column of the table can be used to adjust the *C/I* values. Each value can be adjusted from -80dB to +40dB with a resolution of 0.1dB.
2. An offset can be applied to all the *C/I* levels in the table by using the '*Offset*' spin box below the table. The offset can be varied from -80dB to +20dB. However, many offsets may result in signals levels which cannot be generated by the *TLF3000* unit. When *Sapphire* encounters signal levels which cannot be generated the test is ignored and execution moves to the next test.
3. The offset to be applied to all the *C/I* levels in the table is also shown by the red bar in the gauge at the bottom of the window. It is possible to adjust the offset by clicking on the gauge. Alternatively, if the cursor is placed over the red bar, then a '→' symbol will appear adjacent to the cursor. It is then possible to hold down the left mouse button and drag the red bar.

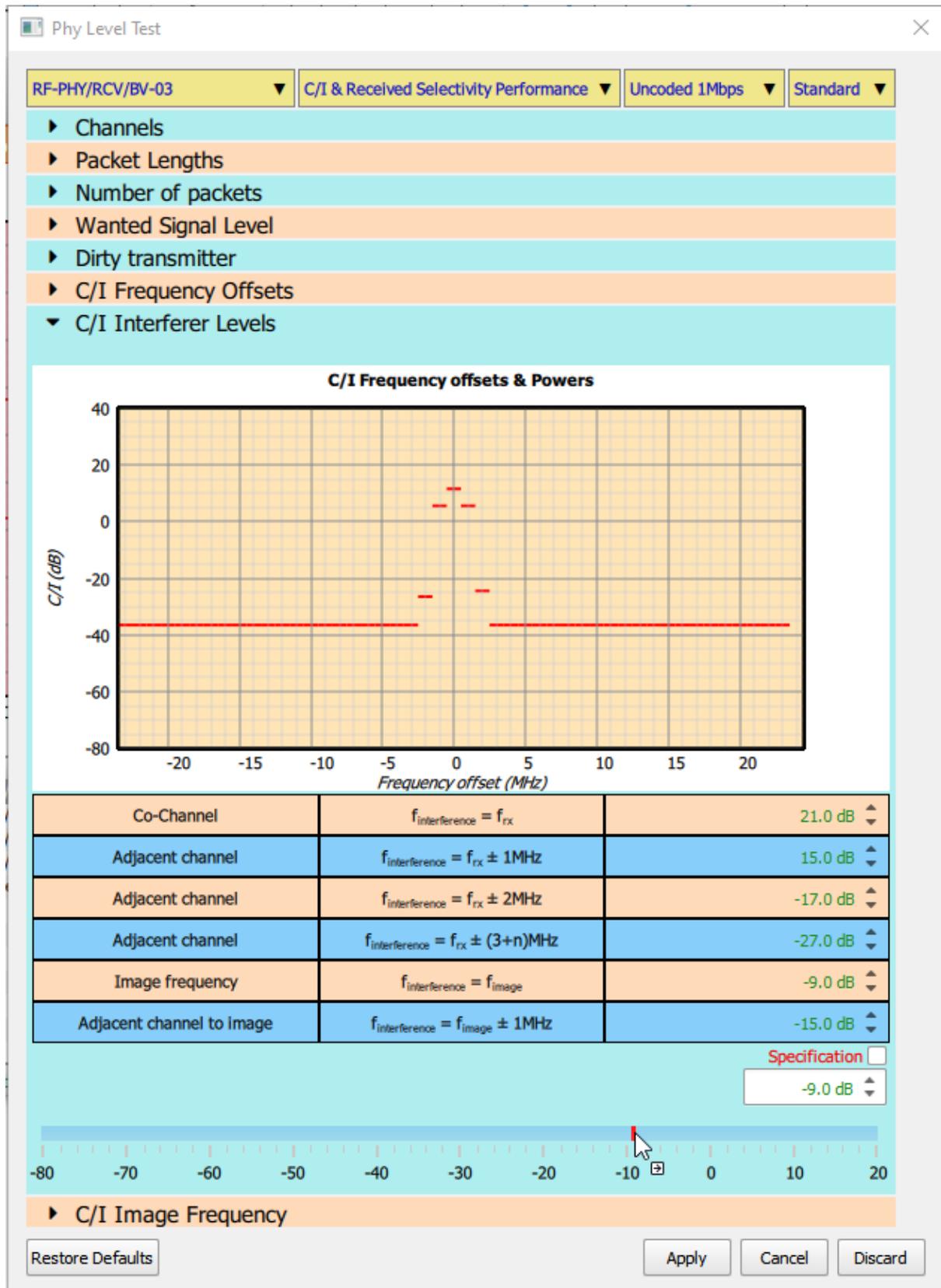


Figure 56: Changing the signal level for C/I receiver tests.

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If it is desired to perform the C/I receiver tests over a range of interfering signal levels, then the 'Swept' checkbox must be ticked. *It is only possible to sweep the interferer signal level if the wanted signal is not being swept.*

The sweep of interferer levels is accomplished by applying a swept offset to all the values in the C/I table. It is not possible to specify individual sweeps for each row of the table. If this facility is required, then multiple C/I tests should be placed in the test script, each test configured to execute one row in the C/I table.

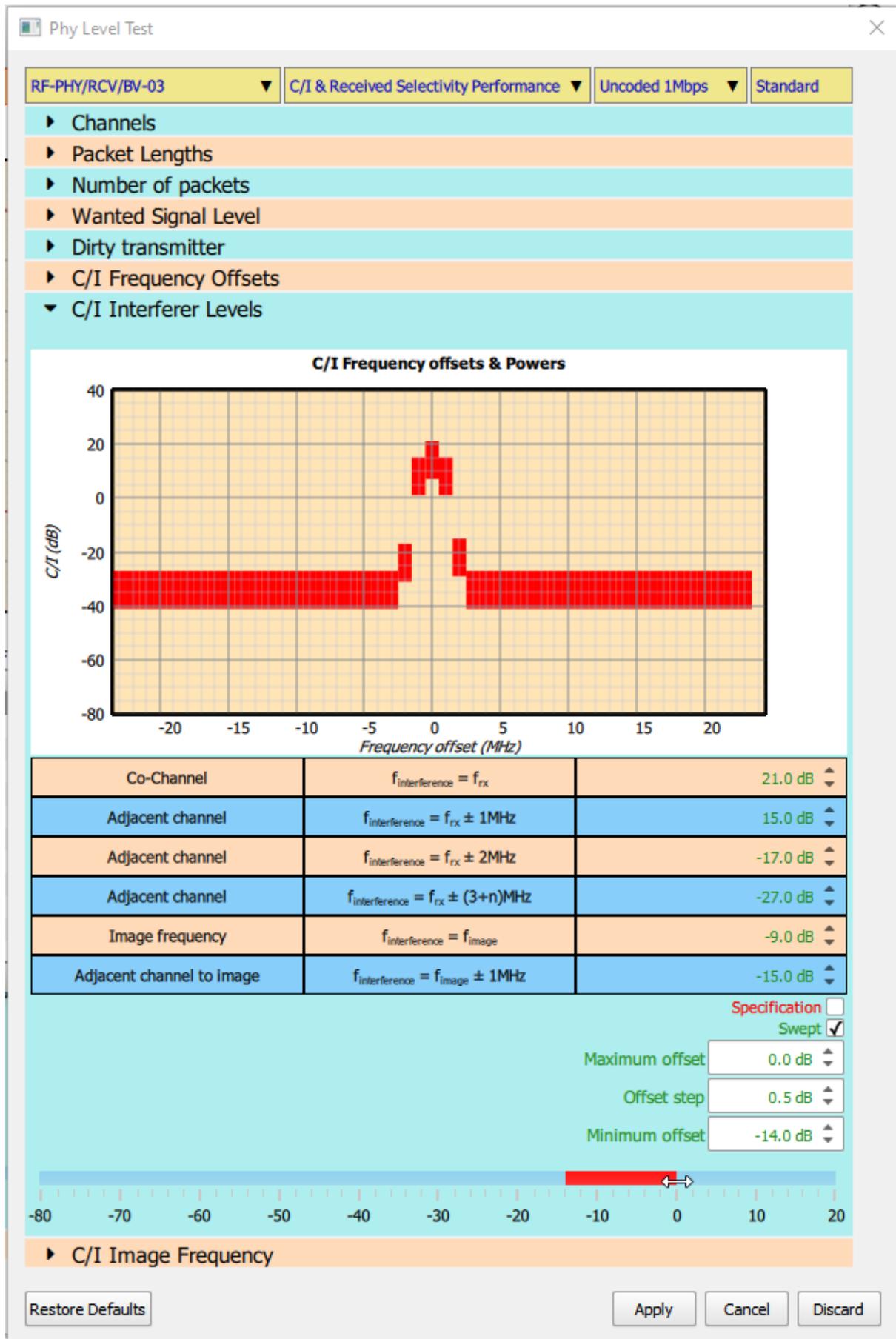
The offset level sweep is defined by the numbers displayed in the three spin boxes:

1. *Maximum Offset.* This indicates the offset at which the sweep will start. The sweep will always be from the maximum C/I towards the minimum C/I. The maximum offset cannot be above +20dB and must be greater than or equal to the minimum offset. The resolution of the offset is 0.1dB.
2. *Offset Step.* This is the step size that the sweep will take from the maximum C/I towards the minimum C/I. The step size cannot be less than 0.5dB. The resolution of the step size is 0.1dB.
3. *Minimum Offset.* This indicates where the C/I sweep should terminate. The last interferer signal level to be tested will be greater than or equal to the signal level defined by this offset. The minimum offset cannot be below -80dB and must be less than or equal to the maximum offset. The resolution of the minimum offset is 0.1dB.

The red bar in the signal level gauge indicates the range selected by the maximum and minimum offsets. This entire range may not be explored during the sweep since the actual values tested are dependent on the selection of the step size.

If the cursor is placed over one of the limits of the red bar, then it will change to a double headed cursor. It is then possible to hold down the left mouse button and drag the edge of the red bar to adjust either the minimum or maximum offset.

If the cursor is placed over the body of the red bar, then a '→' will appear adjacent to the cursor. It is then possible to hold down the left mouse button and drag the entire sweep range up or down the gauge.



*Figure 57: Selecting a range of signal levels for C/I receiver tests.*

#### **10.4.10 Configuring blocker receiver tests**

To configure the blocker frequencies and levels to be used in the blocker receiver tests, expand the *'Blocker'* menu.

At the top of the window is graphical display of the blocker levels which have been selected. This has been provided so that the plausibility of the selected parameters can be seen at a glance.

Below the graphical display, the blocker levels are shown in a tabular form, similar to that of the Bluetooth 5.2 LE RF Phy Test Specification. The range of blocker frequencies is subdivided into a number of segments, each segment occupying one row of the table. The second column shows the frequency at the start of the segment, the third column the step size that will be used to move the blocker through the segment and the fourth column denotes the end of the segment. The final column specifies the blocker level to be used for the segment.

Below the table is a *'Specification'* checkbox. If this check box is ticked, then the blocker frequencies and levels in the table and displayed on the graph are those defined in the Bluetooth 5.2 LE RF Phy Test Specification. Editing of the table is disabled when the *'Specification'* checkbox is ticked.

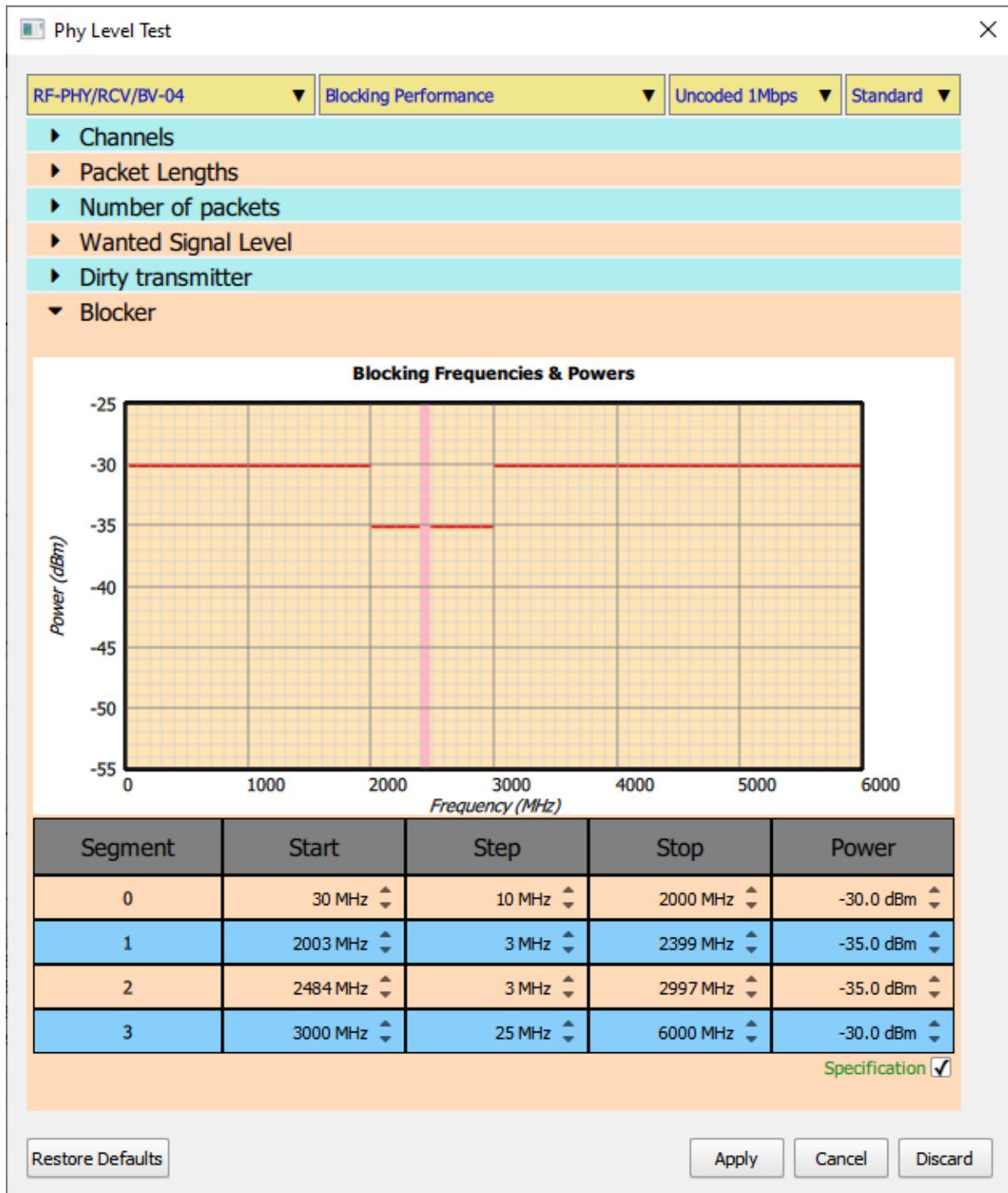


Figure 58: Displaying blocker frequencies and levels.

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To enable the blocker levels to be adjusted, the '*Specification*' checkbox must be cleared. Once the checkbox has been cleared, the following controls are accessible:

1. The individual spin boxes in the last column of the table can be used to adjust the blocker values. Each value can be adjusted from -55dBm to -25dBm with a resolution of 0.1dB.
2. An offset can be applied to all the blocker levels in the table by using the '*Offset*' spin box below the table. The offset can be varied from -40dB to +20dB. However, many offsets may result in blocker levels which cannot be generated by the *TLF3000* unit. When *Sapphire* encounters signal levels which cannot be generated the test is ignored and execution moves to the next test.

The offset to be applied to all the blocker levels in the table is also shown by the red bar in the gauge at the bottom of the window. It is possible to adjust the offset by clicking on the gauge.

Alternatively, if the cursor is placed over the red bar, then a '→' symbol will appear adjacent to the cursor. It is then possible to hold down the left mouse button and drag the red bar.

Clearing the '*Specification*' checkbox also permits the blocker frequencies to be adjusted. The start, step and stop frequencies within the table can now be adjusted using the associated spin box. The segments within the table are always held in order of increasing frequency. The minimum start frequency is 24MHz for the first segment or 1MHz above the stop frequency of the previous segment. The maximum stop frequency is 6GHz for the last segment or 1MHz below the start frequency of the subsequent segment. Step sizes can be varied from 1MHz to 1GHz. The resolution of all blocker frequency parameters is 1MHz.

It is also possible to remove or add blocker frequency segments. To do so, highlight a frequency segment by clicking on the segment number in the first column. If the right mouse button is held down, then a pop-up menu will appear with the following options:

1. *Delete*. The highlighted row will be deleted.
2. *Insert above*. A new frequency segment will be inserted above the highlighted segment.
3. *Insert below*. A new frequency segment will be inserted below the highlighted segment.

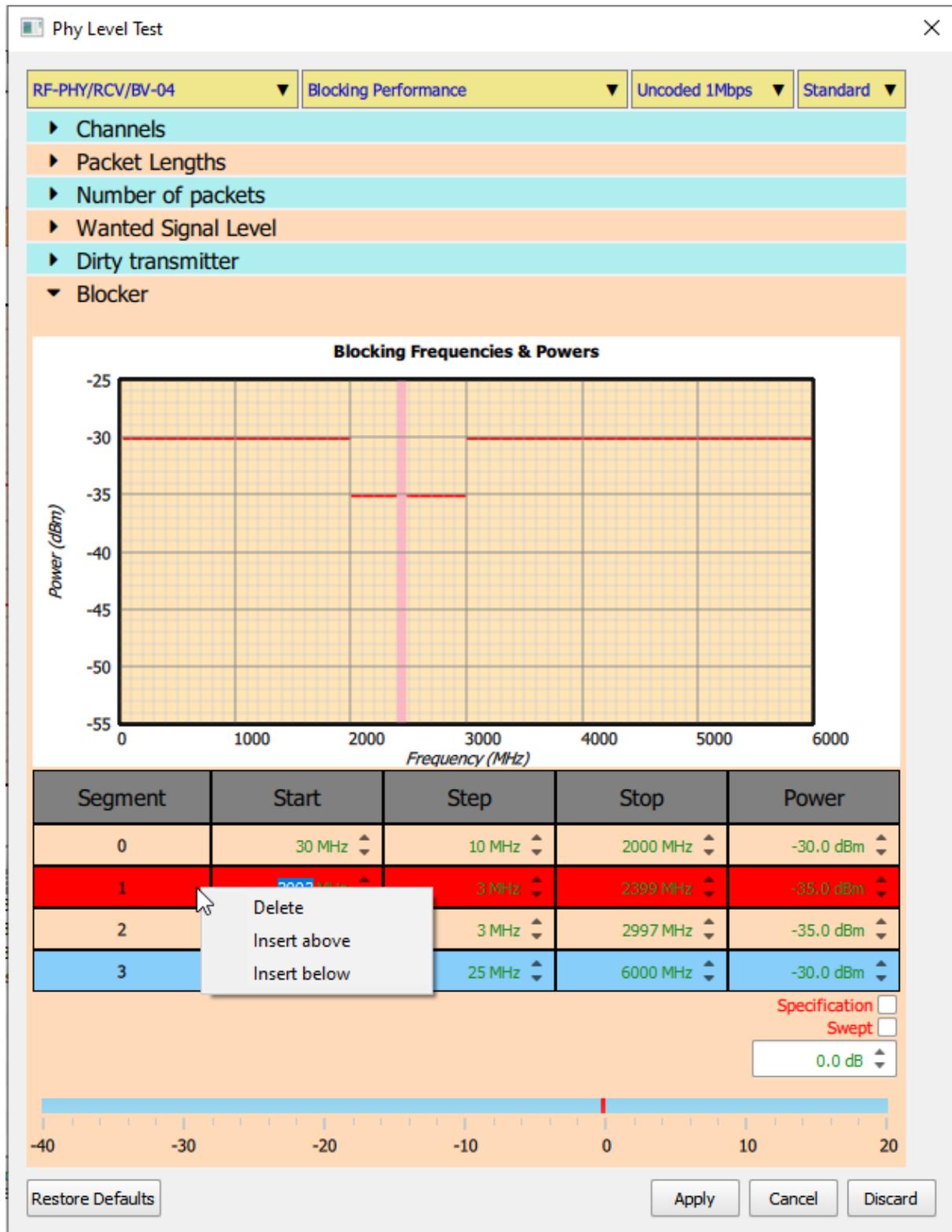


Figure 59: Removing or adding blocker frequencies and levels.

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If it is desired to perform the blocker receiver tests over a range of blocker signal levels, then the 'Swept' checkbox must be ticked. *It is only possible to sweep the blocker signal level if the wanted signal is not being swept.*

The sweep of blocker levels is accomplished by applying a swept offset to all the values in the blocker table. It is not possible to specify individual sweeps for each frequency segment of the table. If this facility is required, then multiple blocker tests should be placed in the test script, each test configured to execute one frequency segment.

The offset level sweep is defined by the numbers displayed in the three spin boxes:

1. *Minimum Offset.* This indicates the offset at which the sweep will start. The sweep will always be from minimum blocker level to maximum blocker level. The minimum offset cannot be below -40dB and must be less than or equal to the maximum offset. The resolution of the offset is 0.1dB.
2. *Offset Step.* This is the step size that the sweep will take from the minimum blocker level to the maximum blocker level. The step size cannot be less than 0.5dB. The resolution of the step size is 0.1dB.
3. *Maximum Offset.* This indicates where the blocker sweep should terminate. The last blocker level to be tested will be less than or equal to the signal level defined by this offset. The maximum offset cannot be above +20dB and must be greater than or equal to the minimum offset. The resolution of the minimum offset is 0.1dB.

The red bar in the signal level gauge indicates the range selected by the maximum and minimum offsets. This entire range may not be explored during the sweep since the actual values tested are dependent on the selection of the step size.

If the cursor is placed over one of the limits of the red bar, then it will change to a double headed cursor. It is then possible to hold down the left mouse button and drag the edge of the red bar to adjust either the minimum or maximum offset.

If the cursor is placed over the body of the red bar, then a '→' will appear adjacent to the cursor. It is then possible to hold down the left mouse button and drag the entire sweep range up or down the gauge.

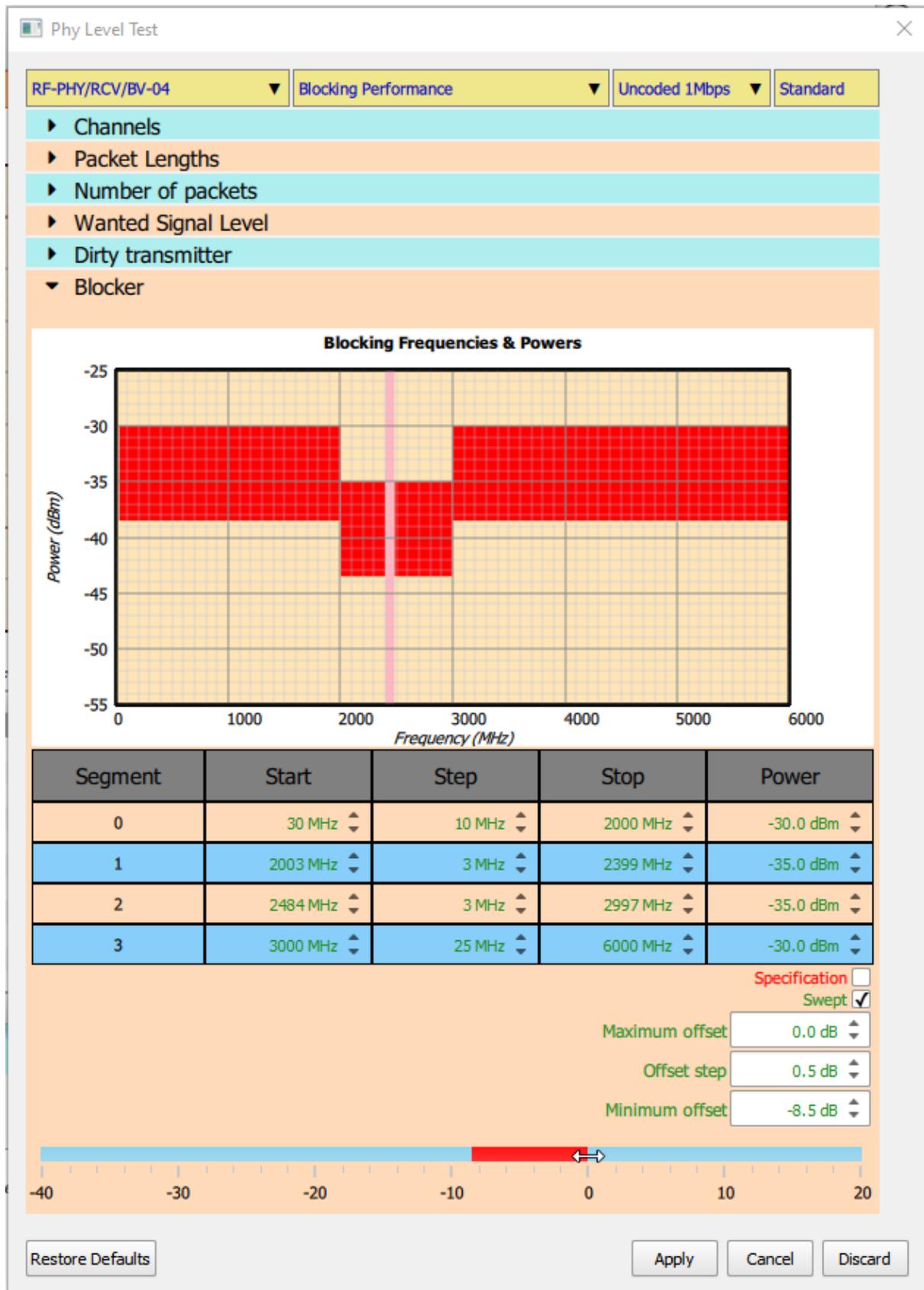


Figure 60: Selecting a range of blocker frequencies and levels.

**10.4.11 Configuring receiver intermodulation tests**

To configure the parameters to be used in the receiver intermodulation tests, expand the 'Intermodulation Spacings and Levels' menu.

At the top of the window is graphical display of the interferer levels and frequencies which have been selected. This has been provided so that the plausibility of the selected parameters can be seen at a glance. The graph is constructed as follows:

1. Wide bars are used to indicate continuously modulated interferer signals
2. Narrow bars are used to indicate CW interferers
3. The bars are colour coded as:
  - a. Green: interferer spacing  $N = 3$
  - b. Blue: interferer spacing  $N = 4$
  - c. Red: interferer spacing  $N = 5$
4. The interferer frequencies are shown below the wanted signal. The test will be performed for the interferer frequencies both below and above the wanted signal.

Below the graphical display are a series of checkboxes to select the frequency offsets of the interfering signals. The frequencies of the interfering signals are related by:

$$F_{wanted} = 2 F_{CW} - F_{modulated}$$

and:

$$| F_{modulated} - F_{CW} | = N$$

where:  $F_{wanted}$  is the frequency of the wanted signal  
 $F_{modulated}$  is the frequency of the continuously modulated interfering signal  
 $F_{CW}$  is the frequency of the CW interfering signal  
 $N$  is the parameter selected by the checkboxes

The Bluetooth 5.2 LE RF Phy Test Specification does not provide a default value for the parameter  $N$ . *Sapphire* adopts the default value of 3.

The interferer signal levels are displayed in a spin box and a signal gauge at the bottom of the window. The CW interferer and the continuously modulated interferer are always constrained to have the same signal level.

Below the checkboxes which select the parameter  $N$  is a 'Specification' checkbox. If this check box is ticked, then the interferer signal levels are those defined in the Bluetooth 5.2 LE RF Phy Test Specification.

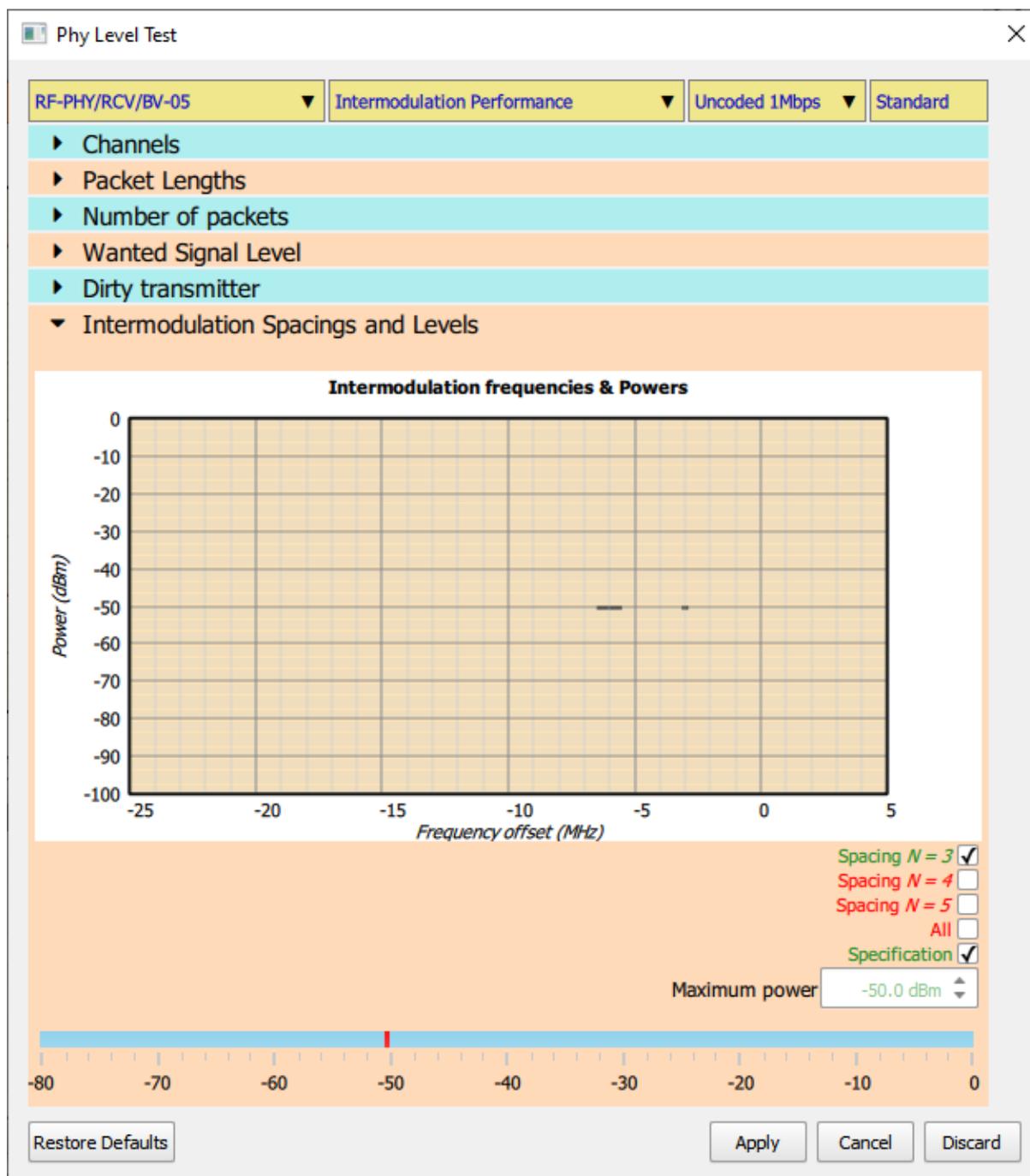


Figure 61: Entering interferer signal levels for intermodulation testing.

If the 'Specification' checkbox is cleared, then the interferer signal levels can be entered into the spin box, either by using the up/down arrows or by entering a numeric value directly into the text field. If the cursor is placed directly over the red bar in the signal level gauge, then a '→' will appear adjacent to the cursor. By holding down the left mouse button it is then possible to drag the red bar to set the interferer signal levels. Interferer signal levels must be in the range -80dBm to 0dBm. The resolution of the interferer signal levels is 0.1dBm.

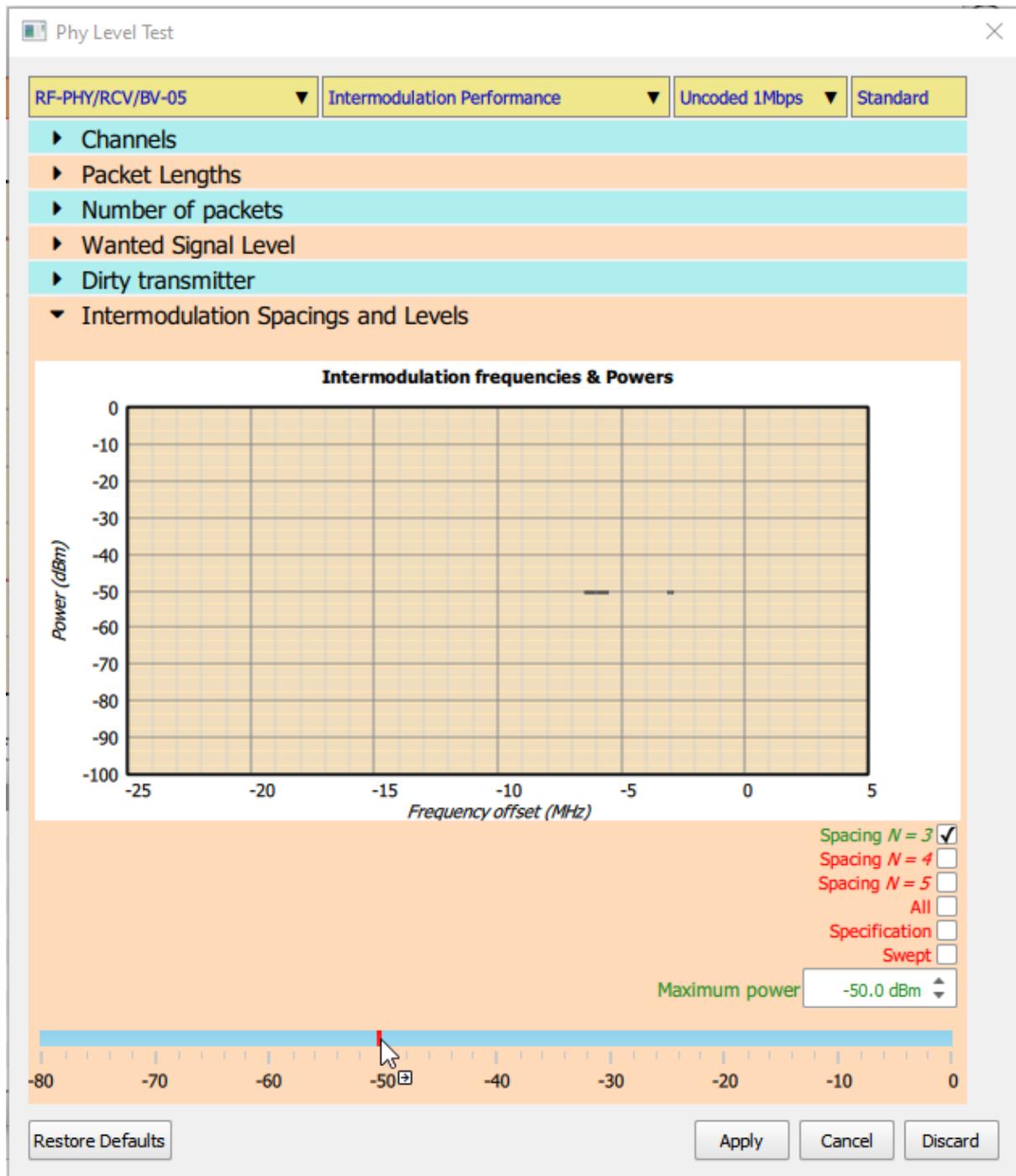


Figure 62: Selecting interferer signal level for intermodulation testing.

If it is desired to sweep the interferer signal levels over a range of values then tick the ‘Swept’ checkbox. **If wanted signal has been programmed to have swept levels, then it is not possible to sweep the interferer signal levels.**

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The interferer signal level power sweep is defined by the numbers displayed in the three spin boxes:

1. *Minimum Power*. This indicates the power level at which the sweep will start. The sweep will always be from the minimum interferer signal power towards the maximum interferer signal power. The minimum power cannot be below -80dBm and must be less than or equal to the maximum power. The resolution of the minimum power is 0.1dBm.
2. *Power Step*. This is the step size that the sweep will take from the minimum power towards the maximum power. The step size cannot be less than 0.5dB. The resolution of the step size is 0.1dB.
3. *Maximum Power*. This indicates where the power sweep should terminate. The last interferer signal power to be test will be less than or equal to the maximum power. The maximum power cannot be above 0dBm and must be greater than or equal to the minimum power. The resolution of the maximum power is 0.1dBm.

The red bar in the signal level gauge indicates the range selected by the maximum and minimum powers. This entire range may not be explored during the sweep since the actual values tested are dependent on the selection of the step size.

If the cursor is placed over one of the limits of the red bar, then it will change to a double headed cursor. It is then possible to hold down the left mouse button and drag the edge of the red bar to adjust either the minimum or maximum power.

If the cursor is placed over the body of the red bar, then a '→' will appear adjacent to the cursor. It is then possible to hold down the left mouse button and drag the entire sweep range up or down the gauge.

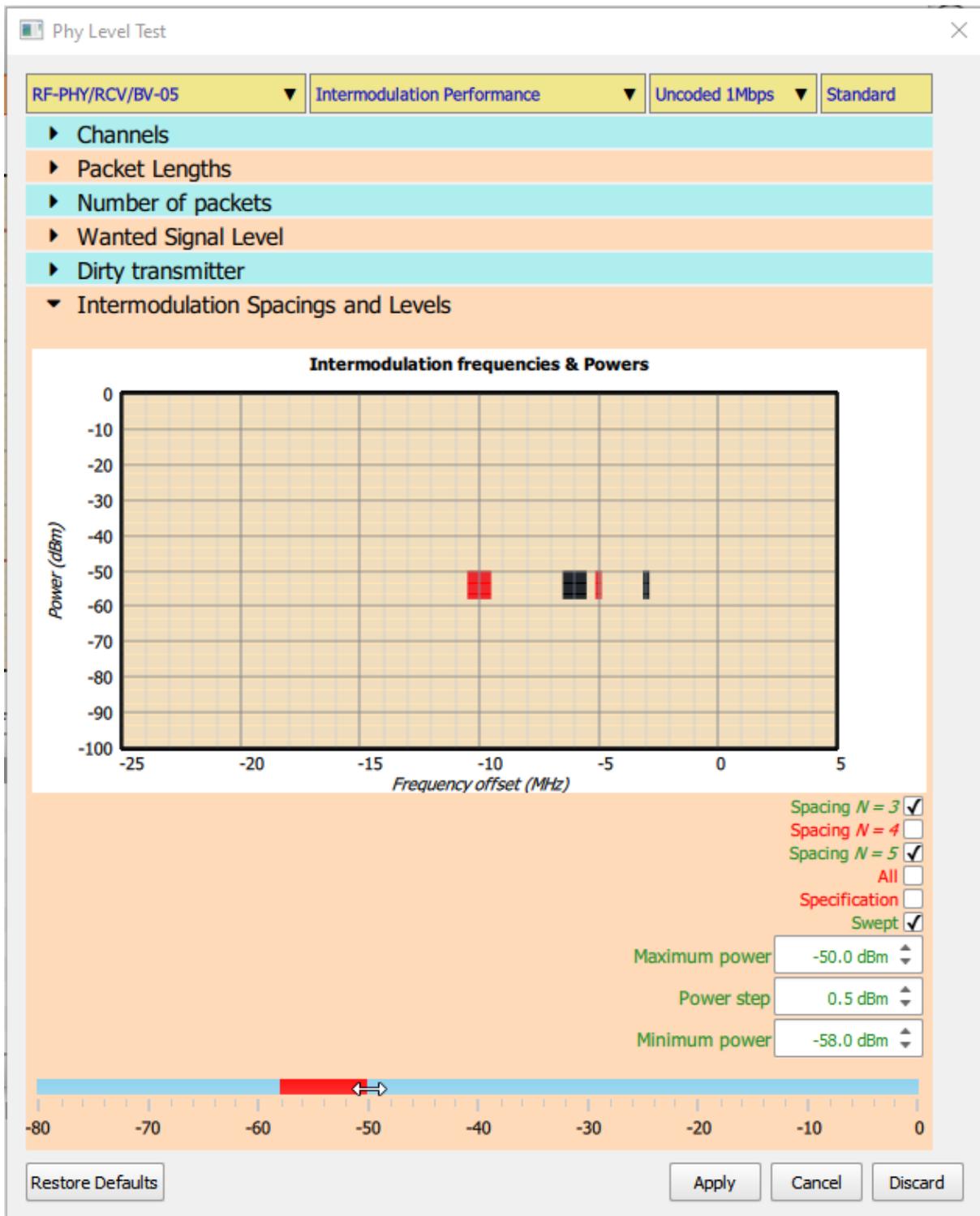


Figure 63: Selecting interferer signal levels over a range of values for intermodulation testing.

#### 10.4.12 Configuring the receiver PER report integrity tests

When running the receiver PER report integrity tests it is possible to configure the number of integrity checks to perform. To access this parameter, expand the *'Integrity Count'* menu.

If the *'Specification'* check box is ticked, then 3 integrity checks will be performed as defined in the Bluetooth 5.2 LE RF Phy Test Specification.

If the *'Specification'* check box is cleared, then the spin box displaying the number of integrity checks becomes enabled. The number of integrity checks can be changed to any number between 1 and 100 inclusive.

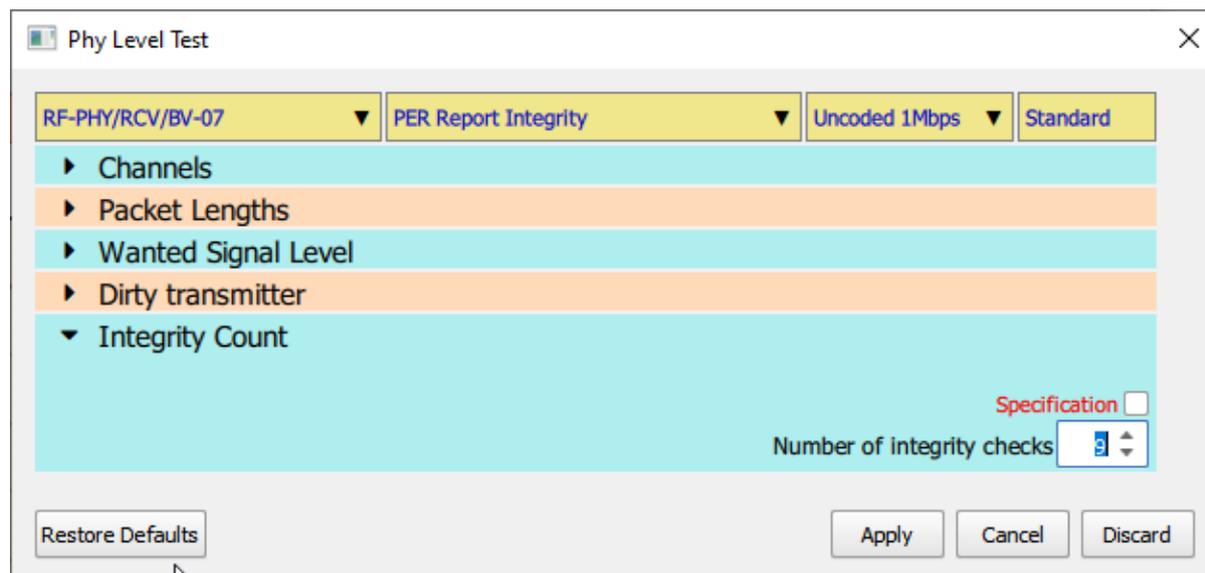


Figure 64: Configuring the receiver PER report integrity tests.

#### 10.4.13 Configuring CTE for AoA output power and carrier frequency offset and drift

When running AoA output power or carrier frequency offset and drift tests, the CTE characteristics can be configured via the *'CTE properties'* menu.

By ticking the *'Specification'* checkbox the CTE length will be set to that specified in the Bluetooth 5.2 LE RF Phy Test Specification. This value may vary depending on the DUT capabilities.

The *'CTE length (slots)'* spin box is used to set the CTE length in units of 8 $\mu$ s slots.

The *'DUT antenna index to use'* spin box is used to specify the DUT antenna index to be sent in the HCI command. This value should be ignored by the DUT.

Ticking the *'Mimic R&S CMW implementation'* checkbox will force *Sapphire* to mimic the HCI commands used by Rohde and Schwarz in their CMW. This will result in unnecessary event masks being set.

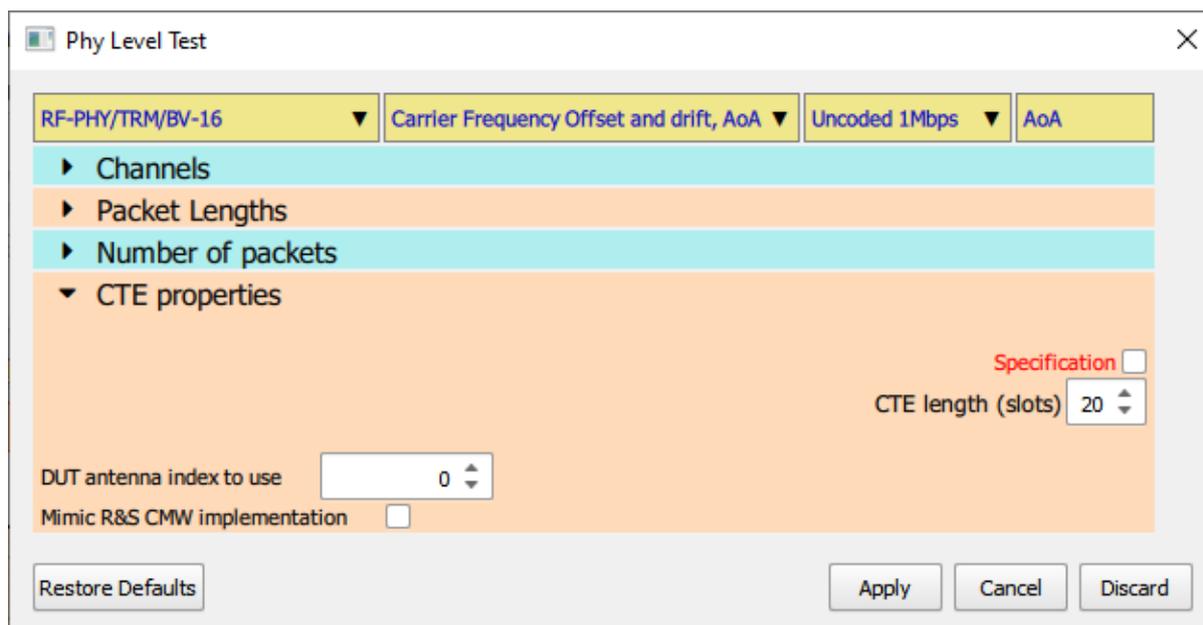


Figure 65: Configuring CTE for AoA output power and carrier frequency offset and drift.

#### 10.4.14 Configuring CTE for transmit power stability and antenna switching integrity

When running AoD transmit power stability or antenna switching integrity tests, the CTE characteristics can be configured via the 'CTE properties' menu.

By ticking the 'Specification' checkbox the CTE length and the number of antenna will be set to that specified in the Bluetooth 5.2 LE RF Phy Test Specification. These values may vary depending on the DUT capabilities.

The 'CTE length (slots)' spin box is used to set the CTE length in units of 8 $\mu$ s slots.

The 'Number of antenna' spin box is used to set the number of antenna on the DUT.

Each antenna to be used in the test must be identified by its antenna ID. This is a number specific to the DUT. Spin boxes are provided to permit the antenna IDs to be specified.

Ticking the 'Mimic R&S CMW implementation' checkbox will force *Sapphire* to mimic the HCI commands used by Rohde and Schwarz in their CMW. This will result in unnecessary event masks being set.

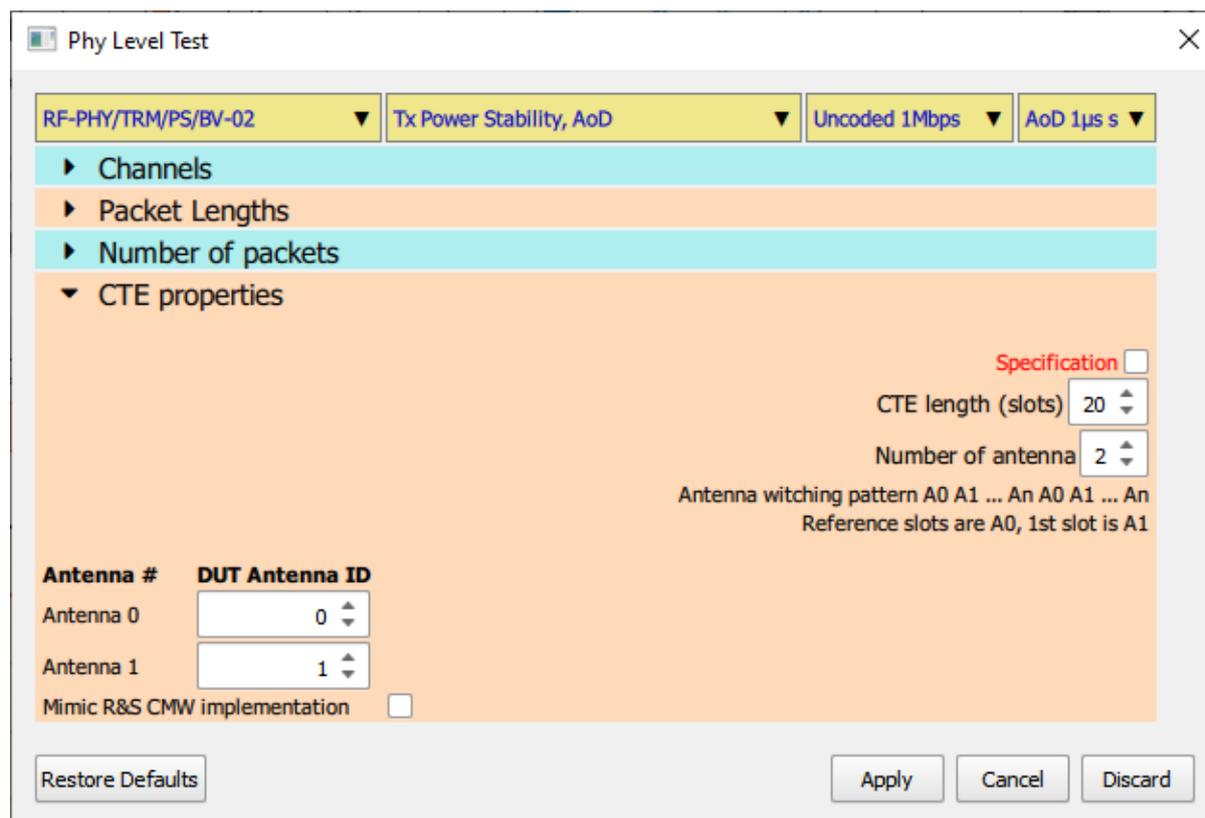


Figure 66: Configuring CTE for transmit power stability and antenna switching integrity.

#### 10.4.15 Configuring CTE for AoA IQ sample coherency tests

The AoA IQ sample coherency test is only available if the DUT is connected via an HCI interface.

When running AoA IQ sample coherency tests, the CTE characteristics can be configured via the 'CTE properties' menu.

By ticking the 'Specification' checkbox the CTE length and the number of antenna will be set to that specified in the Bluetooth 5.2 LE RF Phy Test Specification. These values may vary depending on the DUT capabilities.

The 'CTE length (slots)' spin box is used to set the CTE length in units of 8µs slots.

The 'Number of antenna' spin box is used to set the number of antenna on the DUT.

Each antenna to be used in the test must be identified by its antenna ID. This is a number specific to the DUT. Spin boxes are provided to permit the antenna IDs to be specified.

Ticking the 'Mimic R&S CMW implementation' checkbox will force *Sapphire* to mimic the HCI commands used by Rohde and Schwarz in their CMW. This will result in unnecessary event masks being set.

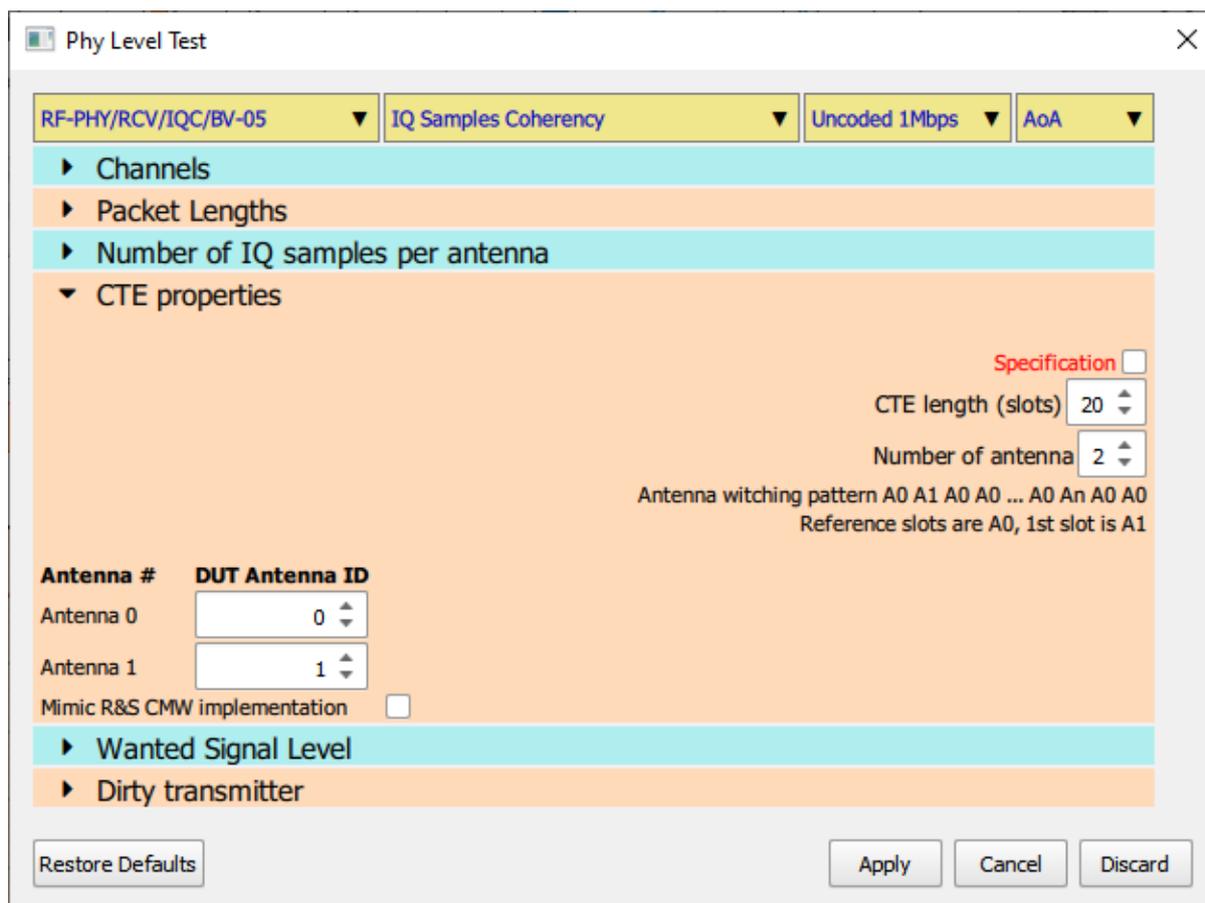


Figure 67: Configuring CTE for AoA IQ sample coherency tests.

#### 10.4.16 Configuring CTE for AoD IQ sample coherency tests

The AoD IQ sample coherency test is only available if the DUT is connected via an HCI interface.

When running AoD IQ sample coherency tests, the CTE characteristics can be configured via the 'CTE properties' menu.

By ticking the 'Specification' checkbox the CTE length and the number of antenna will be set to that specified in the Bluetooth 5.2 LE RF Phy Test Specification. These values may vary depending on the DUT capabilities.

The 'CTE length (slots)' spin box is used to set the CTE length in units of 8µs slots.

The 'Number of antenna' spin box is used to set the number of antenna on the DUT.

For each antenna which the TLF3000 simulates a unique phase can be defined. Spin boxes are provided to set the phase of each antenna simulated.

The 'DUT antenna index to use' spin box is used to specify the DUT antenna index to be sent in the HCI command. This value should be ignored by the DUT.

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Ticking the *'Mimic R&S CMW implementation'* checkbox will force *Sapphire* to mimic the HCI commands used by Rohde and Schwarz in their CMW. This will result in unnecessary event masks being set.

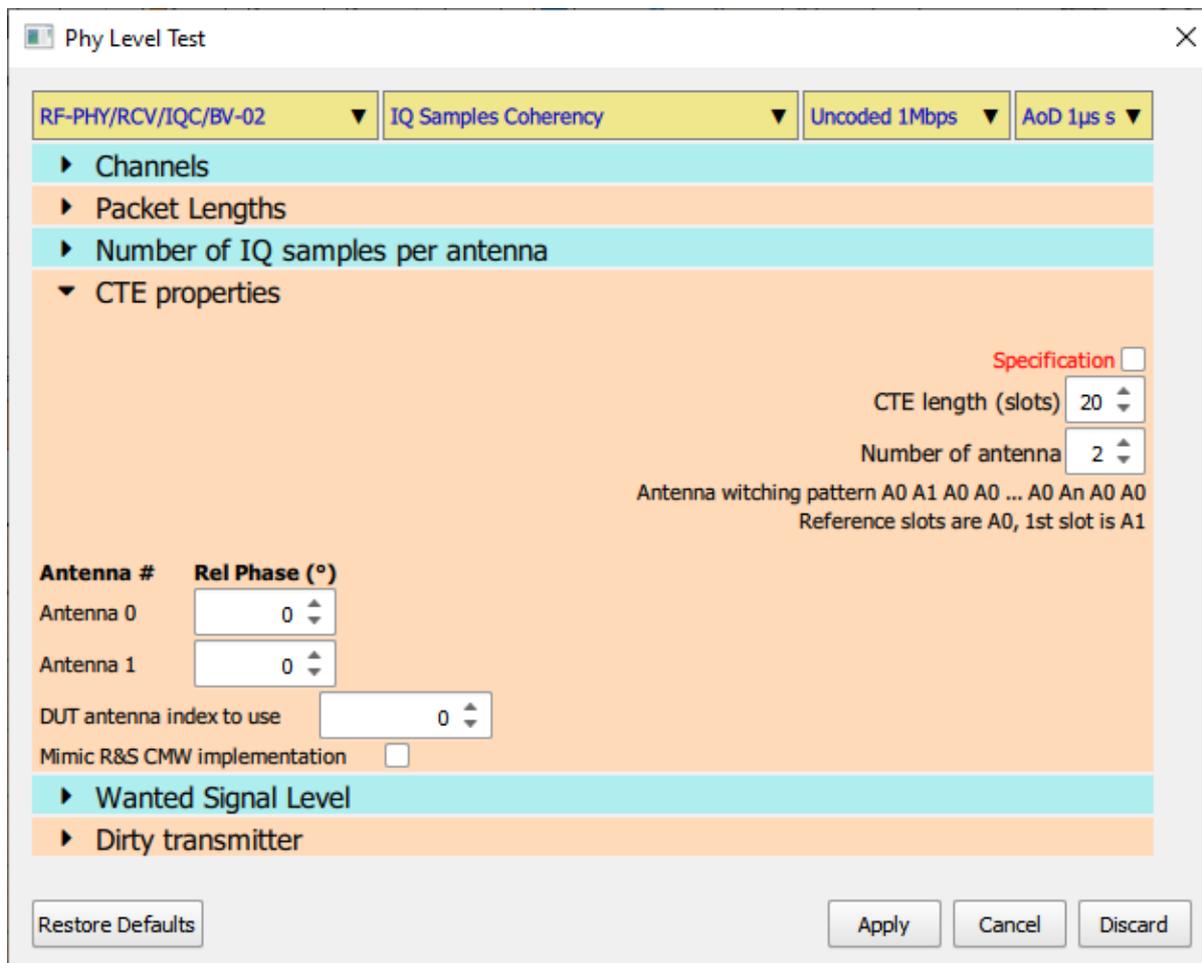


Figure 68: Configuring CTE for AoD IQ sample coherency tests.

### 10.4.17 Configuring CTE for AoA IQ sample dynamic range tests

The AoA IQ sample dynamic range test is only available if the DUT is connected via an HCI interface.

When running AoA IQ sample dynamic range tests, the CTE characteristics can be configured via the *'CTE properties'* menu.

By ticking the *'Specification'* checkbox the CTE length, the number of antenna and the antenna amplitudes will be set to the values specified in the Bluetooth 5.2 LE RF Phy Test Specification. The values for CTE length and number of antenna may vary depending on the DUT capabilities.

The *'CTE length (slots)'* spin box is used to set the CTE length in units of 8µs slots.

The *'Number of antenna'* spin box is used to set the number of antenna on the DUT.

Each antenna to be used in the test the following can be specified:

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1. 'DUT antenna ID'. The antenna ID which is used to identify the antenna on the DUT. This number will be specific to the DUT.
2. 'Rel phase (°)'. The phase the TLF3000 should transmit whilst simulating this antenna.
3. 'Rel amplitude (dB)'. The amplitude relative to that of the packet payload which the TLF3000 should transmit whilst simulating this antenna. The relative amplitude can be set in the range -10dB to +10dB.

Ticking the 'Mimic R&S CMW implementation' checkbox will force *Sapphire* to mimic the HCI commands used by Rohde and Schwarz in their CMW. This will result in unnecessary event masks being set.

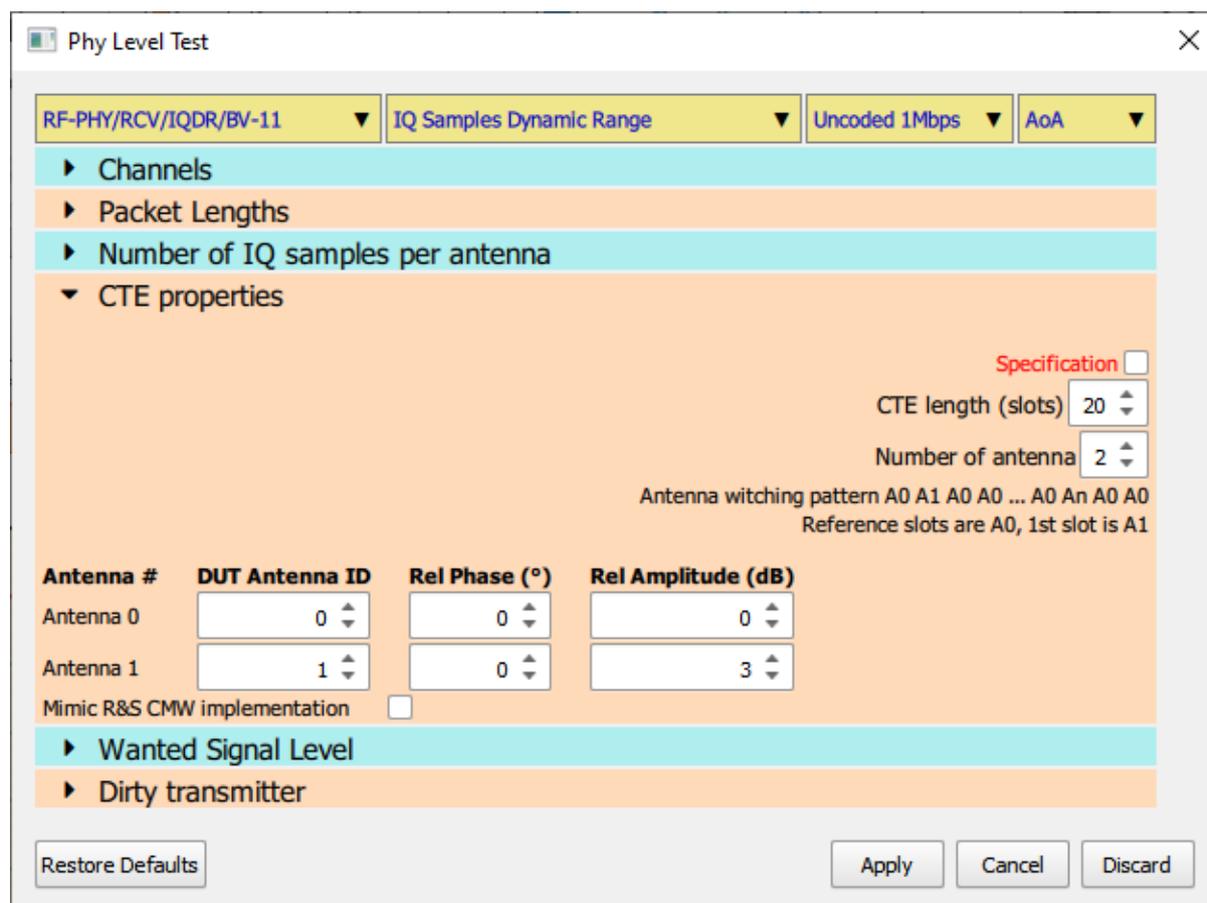


Figure 69: Configuring CTE for AoA IQ sample dynamic range tests.

### 10.4.18 Configuring CTE for AoD IQ sample dynamic range tests

The AoD IQ sample dynamic range test is only available if the DUT is connected via an HCI interface.

When running AoD IQ sample dynamic range tests, the CTE characteristics can be configured via the 'CTE properties' menu.

By ticking the 'Specification' checkbox the CTE length, the number of antenna and the antenna amplitudes will be set to the values specified in the Bluetooth 5.2 LE RF Phy Test Specification. The values for CTE length and number of antenna may vary depending on the DUT capabilities.

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The 'CTE length (slots)' spin box is used to set the CTE length in units of 8 $\mu$ s slots.

The 'Number of antenna' spin box is used to set the number of antenna on the DUT.

Each antenna to be used in the test the following can be specified:

1. 'Rel phase (°)'. The phase the TLF3000 should transmit whilst simulating this antenna.
2. 'Rel amplitude (dB)'. The amplitude relative to that of the packet payload which the TLF3000 should transmit whilst simulating this antenna. The relative amplitude can be set in the range -10dB to +10dB.

The 'DUT antenna index to use' spin box is used to specify the DUT antenna index to be sent in the HCI command. This value should be ignored by the DUT.

Ticking the 'Mimic R&S CMW implementation' checkbox will force Sapphire to mimic the HCI commands used by Rohde and Schwarz in their CMW. This will result in unnecessary event masks being set.

The screenshot shows the 'Phy Level Test' configuration window. At the top, there are four dropdown menus: 'RF-PHY/RCV/IQDR/BV-07', 'IQ Samples Dynamic Range', 'Uncoded 1Mbps', and 'AoD 2 $\mu$ s'. Below these are expandable sections: 'Channels', 'Packet Lengths', 'Number of IQ samples per antenna', and 'CTE properties'. The 'CTE properties' section is expanded and contains a 'Specification' checkbox (unchecked), a 'CTE length (slots)' spin box set to 20, and a 'Number of antenna' spin box set to 2. Below these is the text 'Antenna witching pattern A0 A1 A0 A0 ... A0 An A0 A0' and 'Reference slots are A0, 1st slot is A1'. A table with three columns: 'Antenna #', 'Rel Phase (°)', and 'Rel Amplitude (dB)' is shown. The table has two rows: 'Antenna 0' with values 0 and 0, and 'Antenna 1' with values 0 and 3. Below the table is a 'DUT antenna index to use' spin box set to 0 and a 'Mimic R&S CMW implementation' checkbox (unchecked). At the bottom, there are buttons for 'Restore Defaults', 'Apply', 'Cancel', and 'Discard'.

Antenna #	Rel Phase (°)	Rel Amplitude (dB)
Antenna 0	0	0
Antenna 1	0	3

Figure 70: Configuring CTE for AoD IQ sample dynamic range tests.

### 10.4.19 Textual input of test parameters

Many of the menus for configuring the test parameters permit the input of text strings to define ranges of parameter values. These textual descriptions must be of the form:

$a_{start}:a_{step}: a_{stop}, b_{start}: b_{step}: b_{stop}, \dots$

This implies that all values from  $a_{start}$  to  $a_{stop}$  in steps of  $a_{step}$  will be selected, plus all values from  $b_{start}$  to  $b_{stop}$  in steps of  $b_{step}$ , etc.

If  $a_{step}$  is unity, then  $a_{start}:a_{step}: a_{stop}$  can be abbreviated to  $a_{start}: a_{stop}$ .

If  $a_{step}$  is equal to  $a_{stop}$  then  $a_{start}:a_{step}: a_{stop}$  can be abbreviated to  $a_{start}$ .

## 10.5 Test duplication

Running any of the modulation characteristics tests will automatically generate results for the corresponding carrier offset and drift tests. This occurs since the packets the DUT must transmit for the carrier offset and drift tests are a subset of those required for the modulation characteristic tests. Furthermore, the test channels used for modulation characteristic measurements are the same as those required for carrier offset and drift measurements. It is therefore unnecessary to explicitly include the carrier offset and drift tests within the test script if the corresponding modulation characteristics test are present.

## 10.6 Test script window

The test script displayed at the bottom of the window underneath the graphics area. Each row in the table represents one test in the test script. The columns in the table contain:

1. Column 1 contains the test script number as defined in the Bluetooth 5.2 LE RF Phy Test Specification
2. Column 2 contains the test script title, providing a textual description of the test
3. Column 3 indicates the modulation scheme which will be used for the test
4. Column 4 indicates the test status:
  - a. '?' indicates that the test has not been run and no results are available
  - b. ▶ indicates that the test is currently being run
  - c. '✓' indicates that the test has been run and the test limits have been passed
  - d. '✗' indicates that the test has been run and at least one test limit has failed
5. Column 5 indicates the time taken to perform the test

When a test is running it is highlighted in the test script window.

By clicking on a test number the test entry will be expanded to show the parameters defining the test configuration.

Tests can be added to the test script by clicking on the 'click to add test' text at the bottom of the test script. To edit a test, double click the entry in the test script. To delete a test, double click on the entry and then select 'Discard' in the test definition pop-up window.

Test Number	Test Description	Test Modulation	Status	Time
▶ RF-PHY/TRM/BV-01	Output Power	Uncoded 1Mbps : Standard	✓	0.363s
▼ RF-PHY/TRM/BV-05	Modulation Characteristics	Uncoded 1Mbps : Standard	✓	0.672s
	Wanted signal channels			0,19,39
	Modulation scheme	1000		kbps
	Packet lengths	255		
	Number of packets	10		
▶ RF-PHY/TRM/BV-06	Carrier Frequency Offset & Drift	Uncoded 1Mbps : Standard	✓	0.617s
▶ RF-PHY/RCV/BV-01	Receiver Sensitivity	Uncoded 1Mbps : Standard	✓	8.176s
	click to add test			

Figure 71: The test script window.

## 10.7 Saving and recalling test scripts

The current test script can be saved by clicking the 'Save' button in the toolbar. The test script can be saved in two formats:

1. Test script file (\*.tsf). This is an XML file containing the test script. These files can be read back into the *Sapphire* GUI. Test script files should never be edited manually. To edit a test script file, read it back into the *Sapphire* GUI, edit it and then save it again. This format also contains all the settings contained in the 'DUT' and 'Analysis' tabs.
2. Text file (\*.txt). This is an ASCII text file representation of the test script. This file can be used to define tests when running *Sapphire* from a C dll or Python script.

To recall a test script, click the 'Open' button in the toolbar and filter by test script files (\*.tsf).

## 10.8 Running a test script

In order to run a test script the following steps must be taken:

1. I must be told how to communicate with the DUT(s) by setting the parameters in the 'DUT control' menu under the 'DUT' tab. If a test script is loaded from a test script file, then these parameters will be read in from the file.
2. *Sapphire* must be informed which features the DUT supports by setting the parameter in the 'DUT features' menu under the 'DUT' tab. If a test script is loaded from a test script file, then these parameters will be read in from the file.
3. The cable loss between the *TLF3000* unit and the DUT must be entered in the 'Cable loss' menu under the 'DUT' tab. If a test script is loaded from a test script file, then these parameters will be read in from the file.
4. The termination criteria must be set in the 'Run mode' menu under the 'DUT' tab. If a test script is loaded from a test script file, then these parameters will be read in from the file.
5. A test script must either be entered manually (see [Building a test script](#)) or loaded from a file using the 'Open' button in the toolbar.
6. The DUT(s) must be physically connected to the *TLF3000* unit by:
  - a. RF cable connected to the Tx/Rx port
  - b. Serial cable connected to the digital IO port or to the host computer if the serial communications is to be via the host.
  - c. If appropriate, an IO voltage may also be connected to the digital IO port

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Once these steps have been taken, the test script can be executed by pressing the *'Play'* button in the toolbar.

While the test script is executing the GUI will display the following:

1. The test currently being run will be highlighted in the test script panel
2. The status of the test being run will change from '?' to '▶'
3. The graphics window will plot one of the quantities being tested

After each test in the test script terminates, its displayed status will change to either:

1. '✓' to indicate that all test limits associated with test passed
2. '✗' to indicate that one or more the test limits associated with the test failed

The time taken by the test will also be displayed.

When the test script terminates execution the *'Stop'* button in the toolbar will revert to the *'Play'* button. If appropriate, an error message will be displayed in the status indicating why the test script terminated.

If the test script terminates due to a test limit failure, then the graphics window will plot the quantity which failed.

### 10.9 Viewing the results

#### 10.9.1 Overview

Once a test script has been run, the results can be viewed using the controls under the *'Analysis'* tab.

The results which are plotted in the graphics area can be filtered by:

1. RF channel number
2. Packet length

#### 10.9.2 Filtering by RF channel number

To filter the displayed results by RF channel number, expand the *'Channel filter'* menu under the *'Analysis'* tab. The required RF channels can be selected by:

1. Ticking the individual channel checkboxes
2. Using the toggle buttons at the bottom left of the window:
  - a. *Clear all*. All RF channels will be deselected.
  - b. *Select all*. All RF channels which are supported by the DUT will be selected.
  - c. *Primary advertising*. The primary advertising channels will be selected.
  - d. *Data/Secondary advertising*. The data and secondary advertising channels supported by the DUT will be selected.
  - e. *Specification channels*. The RF channels defined for the test in Bluetooth 5.2 LE RF Phy Test Specification will be selected.
3. Entering a text string in the text field at the bottom of the window. The required format of the text string is described in [Textual input of test parameters](#).

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If the quantity to be displayed is to be plotted against RF channel number, the RF channel filter settings are ignored.

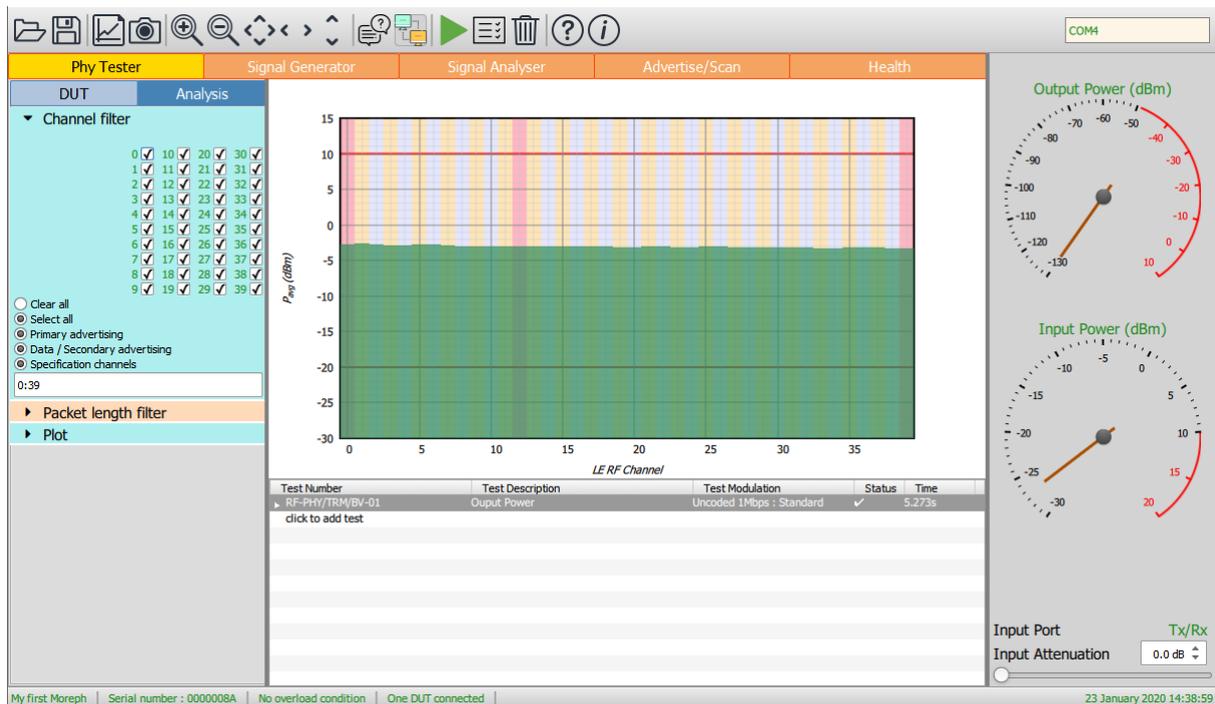


Figure 72: Filtering by RF channel number.

## 10.9.3 Filtering by packet length

To filter the displayed results by packet length, expand the 'Packet length filter' menu under the 'Analysis' tab. The required packet lengths can be selected by:

1. Ticking the individual packet length checkboxes
2. Using the toggle buttons at the bottom left of the window:
  - a. *Clear all*. All packet lengths will be deselected.
  - b. *Select all*. All packet lengths which are supported by the DUT will be selected.
  - c. *Specification*. The packet lengths specified for the test in Bluetooth 5.2 LE RF Phy Test Specification will be selected.
3. Entering a text string in the text field at the bottom of the window. The required format of the text string is described in [Textual input of test parameters](#).

If the quantity to be displayed is to be plotted against packet length, the packet length filter settings are ignored.

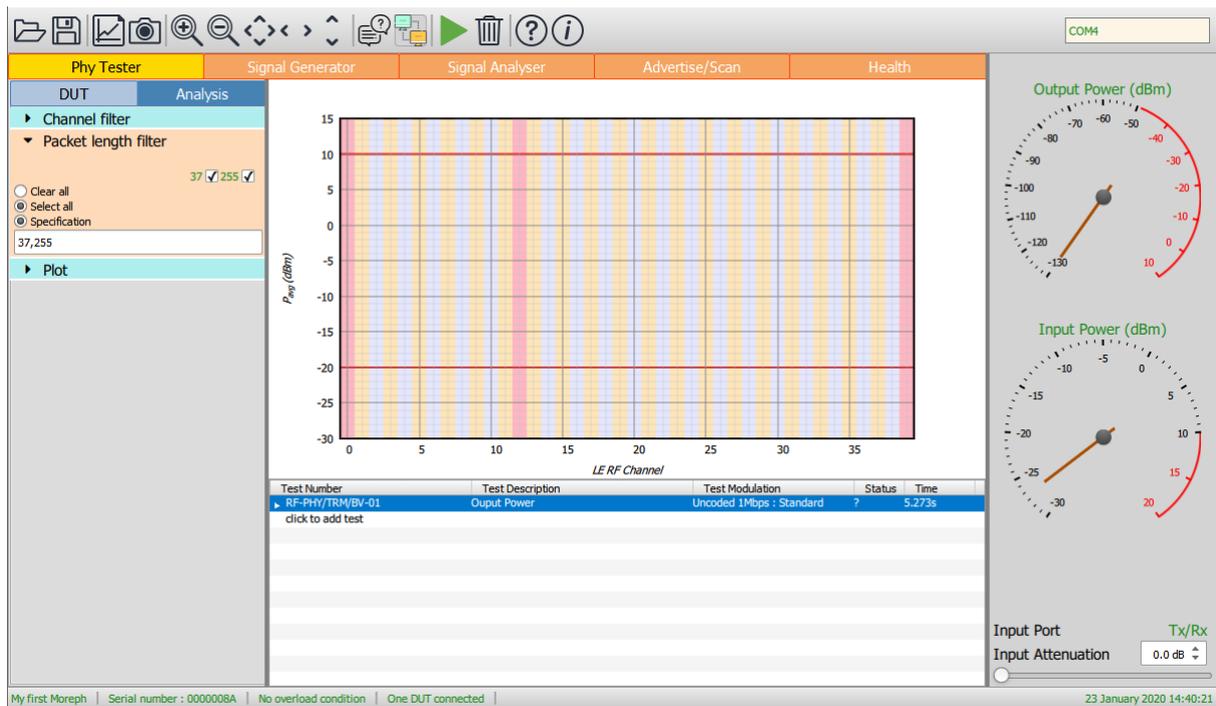


Figure 73: Filtering by packet length.

#### 10.9.4 Selecting the quantity to be plotted

To select which test results are to be plotted, highlight the associated test in the test script window by clicking it.

To change the contents of the graphics area, expand the 'Plot' menu under the 'Analysis' tab. The left-hand combo box determines the quantity to be plotted on the y-axis and the right hand combo box the quantity to be plotted on the x-axis.

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### 10.9.4.1 *Transmitter and CTE tests*

For transmitter tests, the quantity plotted on the y-axis can be anyone of the quantities against which a test limit is applied in the Bluetooth 5.2 LE RF Phy Test Specification:

1. Power measurements (including CTE output power):
  - a.  $P_{avg}$
  - b.  $P_k - P_{avg}$
2. Modulation characteristics:
  - a.  $\Delta F1_{avg}$
  - b.  $\Delta F2_{avg} / \Delta F1_{avg}$
  - c.  $\Delta F2_{max} 99.9\%$
3. Drift and carrier offset measurements:
  - a.  $F_0$
  - b.  $F_n$
  - c.  $|F_1 - F_0|$  or  $|F_3 - F_0|$  for 125kbps
  - d.  $|F_0 - F_n|$
  - e.  $|F_n - F_{n-5}|$  or  $|F_n - F_{n-3}|$  for 125kbps
4. In-band emissions:
  - a.  $F_{tx} \pm 2\text{MHz}$  or  $F_{tx} \pm (4,5)\text{MHz}$  for 2Mbps
  - b.  $F_{tx} \pm (3+n)\text{MHz}$  or  $F_{tx} \pm (6+n)\text{MHz}$  for 2Mbps
  - c. Number of exceptions
  - d. Maximum exception
5. AoA carrier frequency offset and drift:
  - a.  $F_{S_i}$
  - b.  $F_{S_1} - F_p$
  - c.  $F_{S_i} - F_0$
  - d.  $F_{S_i} - F_{S_{i-3}}$
6. AoD transmit power stability:
  - a.  $P_{rev,dev} - P_{ref,ave}$
  - b.  $P_{n,dev} - P_{n,ave}$
7. AoD antenna switching integrity:
  - a.  $P_{m,ave,on} - P_{m,ave,off}$
8. IQ sample coherency:
  - a.  $|MRPD|$
  - b.  $\text{Min } |MRP(m)|$
  - c.  $|v - MRP(m)| \leq 0.52$
  - d.  $|v - MRP(m)|$  95% percentile
9. IQ sample dynamic range:
  - a.  $10\text{Log}_{10}[MEAN_{ant,M} / MEAN_{ant,N}]$

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The selected quantity may be plotted against:

1. RF channel number
2. Packet length

The selected quantity is plotted in the graphics area as a series of green bars. The associated test limits are plotted as red lines.

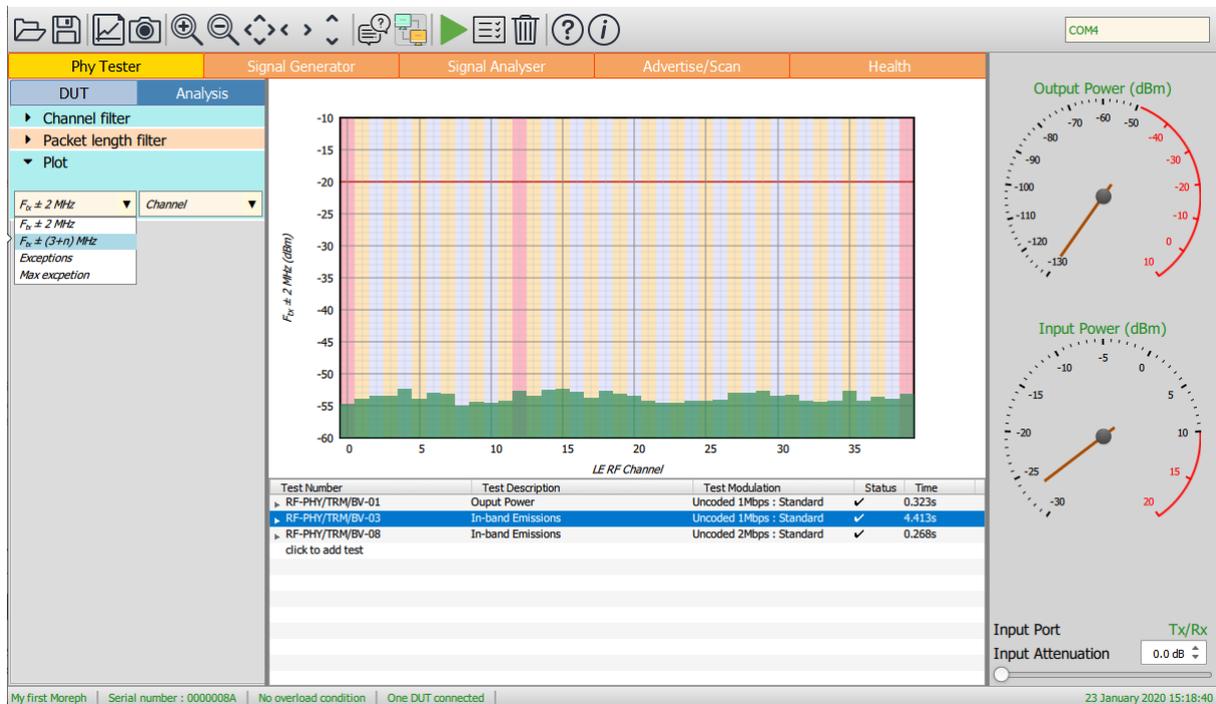


Figure 74: Displaying transmitter and CTE test results.

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## 10.9.4.2 Receiver sensitivity, maximum input signal and PER report integrity tests

The y-axis can be selected to be either:

1. Wanted signal level
2.  $\text{Log}_{10}(\text{PER})$

If the y-axis is selected to be wanted signal level, then the x-axis can be either:

1. RF channel number
2. Packet length

If the y-axis is selected to be  $\text{Log}_{10}(\text{PER})$  then the x-axis is wanted signal level and a classical PER curve is displayed.

The results are plotted as a series of diamonds which are colour coded red for fail and green for pass. Test limits are not displayed since these are functions of the packet length and so may not be the same for all the displayed points.

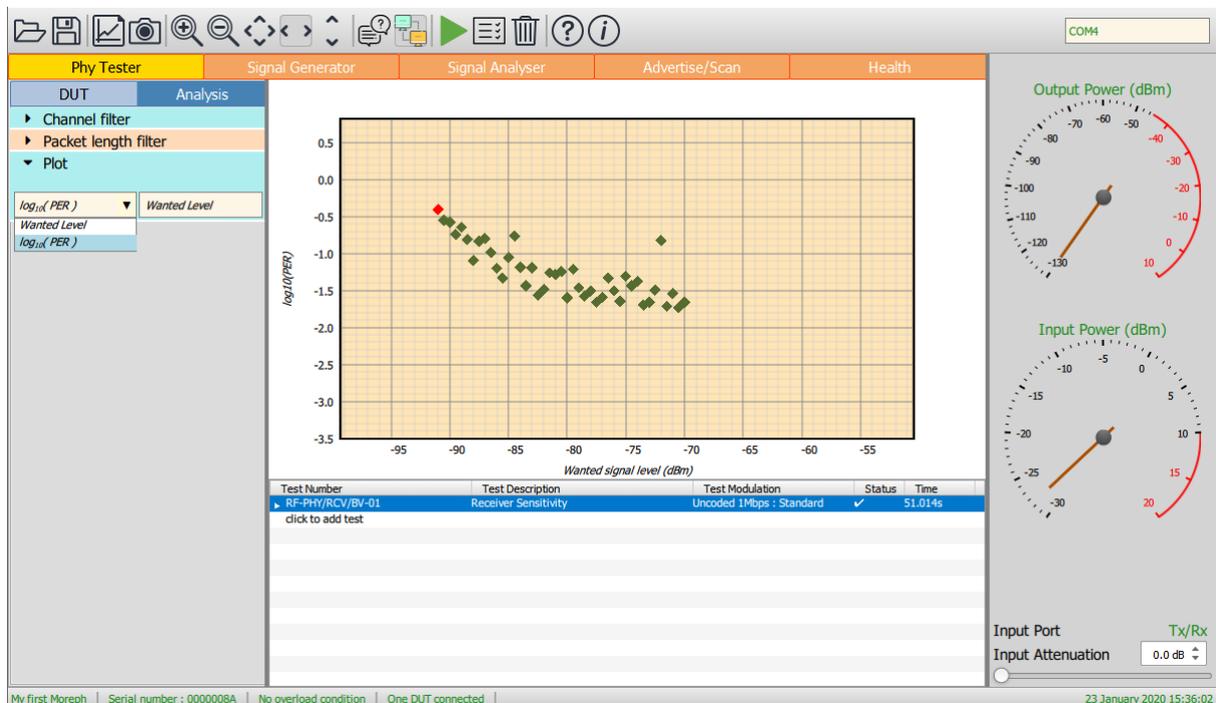


Figure 75: Receiver sensitivity, maximum input signal and PER report integrity tests.

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## 10.9.4.3 Receiver C/I tests

For receiver C/I tests, the x-axis is always the offset of the interferer from the wanted signal. The y-axis may be selected to be one of the following:

1. C/I level
2. Wanted signal level
3. Interferer signal level

Results are plotted as diamonds which are colour coded red for failure and green for pass.. Test limits are not displayed since these are functions of the packet length and so may not be the same for all the displayed points.

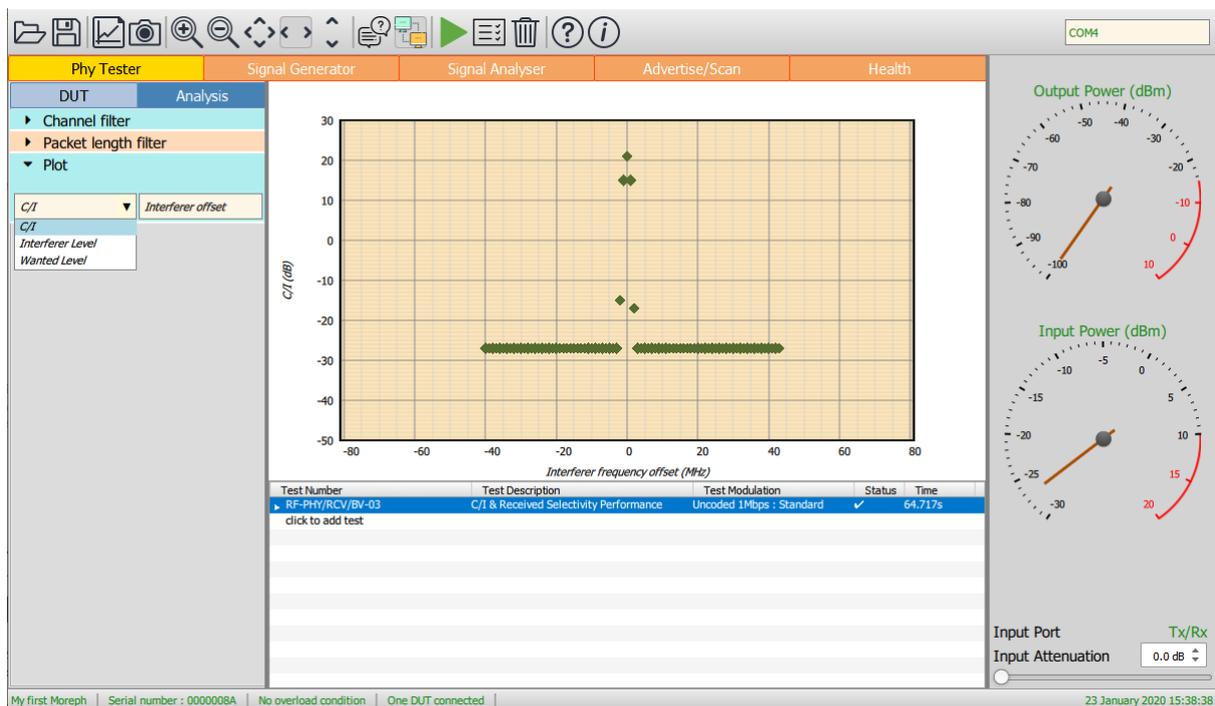


Figure 76: Receiver C/I tests.

### 10.9.5 Receiver blocking tests

For receiver blocking tests, the x-axis is always the blocker frequency. The y-axis may be selected to be one of the following:

1. Blocker level
2. Wanted signal level

Results are plotted as diamonds which are colour coded red for failure and green for pass. Test limits are not displayed since these are functions of the packet length and so may not be the same for all the displayed points.

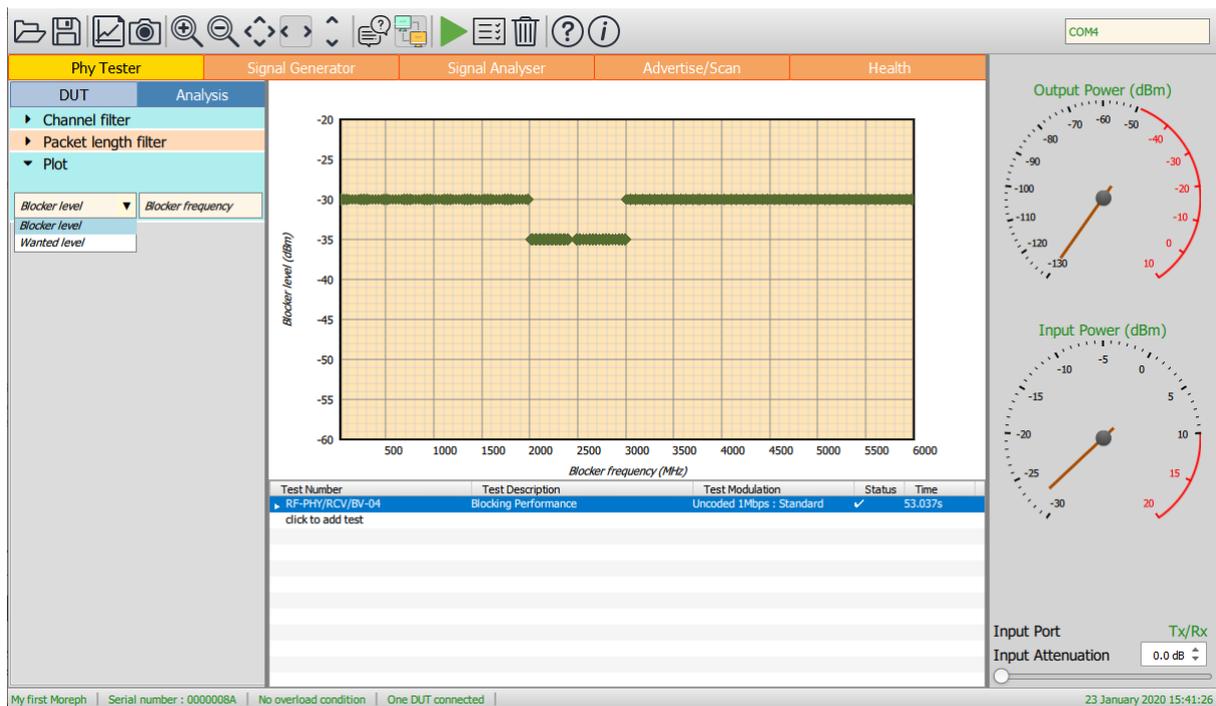


Figure 77: Receiver blocking tests.

### 10.9.6 Receiver intermodulation tests

The y-axis can be selected to be either:

1. Wanted signal level
2. Interferer signal level
3.  $\text{Log}_{10}(\text{PER})$

If the y-axis is either wanted signal level or interferer signal level, the x-axis will be RF channel number.

If the y-axis is selected to be  $\text{Log}_{10}(\text{PER})$  then the x-axis is wanted signal level and a classical PER curve is displayed against either the wanted signal level or the interferer signal level.

Results are plotted as diamonds which are colour coded red for failure and green for pass. Test limits are not displayed since these are functions of the packet length and so may not be the same for all the displayed points.

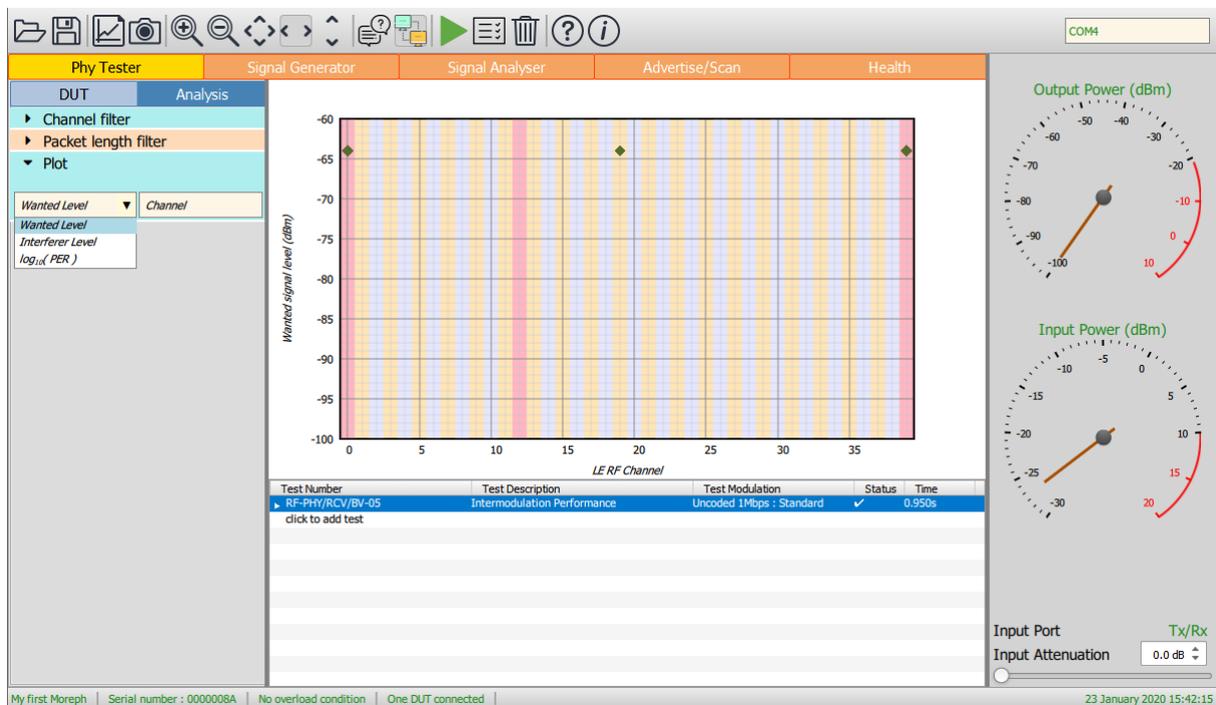


Figure 78: Receiver intermodulation tests.

### 10.10 Saving results

The test script results can be saved by clicking the 'Save' button on the toolbar. The format of the results file depends on the file type selected to save the current test script results. The results can be saved in the following formats:

1. xml: permitting the results to be read by a range of other applications
2. txt: a simple ascii text file
3. csv: permitting the results to be read by spreadsheets
4. html: for viewing the results in a web browser or for inclusion in a test report

The current graph can also be saved as an image by clicking the 'Graph' button on the toolbar. The range of possible graphics formats includes:

1. Windows bitmap files (\*.bmp)
2. Joint photographic expert group files (\*.jpg)
3. Portable network graphics files (\*.png)
4. Portable bitmap files (\*.pbm)
5. Portable graymap files (\*.pgm)
6. Portable pixmap files (\*.ppm)
7. X11 bitmap files (\*.xbm)
8. X11 pixmap files (\*.xpm)

## 10.11 List of supported tests

Test number	Test description	Switching	Phy	Notes
RF-PHY/TRM/BV-01-C	Output power		Uncoded, 1Mbps	
RF-PHY/TRM/BV-03-C	In-band emissions		Uncoded, 1Mbps	
RF-PHY/TRM/BV-05-C	Modulation characteristics		Uncoded, 1Mbps	
RF-PHY/TRM/BV-06-C	Carrier frequency offset & drift		Uncoded, 1Mbps	
RF-PHY/TRM/BV-08-C	In-band emissions		2Mbps	
RF-PHY/TRM/BV-09-C	Modulation characteristics		Stable, uncoded, 1Mbps	
RF-PHY/TRM/BV-10-C	Modulation characteristics		2Mbps	
RF-PHY/TRM/BV-11-C	Modulation characteristics		Stable, 2Mbps	
RF-PHY/TRM/BV-12-C	Carrier frequency offset & drift		2Mbps	
RF-PHY/TRM/BV-13-C	Modulation characteristics		LE Coded, S=8	
RF-PHY/TRM/BV-14-C	Carrier frequency offset & drift		LE Coded, S=8	
RF-PHY/TRM/BV-15-C	Output power, with CTE		Uncoded, 1Mbps	
RF-PHY/TRM/BV-16-C	Carrier frequency offset & drift, CTE		Uncoded, 1Mbps	
RF-PHY/TRM/BV-17-C	Carrier frequency offset & drift, CTE		Uncoded, 2Mbps	
RF-PHY/TRM/PS/BV-01-C	Tx power stability, AoD	2µs	Uncoded, 1Mbps	
RF-PHY/TRM/PS/BV-02-C	Tx power stability, AoD	1µs	Uncoded, 1Mbps	
RF-PHY/TRM/PS/BV-03-C	Tx power stability, AoD	2µs	Uncoded, 2Mbps	
RF-PHY/TRM/PS/BV-04-C	Tx power stability, AoD	1µs	Uncoded, 2Mbps	
RF-PHY/TRM/ASI/BV-01-C	Antenna switching integrity AoD	2µs	Uncoded, 1Mbps	
RF-PHY/TRM/ASI/BV-02-C	Antenna switching integrity AoD	1µs	Uncoded, 1Mbps	
RF-PHY/TRM/ASI/BV-03-C	Antenna switching integrity AoD	2µs	Uncoded, 2Mbps	
RF-PHY/TRM/ASI/BV-04-C	Antenna switching integrity AoD	1µs	Uncoded, 2Mbps	
RF-PHY/RCV/BV-01-C	Receiver sensitivity		Uncoded, 1Mbps	
RF-PHY/RCV /BV-03-C	C/I & receiver selectivity		Uncoded, 1Mbps	
RF-PHY/RCV /BV-04-C	Blocking		Uncoded, 1Mbps	See (a)
RF-PHY/RCV /BV-05-C	Intermodulation		Uncoded, 1Mbps	See (b)
RF-PHY/RCV /BV-06-C	Maximum input signal		Uncoded, 1Mbps	
RF-PHY/RCV /BV-07-C	PER report integrity		Uncoded, 1Mbps	
RF-PHY/RCV /BV-08-C	Receiver sensitivity		2Mbps	
RF-PHY/RCV /BV-09-C	C/I & receiver selectivity		2Mbps	
RF-PHY/RCV /BV-10-C	Blocking		2Mbps	See (a)
RF-PHY/RCV /BV-11-C	Intermodulation		2Mbps	See (b)
RF-PHY/RCV /BV-12-C	Maximum input signal		2Mbps	
RF-PHY/RCV /BV-13-C	PER report integrity		2Mbps	
RF-PHY/RCV /BV-14-C	Receiver sensitivity		Stable, uncoded, 1Mbps	
RF-PHY/RCV /BV-15-C	C/I & receiver selectivity		Stable, uncoded, 1Mbps	
RF-PHY/RCV /BV-16-C	Blocking		Stable, uncoded, 1Mbps	See (a)
RF-PHY/RCV /BV-17-C	Intermodulation		Stable, uncoded, 1Mbps	See (b)
RF-PHY/RCV /BV-18-C	Maximum input signal		Stable, uncoded, 1Mbps	
RF-PHY/RCV /BV-19-C	PER report integrity		Stable, uncoded, 1Mbps	
RF-PHY/RCV /BV-20-C	Receiver sensitivity		Stable, 2Mbps	
RF-PHY/RCV /BV-21-C	C/I & receiver selectivity		Stable, 2Mbps	
RF-PHY/RCV /BV-22-C	Blocking		Stable, 2Mbps	See (a)
RF-PHY/RCV /BV-23-C	Intermodulation		Stable, 2Mbps	See (b)
RF-PHY/RCV /BV-24-C	Maximum input signal		Stable, 2Mbps	
RF-PHY/RCV /BV-25-C	PER report integrity		Stable, 2Mbps	
RF-PHY/RCV /BV-26-C	Receiver sensitivity		LE coded, S=2	
RF-PHY/RCV /BV-27-C	Receiver sensitivity		LE coded, S=8	

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RF-PHY/RCV /BV-28-C	C/I & receiver selectivity		LE coded, S=2	
RF-PHY/RCV /BV-29-C	C/I & receiver selectivity		LE coded, S=8	
RF-PHY/RCV /BV-30-C	PER report integrity		LE coded, S=2	
RF-PHY/RCV /BV-31-C	PER report integrity		LE coded, S=8	
RF-PHY/RCV /BV-32-C	Receiver sensitivity		Stable, LE coded, S=2	
RF-PHY/RCV /BV-33-C	Receiver sensitivity		Stable, LE coded, S=8	
RF-PHY/RCV /BV-34-C	C/I & receiver selectivity		Stable, LE coded, S=2	
RF-PHY/RCV /BV-35-C	C/I & receiver selectivity		Stable, LE coded, S=8	
RF-PHY/RCV /BV-36-C	PER report integrity		Stable, LE coded, S=2	
RF-PHY/RCV /BV-37-C	PER report integrity		Stable, LE coded, S=8	
RF-PHY/RCV /IQC/BV-01-C	IQ sample coherency, AoD receiver	2µs	Uncoded, 1Mbps	
RF-PHY/RCV /IQC/BV-02-C	IQ sample coherency, AoD receiver	1µs	Uncoded, 1Mbps	
RF-PHY/RCV /IQC/BV-03-C	IQ sample coherency, AoD receiver	2µs	Uncoded, 2Mbps	
RF-PHY/RCV /IQC/BV-04-C	IQ sample coherency, AoD receiver	1µs	Uncoded, 2Mbps	
RF-PHY/RCV /IQC/BV-05-C	IQ sample coherency, AoA receiver	2µs	Uncoded, 1Mbps	
RF-PHY/RCV /IQC/BV-06-C	IQ sample coherency, AoA receiver	2µs	Uncoded, 2Mbps	
RF-PHY/RCV /IQDR/BV-01-C	IQ samples dynamic range, AoD rx	2µs	Uncoded, 1Mbps	
RF-PHY/RCV /IQDR/BV-02-C	IQ samples dynamic range, AoD rx	1µs	Uncoded, 1Mbps	
RF-PHY/RCV /IQDR/BV-03-C	IQ samples dynamic range, AoD rx	2µs	Uncoded, 2Mbps	
RF-PHY/RCV /IQDR/BV-04-C	IQ samples dynamic range, AoD rx	1µs	Uncoded, 2Mbps	
RF-PHY/RCV /IQDR/BV-05-C	IQ samples dynamic range, AoA rx	2µs	Uncoded, 1Mbps	
RF-PHY/RCV /IQDR/BV-06-C	IQ samples dynamic range, AoA rx	2µs	Uncoded, 2Mbps	
RF-PHY/TRM/BV-90-C	Output power		Uncoded, 2Mbps	see (c)
RF-PHY/TRM/BV-91-C	Output power		LE coded, S=2	see (c)
RF-PHY/TRM/BV-92-C	Output power		LE coded, S=8	see (c)
RF-PHY/TRM/BV-93-C	In-band emissions		LE coded, S=2	see (c)
RF-PHY/TRM/BV-94-C	In-band emissions		LE coded, S=8	see (c)

### Limitations:

- a) Blocking tests are limited to the range 25MHz to 6GHz. The Bluetooth 5.2 test specification has an upper limit of 12.75GHz. The supported range does include the 2nd harmonic of the 2.4GHz band. If the blocking test passes at the 2nd harmonic, then it is highly likely to pass for higher test frequencies. The blocking source used in the TLF3000 has significant harmonic content. Some internal filtering of the source is applied to attenuate harmonics falling within the 2.4GHz band. If blocking failures do occur, then further testing may be required to ascertain whether these are due to the fundamental of the blocker or one of its harmonics.
- b) The specification states that the intermodulation tests should be performed with the interfering signals both on the low side and the high side of the wanted signal. Under some circumstances, when the wanted signal is close to the band edge, this can lead to the interfering signals being placed outside the TLF3000 signal generator bandwidth of 2395MHz to 2485MHz. When these circumstances arise, the test will only be performed with the interfering signals positioned closer to the band centre. The requirement to perform intermodulation tests with the signals both above and below the wanted signal is somewhat perverse. If the wanted signal is at the band edge and the interfering

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signals are positioned outside the band, then the interfering signals will be attenuated by frontend filtering and the intermodulation performance of the device improved. Hence the inability of TLF3000 to test this scenario is considered somewhat academic. The table below sets out which tests can be performed if the TLF3000 unit has undergone extended calibration:

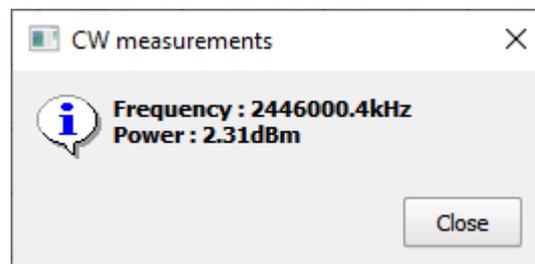
Channel	Interferers below			Interferers above		
	N = 3	N = 4	N = 5	N = 3	N = 4	N = 5
2402	Y	Y	Y	Y	Y	Y
2403	Y	Y	Y	Y	Y	Y
...	...	...	...	...	...	...
2478	Y	Y	Y	Y	Y	Y
2479	Y	Y	Y	Y	Y	N
2480	Y	Y	Y	Y	Y	N

- c) These tests are not specified by the Bluetooth SIG but have been added due to customer request.

### 10.12 Performing CW measurements

When in phy tester mode, it is possible to measure the frequency and power of a CW signal generated by the DUT. These measurements can be used to trim the crystal frequency of the DUT prior to perform a test run.

To initiate a CW measurement, press the CW measurement icon on the tool bar. The measured CW frequency and power will be displayed in a pop-up window.



## 11 Advertise/Scan mode.

### 11.1 Overview

The advertise/scan mode permits restricted testing of devices for which no test interface is available, for example, devices assembled into final products on a production line. In the advertise/scan mode, normal LE packets are used to provoke a response from the DUT so that receiver performance can be checked, and transmission quality verified.

There are two modes of operation:

1. *Advertise*. In this mode of operation, the *Sapphire* application sends out pre-defined advertising packets at a specified signal level and waits for scan or connection requests from the device under test.
2. *Scan*. In this mode the DUT advertises and the *Sapphire* application sends out scan requests at a specified signal level to trigger a response from the DUT.

In advertise/scan mode an approximation to the following Bluetooth 5.2 LE RF Phy Test Specification tests can be performed:

1. All transmitter tests, including in-band emissions but excluding CTE tests
2. Receiver sensitivity

In principle, the *TLF3000* unit is capable to performing an approximation to all of the receiver tests defined in the Bluetooth 5.2 LE RF Phy Test Specification whilst in advertise/scan mode, however, these are not currently implemented.

The *Sapphire* application incorporates a number of features to ensure that the device which packets are received from and transmitted to are indeed the DUT and not some other LE device in the vicinity.

In advertise/scan mode the left-hand mode control panel is divided into two separate tabs:

1. *Collection*. This tab contains the parameters which define how the DUT will be provoked into transmission and how the captured data will be processed.
2. *Analysis*. This tab contains the parameters which define how the captured results will be displayed.

The central graphics area is used to plot the results in a manner defined by the parameters under the analysis tab.

Below the analysis tab is a results table which displays statistics of the test quantities defined in the Bluetooth 5.2 LE RF Phy Test Specification. These results are filtered by the parameters set under the '*Analysis*' tab in the mode control panel. ***If no results are displayed this may be because the analysis filter settings are inconsistent with the packets being received.***

The receiver port and front-end attenuation are set using the controls in the monitor panel on the right-hand side of the window.

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Testing is started/stopped by toggling the 'Play' button in the toolbar.

The 'Clear' button in the toolbar will discard all results which have been collected.

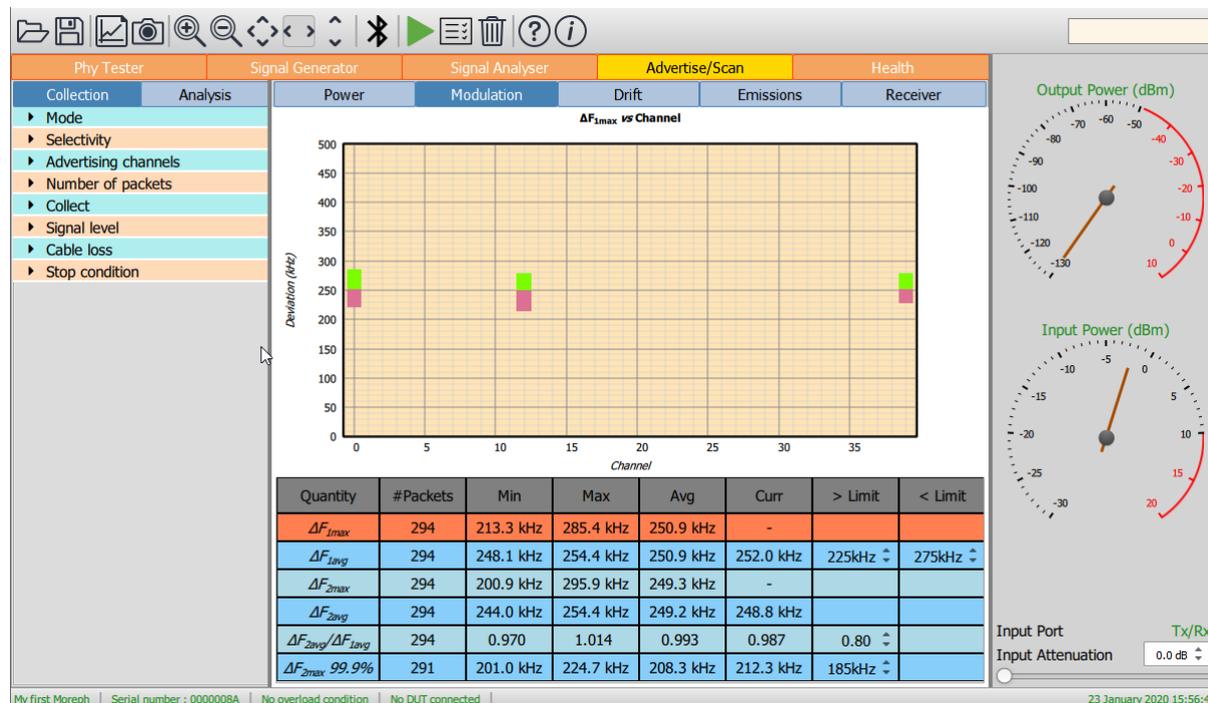


Figure 79: Sapphire advertiser/scan mode.

## 11.2 RF connections

If a conducted link to the DUT is available, then it should be connected to the 'Tx/Rx' port. The 'Tx/Rx' port should also be selected as the receive port in the monitor panel.

For over-the-air measurements where the DUT is adjacent to the TLF3000 unit, then an antenna should be connected to the 'Tx/Rx' port and the 'Tx/Rx' port selected as the receive port in the monitor panel. When using this configuration check that the received power from the DUT is sufficient to perform accurate modulation measurements. If it is not, it will be necessary to use the configuration described below.

For over-the-air measurements the DUT is not close to the TLF3000 unit, then antenna should be connected to both the 'Tx/Rx' port and the 'Monitor In' port. The 'Monitor In' port should be selected as the receive port in the monitor panel. It may be necessary to add front-end attenuation using the controls on the monitor panel to prevent the receiver overloading. See [Selection of input port and input attenuation](#).

The loss between the DUT and the TLF3000 should be entered using the 'Cable loss' menu under the 'DUT' tab in the mode control panel.

## 11.3 Programming the advertise/scan mode

### 11.3.1 Overview

To program the advertise/scan mode, then following parameters need to be set:

1. Whether the *Sapphire* should be run as an advertiser or scanner
2. The contents of the advertising packets or scan request packets
3. Parameters *Sapphire* should check prior to processing a packet from the DUT
4. Which advertising channel(s) to use
5. The number of packets to be sent
6. The transmitter measurements which are to be made
7. The range of signal levels *Sapphire* should transmit at
8. The termination criteria for the test

All of these parameters are accessible from the 'Collection' tab of the mode control panel.

### 11.3.2 Programming the advertise/scan packets

The programming of the advertising or scan request packets is done via the 'Mode' menu under the 'Collection' tab.

The choice between advertising and scanning is made through the 'Tester mode' combo box.

If advertising is selected, then the packet PDU type must also be selected. Options for the packet PDU are:

1. ADV\_IND, connectable and scannable undirected advertising events
2. ADV\_DIRECT\_IND, connectable directed advertising events
3. ADV\_SCAN\_IND, scannable undirected advertising events

If scanning is selected, then the packet PDU type is set to SCAN\_REQ.

Further parameters may be required to define the advertising or scan request packets:

#### 11.3.2.1 ChSel

Controls the setting of bit 5 in the packet header. This indicates which channel selection algorithm is supported. Options are:

1. 0 : algorithm #1)
2. 1 : algorithm #2)

The value is set by clicking the green text to toggle the value.

#### 11.3.2.2 TxAdd

Controls the setting of bit 6 in the packet header. This indicates the nature of the AdvA field for advertising packets and the ScanA field for scan request packets. Options are:

1. 0 : the address is public
2. 1 : the address is random

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The value is set by clicking the green text to toggle the value.

### 11.3.2.3 *RxAdd*

Controls the setting of bit 7 in the packet header. This indicates the nature of the TargetA field for the ADV\_DIRECT\_IND advertising packets. Options are:

1. 0 : the address is public
2. 1 : the address is random

The value is set by clicking the green text to toggle the value.

### 11.3.2.4 *AdvA*

Sets the AdvA field in the advertising packet. Hex values may be entered directly by editing the green text.

### 11.3.2.5 *TargetA*

Sets the TargetA field in the ADV\_DIRECT\_IND packet PDU. Hex values may be entered directly by editing the green text.

### 11.3.2.6 *ScanA*

Sets the ScanA field in the scan request packet. Hex values may be entered directly by editing the green text.

### 11.3.2.7 *AdvData data length*

Sets the length of the AdvData field in the advertising packet PDU. Valid values are between 0 and 31 inclusive. The value is set using the associated spin box.

### 11.3.2.8 *AdvData*

Sets the contents of the AdvData field in the advertising packet PDU. Hex values may be entered directly by editing the green text.



Figure 80: Programming advertising packets.

### 11.3.3 Programming the checks to be performed on received packets

The programming of the checks to be performed on received packets is done via the 'Mode' menu under the 'Selectivity' tab. Only those packets which pass all the selected criteria will be analysed. All other packets will be discarded and will not contribute to the displayed statistics.

#### 11.3.3.1 RSSI threshold

Only those packets with a signal strength greater than the RSSI threshold will be analysed. This applies to both advertise and scan modes. This helps the *Sapphire* application distinguish between packets from the device under test and more distant devices. The RSSI threshold can be set in the range -120dBm to +20dBm. The lower limit effectively disables the RSSI threshold.

#### 11.3.3.2 Check InitA / ScanA

This option is only applicable to advertise mode. When the *Sapphire* application receives a connection request or scan request it can check the corresponding InitA or ScanA address to ensure that it is from the DUT and not some other device. The 48bit address can be typed into the *InitA / ScanA address* field the *InitA / ScanA* field can be toggled to indicate whether the address is public or random.

#### 11.3.3.3 Check AdvA address

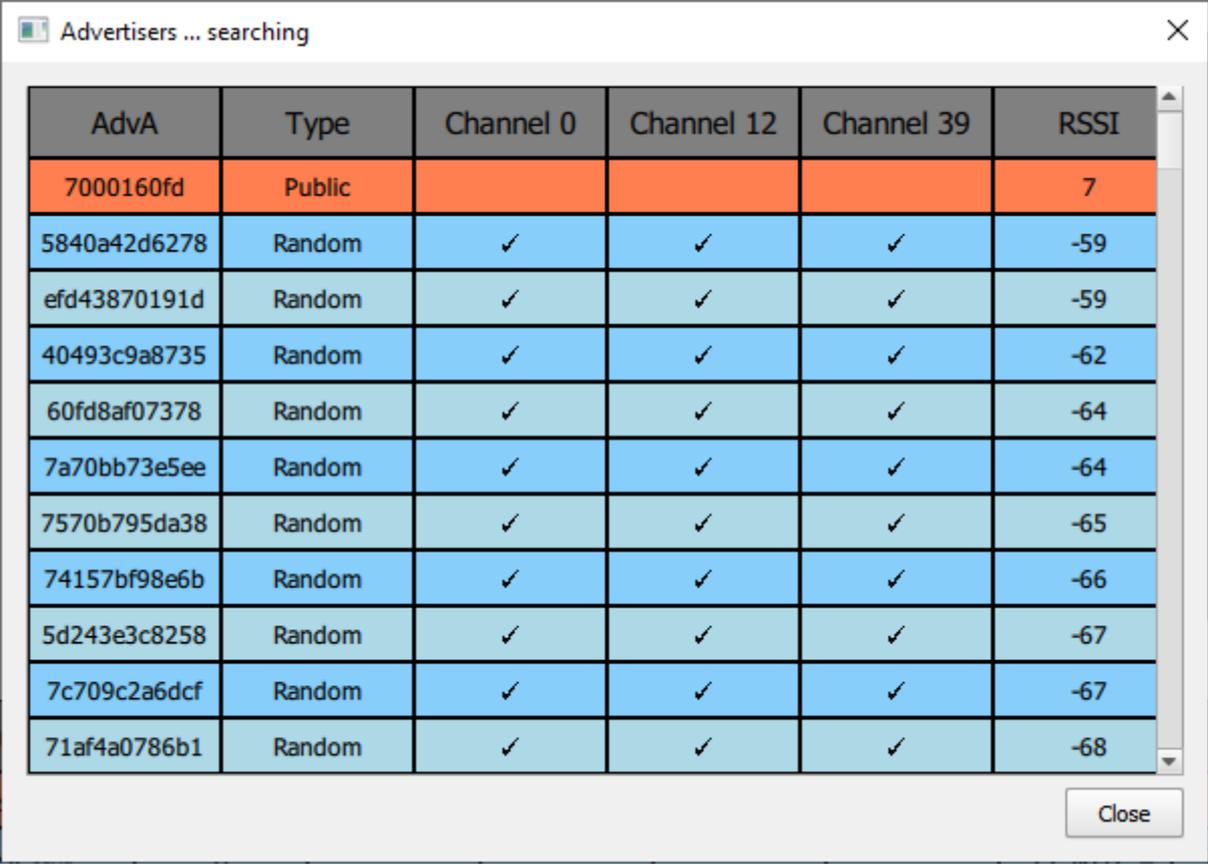
This option is only applicable in scan mode. When the *Sapphire* application receives an advertising packet it can check the corresponding AdvA address to ensure that it is from the DUT and not some other device. The 48bit address can be typed in the *AdvA address* field and the *AdvA* field can be toggled to indicate whether the address is public or random.

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The AdvA is an extremely powerful means of ensuring that the packets being received are indeed from the DUT and not from another LE device in the vicinity. If the *Sapphire* application is being run in the scan mode, then it is possible to obtain a list of the advertising devices in the vicinity by pressing the 'Search' button on the toolbar. This will pop-up a window showing all the advertising devices in the vicinity list in order of signal strength. For each device the following information is displayed:

1. The AdvA address
2. The advertising channels on which the device has been observed
3. The received signal strength (RSSI)

If a device in the list is highlighted by clicking on it, then its AdvA address will automatically be used to populate the 'AdvA' field in the 'Selectivity' menu.



AdvA	Type	Channel 0	Channel 12	Channel 39	RSSI
7000160fd	Public				7
5840a42d6278	Random	✓	✓	✓	-59
efd43870191d	Random	✓	✓	✓	-59
40493c9a8735	Random	✓	✓	✓	-62
60fd8af07378	Random	✓	✓	✓	-64
7a70bb73e5ee	Random	✓	✓	✓	-64
7570b795da38	Random	✓	✓	✓	-65
74157bf98e6b	Random	✓	✓	✓	-66
5d243e3c8258	Random	✓	✓	✓	-67
7c709c2a6dcf	Random	✓	✓	✓	-67
71af4a0786b1	Random	✓	✓	✓	-68

Figure 81: Searching for advertising devices.

### 11.3.3.4 Monitor for SCAN\_REQ

This option is only applicable in advertise mode. In order for the *Sapphire* application to analyse SCAN\_REQ packets this field must be checked.

### 11.3.3.5 Monitor for CONNECT\_IND

This option is only applicable in advertise mode. In order for the *Sapphire* application to analyse CONNECT\_IND packets this field must be checked.

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## 11.3.3.6 Respond to ADV\_IND packets

This option is only applicable in scan mode. In order for the *Sapphire* application to issue a scan request in respond to an ADV\_IND packet this field must be checked.

## 11.3.3.7 Respond to ADV\_SCAN\_IND packets

This option is only applicable in scan mode. In order for the *Sapphire* application to issue a scan request in respond to an ADV\_SCAN\_IND packet this field must be checked.



Figure 82: Programming selectivity in advertise mode.

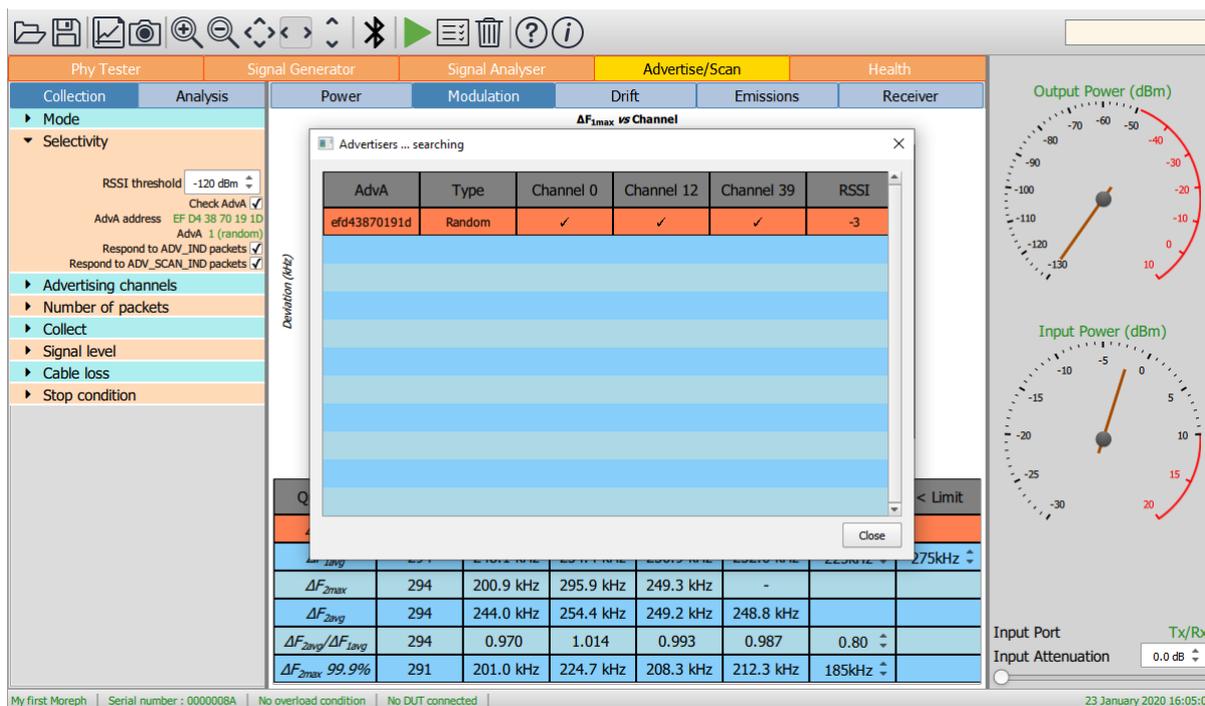


Figure 83: Programming selectivity in scan mode.

### 11.3.4 Programming the advertising channels to use

The Sapphire application is capable of listening on 40 LE channels simultaneously as well as transmitting on all 3 primary advertising channels simultaneously. The capability alleviates the need for Sapphire to cycle round to the correct advertising channel before provoking a response from the DUT.

The choice of which primary advertising channels to use is made via the 'Channels' menu under the 'Collection' tab. The required channels are selected by ticking the appropriate checkboxes.

The 'Concurrent analysis' checkbox determines whether the Sapphire application will analyse/transmit on all selected channels simultaneously or whether it will cycle around the channels in ascending order. If concurrent analysis is selected, then there is a danger that not all channels will get equal test coverage. However, concurrent analysis will generally result in far faster testing.

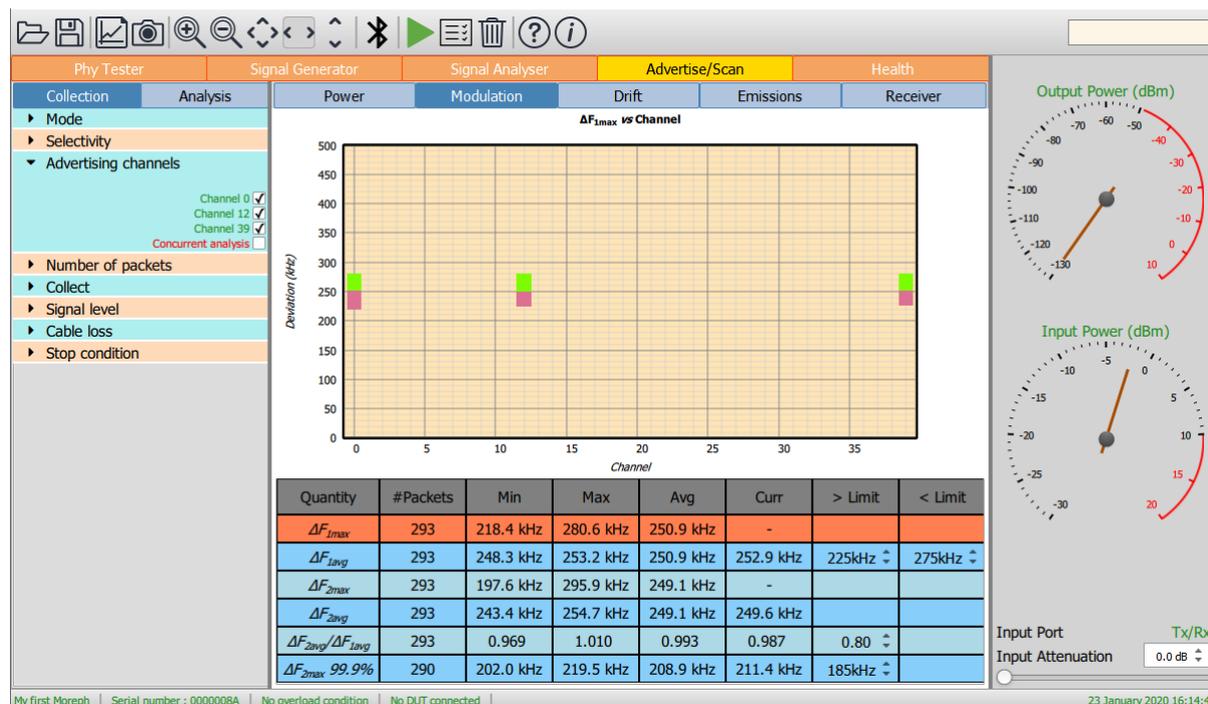


Figure 84: Programming the advertising channels to use.

### 11.3.5 Programming the number of packets to transmit

The number of packets to be transmitted can be set by expanding the 'Number of packets' menu. If the 'Continuous transmission' checkbox is ticked, then test will continue until the 'Stop' button in the toolbar is clicked, otherwise the number of packets specified in the 'Packet count' spin box will be transmitted. The packet count can be set to any value between 1 and 65535, inclusive.

In advertising mode, the packet count is the number of advertising packets which are transmitted. If multiple transmission signal levels have been defined, then this number of advertising packets is transmitted at each signal level.

In scan mode, the packet count is the number of scan request packets which are transmitted. If multiple transmission signal levels have been defined, this is the number of scan request packets transmitted at each signal level.

If concurrent analysis has been selected, then number of packets represents the total number of packets which will be transmitted/analysed over all selected channels. If concurrent analysis has not been selected, then number of packets represents the number of packets which will be transmitted/analysed on each selected channel.

To reduce test time in scan mode, the DUT should be made to advertise as frequently as possible.



Figure 85: Programming the number of packets to transmit.

### 11.3.6 Programming the transmitter measurements to be performed

Sapphire divides the Bluetooth 5.2 LE RF Phy transmitter test measurements into five groups:

1. Power measurements, which includes:
  - a.  $P_{avg}$
  - b.  $P_k - P_{avg}$
2. Modulation characteristics, which includes:
  - a.  $\Delta F1_{max}$
  - b.  $\Delta F1_{avg}$
  - c.  $\Delta F2_{max}$
  - d.  $\Delta F2_{avg}$
  - e.  $\Delta F2_{avg} / \Delta F1_{avg}$
  - f.  $\Delta F2_{max}$  99.9%
3. Drift and carrier offset measurements, which includes:
  - a.  $F_0$
  - b.  $F_n$
  - c.  $|F_1 - F_0|$  or  $|F_3 - F_0|$  for 125kbps
  - d.  $|F_0 - F_n|$
  - e.  $|F_n - F_{n-5}|$  or  $|F_n - F_{n-3}|$  for 125kbps
4. In-band emissions, which includes:
  - a.  $F_{tx} \pm 2MHz$  or  $F_{tx} \pm (4,5)MHz$  for 2Mbps
  - b.  $F_{tx} \pm (3+n)MHz$  or  $F_{tx} \pm (6+n)MHz$  for 2Mbps
  - c. Number of exceptions
  - d. Maximum exception

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Each of these groups of measurements can be individually selected under the 'Collect' menu of the 'Collection' tab.

If the 'Waveform' item is selected, then raw IQ data for the last packet analysed is also saved. The raw IQ data is 32x oversampled, as per the Bluetooth 5.2 LE RF Phy Test Specification. Although it is possible to alter the oversampling ratio using the native language, this is currently not supported in the Sapphire GUI. If the 'Waveform' item is selected, the volume of data which needs to be transferred to the host is large. This may have an impact on the rate at which packets can be analysed. If it is important to analyse packets as fast as possible, then it is advisable to disable collection of raw IQ data.

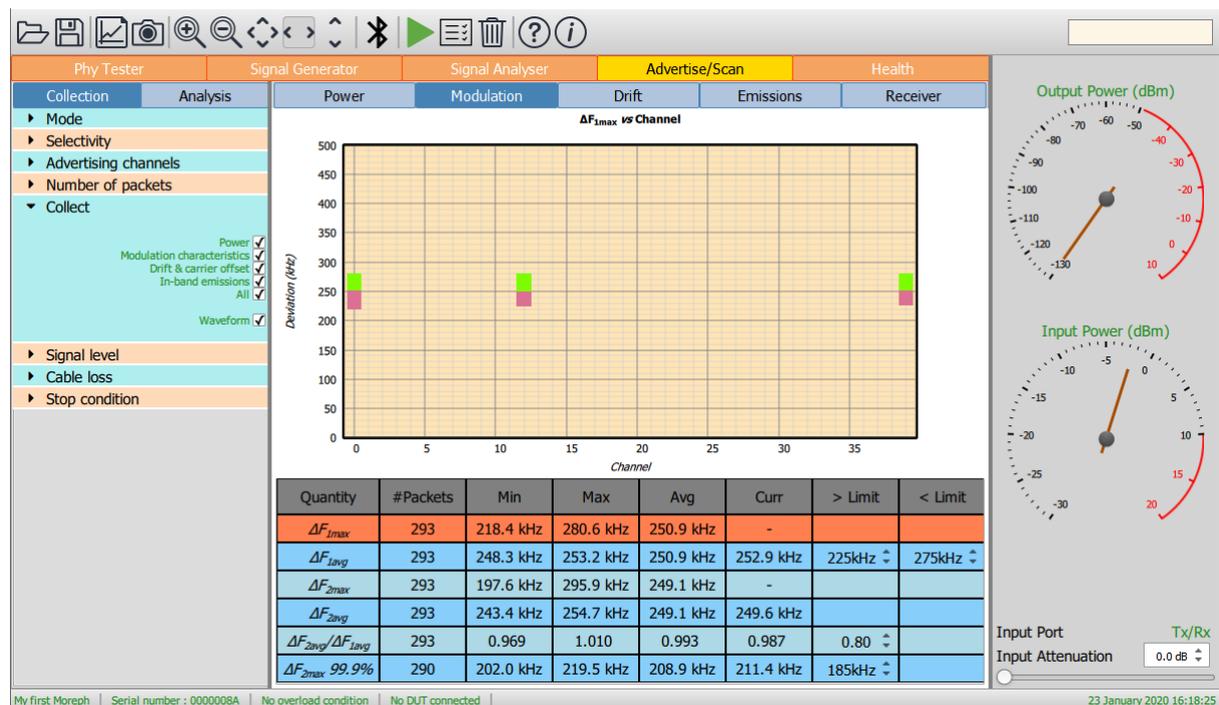


Figure 86: Programming the transmitter measurements to be performed.

### 11.3.7 Programming the packet transmission levels

The advertising and scan request packet transmission levels can be set by expanding the ‘Signal level’ menu.

The signal level can be entered into the spin box, either by using the up/down arrows or by entering a numeric value directly into the text field. If the cursor is placed directly over the red bar in the signal level gauge, then a ‘→’ will appear adjacent to the cursor. By holding down the left mouse button it is then possible to drag the red bar to set the signal level. Signal levels must be in the range -100dBm to 0dBm. The resolution of the signal level is 0.1dBm.



Figure 87: Programming the packet transmission levels.

If the user desires to sweep the signal level over a range of values, for example, to determine the sensitivity of the DUT receiver, then tick the ‘Swept’ checkbox.

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The signal level power sweep is defined by the numbers displayed in the three spin boxes:

1. *Maximum Power*. This indicates the power level at which the sweep will start. The sweep will always be from the maximum signal power towards the minimum signal power. The maximum power cannot be above 0dBm and must be greater than or equal to the minimum power. The resolution of the maximum power is 0.1dBm.
2. *Power Step*. This is the step size that the sweep will take from the maximum power towards the minimum power. The step size cannot be less than 0.5dB. The resolution of the step size is 0.1dB.
3. *Minimum Power*. This indicates where the power sweep should terminate. The last signal power to be test will be greater than or equal to the minimum power. The minimum power cannot be below -100dBm and must be less than or equal to the maximum power. The resolution of the minimum power is 0.1dBm.

The red bar in the signal level gauge indicates the range selected by the maximum and minimum powers. This entire range may not be explored during the sweep since the actual values tested are dependent on the selection of the step size.

If the cursor is placed over one of the limits of the red bar, then it will change to a double headed cursor. It is then possible to hold down the left mouse button and drag the edge of the red bar to adjust either the minimum or maximum power.

If the cursor is placed over the body of the red bar, then a '→' will appear adjacent to the cursor. It is then possible to hold down the left mouse button and drag the entire sweep range up or down the gauge.

***In advertise/scan mode a maximum of 32 different signal levels may be specified in the sweep. The power step size will automatically be adjusted to restrict the number of signal levels to 32.***



Figure 88: Programming a range of packet transmission levels.

### 11.3.8 Setting the cable loss

The cable loss or over-the-air loss between the DUT and the TLF3000 can be specified under the 'Cable loss' menu. Details of how to do this are contained in [Compensating for cable loss](#).

### 11.3.9 Programming the termination criterion

The test termination criterion is set under the 'Stop condition' menu. Two basic termination criteria are possible:

1. The advertise/scan tester runs until the specified number of packets have been sent at each of the selected signal levels/channels.
2. The advertise/scan tester runs until a test limit failure is detected

The 'Stop on limit failure' checkbox selects which of these two termination criteria is used.

On termination as test report can automatically be displayed in a browser. This will occur if the 'Show table' checkbox is ticked. The test report can be regenerated at any time by clicking the 'Report' button on the toolbar.

In the scan mode of operation, it is also possible to specify a timeout. This specifies how long the Sapphire application should wait on each of the selected power levels/channels for the specified number advertising packets to be received and the associated scan requests issued. This parameter needs to be consistent with the advertiser's beacon period and the specified number of packets.



Figure 89: Programming the termination criterion.

### 11.3.10 Programming the test limits

The test limits are shown in the results table. The penultimate column of the results table displays the lower limit and the final column the upper limit. They can be altered by changing the values in the spin boxes, either by using the up/down arrows or by entering numeric text directly.

### 11.3.11 Setting the RF input port

In advertise/scan mode signals can be received and analysed on either the 'Monitor In' RF port or the 'Tx/Rx' RF port. The selection of which port is used is made clicking the port displayed towards the bottom of the monitor panel.

The 'Monitor In' port is designed for monitoring signals off-air. The 'Tx/Rx' port is designed for conducted measurements but can be used for over-the-air measurements provided the DUT is adjacent to the TLF3000 unit.

**If the monitor panel shows a lack of RF input energy, check that the DUT is connected to the same RF port as selected by the label at the bottom of the monitor panel.**

### 11.3.12 Adjusting the RF frontend attenuation

The RF frontend attenuation is set via either:

1. The slider at the bottom of the monitor panel
2. The spin box at the bottom of the monitor panel

The RF frontend attenuation can be set between 0dB and 31.5dB in steps of 0.5dB.

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To set the RF attenuation, the *'Input Power'* gauge on the monitor panel must be examined. This shows both the current input signal level (the position of the needle) and the point at which saturation of the *TLF3000* receiver will occur (the red arc). The RF attenuation should be adjusted such that the input signal level is just below the saturation level.

If too little attenuation is applied, then there is a danger that the *TLF3000* receiver will be overloaded. An overload condition on the receiver is indicated by:

1. The needle on the *'Input Power'* gauge on the monitor panel entering the region of the red arc (the input power measurement is only approximate, so this is only a rough guide)
2. The title of the *'Input Power'* gauge on the monitor panel turning red
3. The text *'Rx overload'* appearing in red within the status bar at the bottom of the window

If too much attenuation is applied, then the test results may become unreliable. In order to calculate the frequency deviation within a packet, an FM demodulation process is employed. The quality of the output of the FM demodulation process is critically dependent on the signal-to-noise ratio of the signal at the input to the demodulator. If too much attenuation is applied, then the signal to be analysed will be pushed down towards the *TLF3000* receiver noise floor and the accuracy of the test results will be compromised.

### 11.4 Controlling data analysis and presentation

#### 11.4.1 Overview

The *Sapphire* application accumulates results independently for each:

1. LE RF advertising channel
2. Signal transmission level of the advertising or scan request packets

The tabs at the top of the graphics area determine which group of measurements will be displayed.

The displayed results are filtered according to the settings of the *'Channel filter'* and *'Signal level filter'* menus.

The graphics area shows a plot of one of the test quantities. This may be selected either through the *'Plot'* menu or by highlighting a row in the results table. The *'Plot'* menu also defines the format of the plot.

The results table shows the filtered results for the selected measurement group. It also contains the test limits.

### 11.4.2 Selecting the measurement group to display

*Sapphire* divides the Bluetooth 5.2 LE RF Phy transmitter test measurements into five groups:

1. Power measurements, which includes:
  - a.  $P_{avg}$
  - b.  $P_k - P_{avg}$
2. Modulation characteristics, which includes:
  - a.  $\Delta F1_{max}$
  - b.  $\Delta F1_{avg}$
  - c.  $\Delta F2_{max}$
  - d.  $\Delta F2_{avg}$
  - e.  $\Delta F2_{avg} / \Delta F1_{avg}$
  - f.  $\Delta F2_{max} 99.9\%$
3. Drift and carrier offset measurements, which includes:
  - a.  $F_0$
  - b.  $F_n$
  - c.  $|F_1 - F_0|$  or  $|F_3 - F_0|$  for 125kbps
  - d.  $|F_0 - F_n|$
  - e.  $|F_n - F_{n-5}|$  or  $|F_n - F_{n-3}|$  for 125kbps
4. In-band emissions, which includes:
  - a.  $F_{tx} \pm 2MHz$  or  $F_{tx} \pm (4,5)MHz$  for 2Mbps
  - b.  $F_{tx} \pm (3+n)MHz$  or  $F_{tx} \pm (6+n)MHz$  for 2Mbps
  - c. Number of exceptions
  - d. Maximum exception
5. Received packet count / Packet error rate. If advertise mode is selected, then the number of received packets is accumulated. If scan mode is selected, then the packet error rate is accumulated. It is not possible to calculate a PER in advertise mode since there is no means of knowing which advertising packets were correctly received.

The *Sapphire* GUI displays the results from just one of these measurement groups at any one time. The selection of which measurement group to display is determined by the tabs at the top of the graphics area.

If no results are displayed, then it is possible that no packets have been received or that the filter settings are incompatible with the packets which have been seen.

### 11.4.3 Filtering the displayed results by RF advertising channel

The displayed results can be filtered by RF advertising channel number. The RF advertising channels used to filter the results are selected via the 'Channel filter' menu under the 'Analysis' tab.

The required RF advertising channels can be selected by either:

1. Ticking the individual channel boxes
2. Using the quick channel group selection buttons:
  - a. Clear all
  - b. Select all
3. Entering a textual description (see [Textual input of test parameters](#))

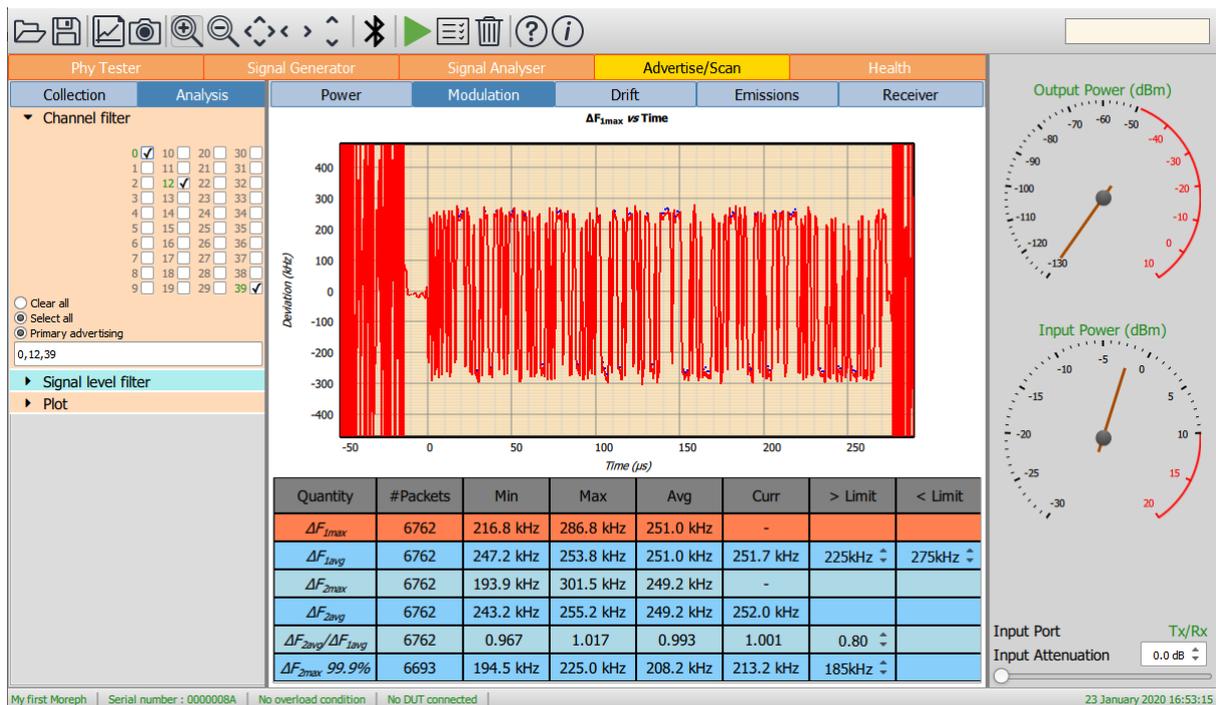


Figure 90: Filtering the displayed results by RF advertising channel.

### 11.4.4 Filtering the displayed results by signal transmission level

The displayed results can be filtered by the transmission level of the advertising or scan request packets. Up to 32 different signal transmission levels may be defined.

The signal transmission level filtering is specified via the ‘Signal level filter’ menu under the ‘Analysis’ tab. The required signal transmission levels are selected by ticking the corresponding boxes. If all signal transmission levels are of interest, then clicking the ‘All’ box at the bottom of the menu will select all signal transmission levels.

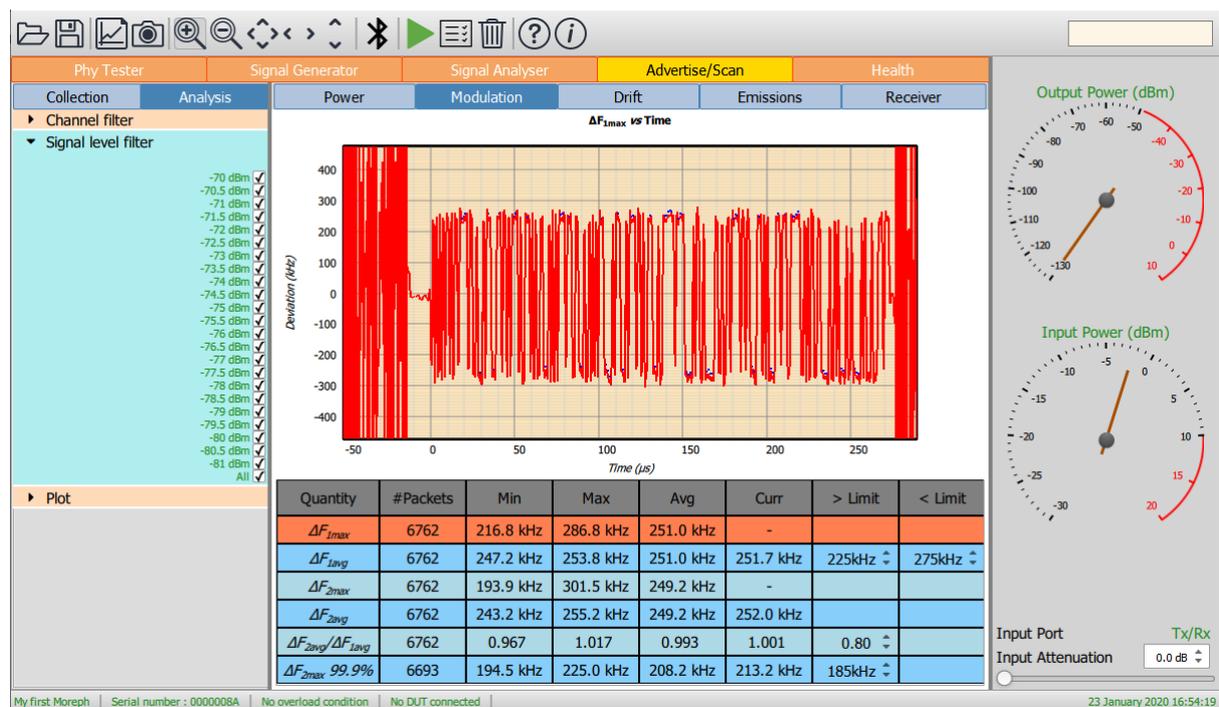


Figure 91: Filtering the displayed results by signal transmission level.

### 11.4.5 Understanding the results table

The results table contains a summary of the results obtained from the selected measurement group when filtered by the selected RF advertising channels and signal transmission levels.

The first column in the table contains the quantities defined in the Bluetooth 5.2 LE RF Test Specification which are members of the currently selected measurement group.

The second column in the table contains the number of packets which have contributed to the results for each measured quantity.

The third and fourth columns contain the minimum and maximum values which have been observed for each measured quantity.

The fifth column contains the average value of the measured quantity overall packets. If the units of the measured quantity are dBm or dB, then the average is the average of the dB values, not an average of the powers or linear ratios.

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If the measured quantity is a scalar quantity, i.e. it has a single value per packet, then the last measured value is displayed in the sixth column.

For scalar quantities with test limits, the lower limit is contained in column seven and the upper limit in column eight.

Quantity	#Packets	Min	Max	Avg	Curr	> Limit	< Limit
$\Delta F_{1max}$	7066	238.9 kHz	263.6 kHz	250.9 kHz	-		
$\Delta F_{1avg}$	7066	250.2 kHz	251.6 kHz	250.9 kHz	251.0 kHz	225kHz ↕	275kHz ↕
$\Delta F_{2max}$	7066	204.2 kHz	242.5 kHz	225.0 kHz	-		
$\Delta F_{2avg}$	7066	223.6 kHz	226.5 kHz	225.0 kHz	225.3 kHz		
$\Delta F_{2avg}/\Delta F_{1avg}$	7066	0.891	0.903	0.897	0.898	0.80 ↕	
$\Delta F_{2max}$ 99.9%	7064	205.6 kHz	207.2 kHz	206.6 kHz	206.6 kHz	185kHz ↕	

Figure 92: Results table obtained from the selected measurement group when filtered by the selected RF advertising channels and signal transmission levels.

When the selected filters include more than one RF advertising channel or signal transmission level, then the displayed values of minimum, maximum and average are the minimum, maximum and average overall packets which satisfy the selected filtering parameters.

If no measurement is available, then the symbol '-' is used to fill the corresponding table cell.

If a cell exceeds one its test limits, then that cell is highlighted in red.

It is possible to select a row in the table by clicking on it. Once a row has been selected, the corresponding quantity will be plotted in the graphics areas. The format of the plot is controlled by the 'Plot' menu under the 'Analysis' tab.

### 11.4.6 Controlling the graphical data

#### 11.4.6.1 Overview

The graphical data which is displayed is controlled by the 'Plot' menu under the 'Analysis' tab. The left-hand combo box lists all the quantities which are measured for the current measurement group (which is selected via the tabs at the top of the graphics area). These are the same quantities as displayed in the first column of the results table. The quantity to be plotted can be selected either through the combo box or by highlighting the appropriate row in the results table.

The right-hand combo box under the 'Plot' menu determines how the measured quantity is to be plotted. Options may include:

1. vs RF advertising channel
2. vs signal transmission level (only available for number of received packets)
3. as a histogram
4. vs time (not available for in-band emission measurements)
5. vs frequency (only available for in-band emission measurements)

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The screen update period can also be altered via the 'Plot' menu. vs RF advertising channel:

## 11.4.6.2 vs RF advertising channel

The quantity to be plotted is shown as a function of the RF advertising channel number. For each RF advertising channel three bars are drawn at channel to indicate:

1. minimum observed value (bottom of pink bar)
2. average value (junction of green and pink bars)
3. maximum observed value (top of green bar)

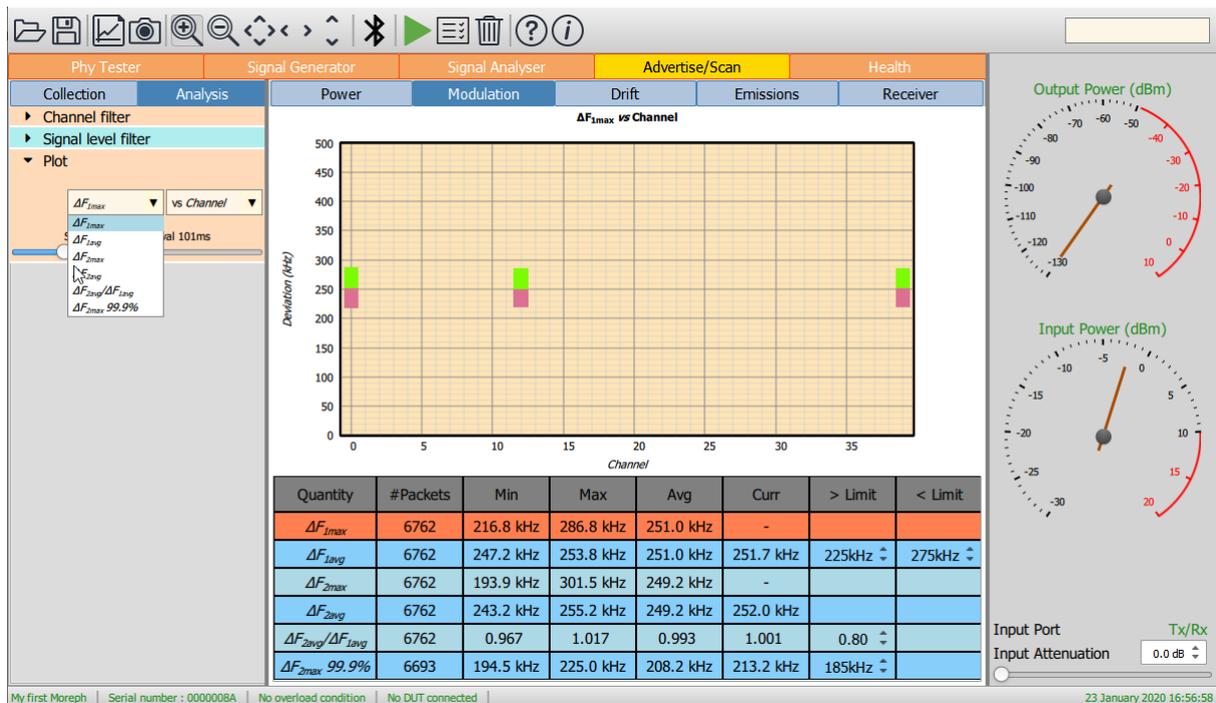


Figure 93: Results vs RF advertising channel.

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### 11.4.6.3 vs transmission signal level

This option is only available for receiver tests.

If *Sapphire* is operating in scan mode, then the PER is displayed. It is possible to calculate a PER since the advertiser should respond if it correctly receives the scan packet emitted by *Sapphire*. The limit line is adjusted for the length of the scan packet emitted by *Sapphire*. To meet the Bluetooth 5.2 RF Phy Test Specification PER requirements, the limit line is placed around 15.5%.

If *Sapphire* is operating in advertise mode, then the number of scan or connection request packets received is displayed. It is not possible to convert the number of received packets into a PER since it is not possible for *Sapphire* to ascertain whether the DUT failed to receive an advertising packet or whether it was not listening when the advertising packet was sent. However, if the scan algorithm of the DUT is known, then the user can convert the number of received packets into an approximate PER.

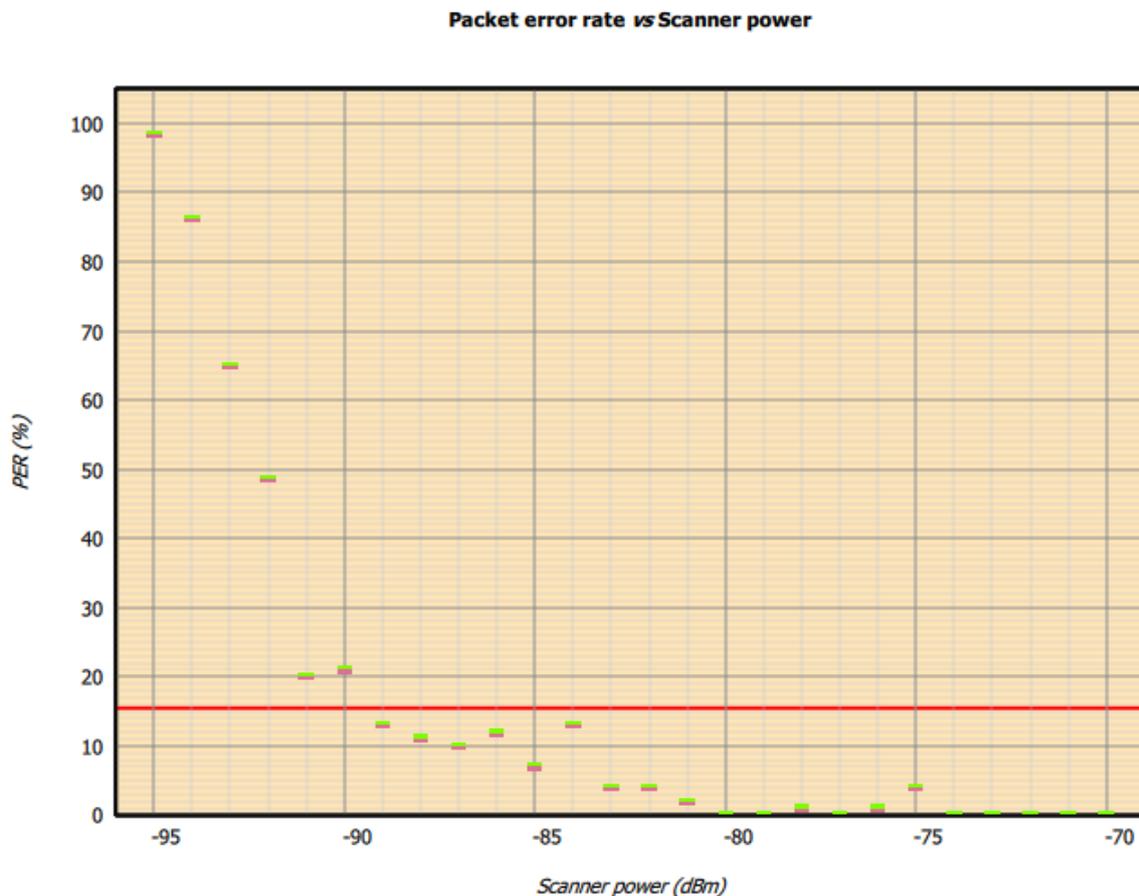


Figure 94: Results vs transmission level.

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## 11.4.6.4 Histogram

A histogram of the plotted quantity is displayed.

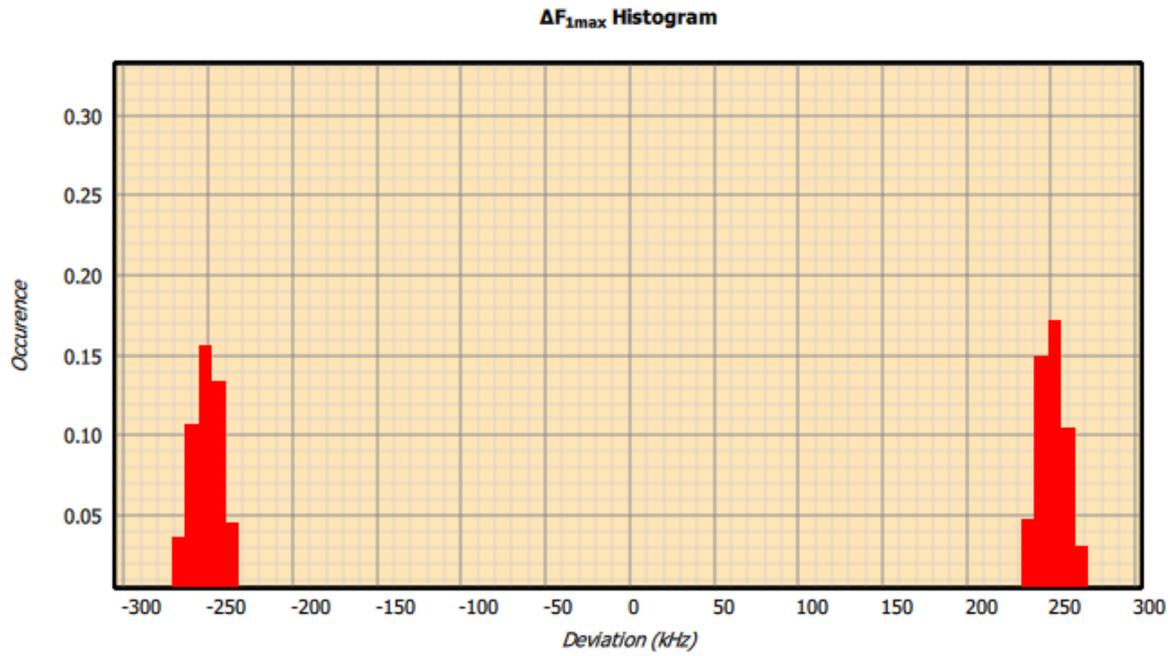


Figure 95: Results as a histogram.

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### 11.4.6.5 *vs time*

This option is not available for in-band emission tests.

The measured quantity is shown by the blue lines on the plot. The plot corresponds to the value(s) obtained from the last packet on which the selected quantity was measurable. If waveform collection has been enabled ('Collect' tab, 'Collect' menu) then either the frequency deviation or the packet power will also be displayed in red. *The waveform data will only be displayed if the quantity to be plotted was measurable on the last received packet.*

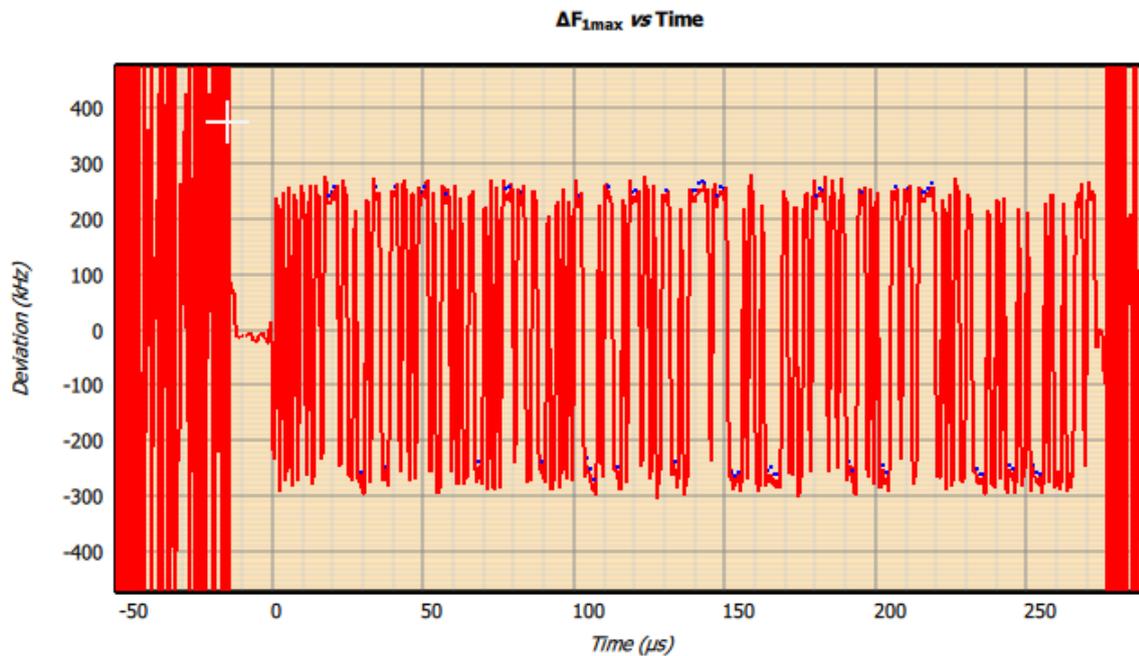


Figure 96: Results vs time.

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## 11.4.6.6 vs frequency

This option is only available for in-band emission tests.

When the vs frequency option is selected for in-band emission tests, additional options become available:

1. Plotting of the in-band emission results for every MHz in the 2.4GHz ISM band (1MHz spectrum)
2. Plotting of the 100kHz resolution measurements which were summed to yield the in-band emission results at every 1MHz (100kHz spectrum)

For each spectrum it is possible to plot:

1. Current in-band emission results (orange line)
2. Maximum in-band emission results (red line)
3. Minimum in-band emission results (green line)
4. Average in-band emission results (blue line)



Figure 97: Emissions results vs frequency.

### 11.4.7 Screen update period

The *'Plot'* menu contains a slider which can be used to alter the rate at which the results table and graphics are updated.

The fastest update period possible is around 50ms, typically limited by the host screen refresh rate. However, if substantial processing is required by *Sapphire*, for example, the transfer of raw IQ data at 32x oversampling, then the specified update rate may not be achievable.

The slowest update rate is 2 seconds. This gives the user time to assimilate the displayed results and waveform data before the next update.

### 11.5 Saving and restoring settings

The current collection, analysis and limit settings can be saved by clicking the *'Save'* button on the toolbar. Select the *'Advertise/scan settings (\*.aas)'* file type to save the current settings.

An existing advertise/scan settings file (\*.aas) can be opened using the *'Open'* button on the toolbar.

The advertise/scan settings file (\*.aas) is an XML file. It is not recommended that this file be edited manually. If it needs to be modified, open it from the advertise/scan mode, modify the required parameters and re-save.

### 11.6 Saving current results table and graphics

The current results can be saved by clicking the *'Save'* button on the toolbar. The format of the results file depends on the file type selected to save the current results. The results can be saved in the following formats:

1. xml: permitting the results to be read by a range of other applications
2. txt: a simple ascii text file
3. csv: permitting the results to be read by spreadsheets
4. html: for viewing the results in a web browser or for inclusion in a test report

The current graph and results table can be saved as an image by clicking the *'Graph'* button on the toolbar. The range of possible graphics formats includes:

1. Windows bitmap files (\*.bmp)
2. Joint photographic expert group files (\*.jpg)
3. Portable network graphics files (\*.png)
4. Portable bitmap files (\*.pbm)
5. Portable graymap files (\*.pgm)
6. Portable pixmap files (\*.ppm)
7. X11 bitmap files (\*.xbm)
8. X11 pixmap files (\*.xpm)

## 12 Standalone Mode

### 12.1 Overview

The standalone mode permits *Sapphire* to be run without a USB or Ethernet connection. In this mode of operation, the *Sapphire* image and test script are held on a memory stick which is attached to the USB port of the *TLF3000*. The supervisor program on the *TLF3000* will automatically launch the *Sapphire* application which will then execute the test script held on the memory stick. Control of the *Sapphire* application and signalling of pass/fail are accomplished by the use of digital IO.

### 12.2 Connectivity

The DUT serial interface should be connected to the digital IO connector on the rear of the *TLF3000* unit. The relevant lines are:

Pin	Name	Direction	Special function
1	Vio	I/O	Max 500 mA from internal 3.3 V supply. External voltage range 0.8 V to 3.6 V.
2	Vio	I/O	
9	GPI #6	I	UART RTS
10	GPI #7	I	UART Rx
17	GPO#6	O	UART CTS
18	GPO#7	O	UART Tx
19	Gnd	-	
20	Gnd	-	

Table 14: Assignments on digital IO connector

The IO voltage for digital interface can be either from the *TLF3000* unit or from the DUT. If the IO voltage is from the *TLF3000* unit, then it is fixed at 3.3 V. If the DUT supplies the IO voltage, then it must be in the range 0.8 V to 3.6 V. The choice of which unit supplies the IO voltage is defined in the *Sapphire.sta* file.

For standalone testing the DUT is connected to the 'Tx/Rx' RF port.

*Sapphire* needs an estimate of the cable loss between the Tx/Rx port and the DUT at 2.4GHz. This is necessary to compensate for receiver power levels and to adjust transmitter output levels. The cable loss is defined in the *Sapphire.sta* file. Permissible values are between 0dB and 25dB.

The cable loss value is also used to compensate the blocker level. Since the cable loss value is only applicable at 2.4GHz and the blocker frequency can be anywhere from 24MHz to 6GHz, the compensation is extremely rough. However, given the accuracy of the blocker signal level and the relatively low levels of cable attenuation, this is not normally an issue.

The memory stick containing the *Sapphire* image and test script file is attached to the *TLF3000* unit via a USB on-the-go adapter. The memory stick can be attached either before or after the *TLF3000* unit has booted.

### 12.3 Memory stick contents

The memory must have a FAT32 file system. If an error log is required, then the memory stick must be write enabled.

The top-level folder of the memory stick must contain the following two files:

1. *Moreph30.rfcapp*. This file contains the *Sapphire* application image.
2. *Sapphire.sta*. This is the test script file.

Both these files can be generated from the *Sapphire* GUI.

#### 12.3.1 Generating the TLF3000.rfcapp file

The *Moreph30.rfcapp* file can be generated by clicking the 'Save' file toolbar button and selecting file type '*Application binary (\*.rfcapp)*'. Enter the name '*Moreph30*' and save the file to the top-level folder of the memory stick.

#### 12.3.2 Generating the Sapphire.sta file

A working version of the *Sapphire.sta* file can be generated from Phy Tester Mode. The GUI should be used to enter:

1. All DUT serial interface communication parameters. DUT control via the host is not supported in standalone mode.
2. All DUT supported features.
3. Cable loss
4. Phy test script

Once all this information has been entered, the *Sapphire.sta* file can be generated by clicking on the toolbar save button and selecting file type '*Standalone files (\*.sta)*'. Enter the name '*Sapphire*' and save to the top-level folder of the memory stick.

The run mode parameters entered in the GUI are not transferred to the *Sapphire.sta* file. In standalone mode the run mode is always set to:

1. Only test against limits
2. Do not run to completion
3. No looping of test script

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### 12.3.3 Standalone test script file format

An example standalone test script file is:

```
H4,115200,1,0,1,NONE // DUT communications
CENTRAL,0,0,37,27,27,328,328 // DUT properties
0 // Cable loss
1 // Vio source
0,0,1 // Control, status & pass lines
TRM1,{37},{0:39},{1} // Test 1
TRM5,{37},{0:39},{10} // Test 2
RCV1,{37},{0,19,39},{100},{-70},,,,,
```

The test script is composed of the following lines:

1. DUT communications. The parameters on this line are:
  - a. Communications protocol (DTM, H4, H5 or BCSP)
  - b. Baud rate.
  - c. Hardware flow control (0 = off, 1 = on)
  - d. Software flow control (0 = off, 1 = on)
  - e. Stop bits (1 or 2)
  - f. Parity (NONE, EVEN or ODD)
2. DUT role and supported features. The parameters on this line are:
  - a. DUT role (CENTRAL, PERIPHERAL, BROADCASTER or OBSERVER)
  - b. Supports advertising extensions
  - c. Supports data length extensions
  - d. Maximum number of advertising octets
  - e. Maximum number of receive payload octets
  - f. Maximum number of transmit payload octets
  - g. Maximum receive packet length in  $\mu$ s
  - h. Maximum transmit packet length in  $\mu$ s
3. Cable loss in dBm
4. Digital IO voltage source (0 = internal 3.3 V, 1 = external)
5. Digital IO lines for control and status. The parameters on this line are:
6. Digital input line to be used for control
7. Digital output line to signify status
8. Digital output line to signify pass/fail

The remaining lines in the test script file define the tests to be performed. The format of these lines is covered in the Sapphire Programmer's Manual.

## 12.4 Control

Control of the standalone *Sapphire* application is performed using three digital IO lines:

1. *Control*. This is an input to the *TLF3000* unit. A transition on the line from '0' to '1' will cause *Sapphire* to attempt to run the test script.
2. *Status*. This is an output from the *TLF3000* unit. When this line is high, the *Sapphire* application is idle. When this line is low, the *Sapphire* application is executing the test script.
3. *Pass/Fail*. This is an output from the *TLF3000* unit. The status of this line is only valid when the status line is low. If this line is high, then the DUT passed the last execution of the test script. If this line is low, then the DUT failed the last execution of then test script.

## 13 High Level Language Programming

Teledyne provide comprehensive support for driving the *Sapphire* application from high level languages. Support is primarily through a C dll. The C dll forms the basis for control of the *Sapphire* application from:

1. C++
2. MatLab
3. LabView

A separate Python interface is also provided.

Example code for C++, LabView, MatLab and Python is available.

Support is available for Windows and Linux. Mac support is available on request.