

AN1046: Radio Frequency Physical Layer Evaluation in *Bluetooth*® SDK v2.x



This application note provides an overview of how to perform Bluetooth-based radio frequency (RF) physical layer (PHY) evaluation with Bluetooth-enabled EFR32xG system-on-chips (SoCs) and BGM/MGM modules using Silicon Labs' software tools and dedicated firmware. A Bluetooth device's RF parameters are validated using a protocol called Direct Test Mode (DTM). DTM is described in the Bluetooth Core Specification versions 4.x and 5.0, Volume 6, Part F.

KEY POINTS

- Basics of Direct Test Mode (DTM)
- Testing with BGTool
- Testing with DTM 2-wire firmware
- Test examples
- Updates for Bluetooth 5.0

Testing can be performed in three ways:

- Through DTM test commands issued by a host system over the SoC's or module's host interface.
- Through DTM test commands issued by a custom application running in the SoC or module itself. Such commands could be autonomously launched by the custom application, for example at boot or following the writing of a dedicated GATT characteristic by a remote companion device over a Bluetooth LE connection.
- In a special test environment supported by dedicated firmware that allows a testing device to control the test target.

With these options, customers can fully evaluate transmit and receive performance, and test the RF functionality of their development kit hardware or custom hardware. Laboratory tests require RF test equipment, such as a spectrum analyzer and an RF signal generator, and /or a Bluetooth tester.

1. Basics of the Direct Test Mode (DTM)

The Bluetooth specification defines a mechanism, called Direct Test Mode (DTM), for testing the radio performance of Bluetooth low energy devices. This mechanism is described in the Bluetooth Core Specification, for example versions 4.2 and 5.0, Volume 6, Part F, which are available at <https://www.bluetooth.com/specifications/bluetooth-core-specification>. DTM is provided for the validation of a Bluetooth low energy device's radio-frequency (RF) physical layer (PHY), so as to ultimately guarantee an end product's interoperability and performance quality. RF testing is essential for a Bluetooth device, as with any device implementing a wireless standardized technology, since factors such as full compliance with the specification for interoperability, and conformance to communication regulations must be carefully assessed and validated before the product is launched. In addition, it may be desirable to evaluate the product's performance during production. The ability to easily accomplish RF testing in a standardized manner throughout the production cycle is useful.

DTM offers two approaches for RF PHY testing. In the first, an *Upper Tester* can enter special HCI (host control interface) commands over the standardized HCI interface of the Device Under Test (DUT) to start and stop the radio tests on the DUT. In the second, the Upper Tester has direct access to the DUT through a dedicated 2-wire connection, and can autonomously start and stop the radio tests on the DUT in accordance with automated test routines.

The DTM protocol enabling the communication between the DUT and the Upper Tester also has provisions for feedback from the DUT, in the form of acknowledgements to the commands given, or in the form of Packet Count information being reported at the time a test is stopped.

A *Lower Tester*, or RF PHY Tester, is also part of the test setup, and is the actual lab equipment measuring the RF activity and performance. The RF PHY Tester can either be a separate device, like a spectrum analyzer, which is normally used with the first method where the HCI commands are issued by a generic host system, or it can be part of the same device. In the latter case the RF PHY Tester functions also as the Upper Tester, as for example commercial Bluetooth testers such as the one referenced later in this document.

The Bluetooth-enabled Silicon Labs EFR32xG SoCs and the BGM/MGM modules support both the approaches mentioned above. Special firmware can be loaded to enable the 2-wire DTM and allow the Upper Tester to take full control of the SoC or module (the device). The 2-wire link is a UART-like connection with no flow control operating at baud rates between 1200-115200, 8N1 (8 data bits, no parity, 1 stop bit). As one alternative, any firmware that configures the device to operate in Network Co-Processor (NCP) mode can be used, since the host system can then issue the test commands included with the BGAPI Bluetooth API over the same host interface that is normally used to implement the BGAPI protocol for the control and configuration of the device's normal Bluetooth LE functionality. Note that in this case BGAPI-formatted test commands are sent and not the HCI commands defined in the standard. However, these BGAPI commands are then internally processed as HCI commands. The SDK does not contain any special firmware or configuration to disable the BGAPI DTM commands/responses and use the raw HCI command/responses instead.

2. Tests Enabled in the DTM Framework

DTM enables a set of RF PHY test cases, which are defined by the Bluetooth Special Interest Group (SIG) in the documents from the sections called “TCRL Release Table” and “Core - Test Requirements for v4.0 or later” found at the beginning of the <https://www.bluetooth.com/specifications/qualification-test-requirements> web page.

Note: The following information was updated in the first half of 2017. For current information, refer to the newer TCRL 2017-1, that is, to the corresponding *2017-1 TCRLs-1.zip* file containing the newer RF-PHY.TS.5.0.1.

The Capability tests (as defined in the standard ISO subgroups) are organized in levels and groups representing protocol services, functional modules, and purposes, the latter being divided in operating conditions for the transmitter and the receiver. All the relevant RF PHY tests are in accordance to the test specifications RF-PHY.TS.4.2.3 or the updated RF-PHY.TS.5.0.0 and are shown in the RF-PHY sheet of the Excel file called *Core.TCRL.2016-2.x/sx* found inside the *2016-2 TCRLs.zip*.

Below are examples of test cases for the Physical Layer Conformance. They are referred to by their identifiers, where TP stands for Test Purpose and TRM-LE and RCV-LE stand for LE Transmitter and LE Receiver test respectively.

- TP/TRM-LE/CA/BV-01-C [Maximum peak and average output power]
- TP/TRM-LE/CA/BV-03-C [In-band spectral emissions]
- TP/TRM-LE/CA/BV-05-C [Modulation Characteristics]
- TP/TRM-LE/CA/BV-06-C [Carrier frequency offset and carrier drift]
- TP/RCV-LE/CA/BV-01-C [Receiver sensitivity]
- TP/RCV-LE/CA/BV-03-C [C/I and Receiver Selectivity Performance] [Additional blocker needed to generate co-/adjacent channel interference]
- TP/RCV-LE/CA/BV-04-C [Blocking Performance] [Additional blocker needed to generate interference outside the 2400MHz - 2483.5MHz band]
- TP/RCV-LE/CA/BV-05-C [Intermodulation Performance] [2 x additional blocker needed to generate both a sinusoidal/un-modulated and a continuous/modulated carrier]
- TP/RCV-LE/CA/BV-06-C [Maximum input signal level]
- TP/RCV-LE/CA/BV-07-C [PER Report Integrity]

Additional test cases have been introduced since the release of Bluetooth 5. A few examples of the many new test cases are listed below:

- TP/TRM-LE/CA/BV-08-C [In-band emissions at 2 Ms/s]
- TP/TRM-LE/CA/BV-10-C [Modulation Characteristics at 2 Ms/s]
- TP/RCV-LE/CA/BV-08-C [Receiver sensitivity at 2 Ms/s]
- TP/RCV-LE/CA/BV-10-C [Blocking performance at 2 Ms/s]

All the above tests can be performed with the EFR32xG SoCs and the BGM/MGM modules, because they are supported by the DTM implementation built in to the Silicon Labs Bluetooth stack.

Notes:

1. According to the latest TCRLs, references to the Extreme Operating Conditions (EOC) and the Normal Operating Conditions (NOC) have been removed, as they became redundant with the removal of the extreme operating test conditions.
2. To accomplish the full set of tests in the specification, up to two external signal generators are needed to provide complete interference signals, in addition to a spectrum analyzer.

3. Testing with BGTool

An easy way to perform the RF PHY tests with the EFR32xG SoCs and the BGM/MGM modules is to use a PC running BGTool as the Upper Tester. The SoC or module must be configured to operate in NCP mode.

AN1042: Using the Silicon Labs Bluetooth® Stack in Network Co-Processor Mode discusses the basics of the NCP firmware and how to load it to a device, and provides an example to help familiarize you with the NCP mode. It also includes instructions on how to get started controlling and configuring the Bluetooth functionality through the BGTool demo program. This chapter describes using BGTool for RF PHY testing, where an SoC or module in a radio board attached to the Wireless Starter Kit (WSTK) is the example DUT, as shown in the following figure.

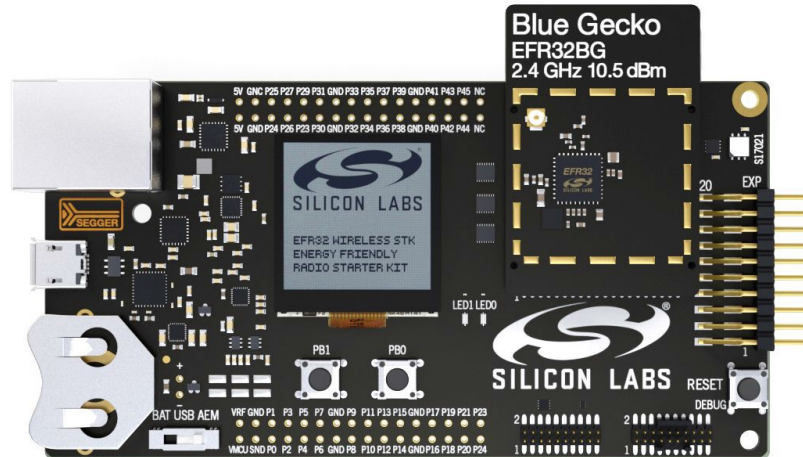


Figure 3.1. WSTK with the Blue Gecko EFR32BG SoC

Launch BGTool and verify that the device in NCP mode responds to the commands entered in the **Interactive view**. Next, change to the **RF regulatory test view**. Click **Open with the connected device**.

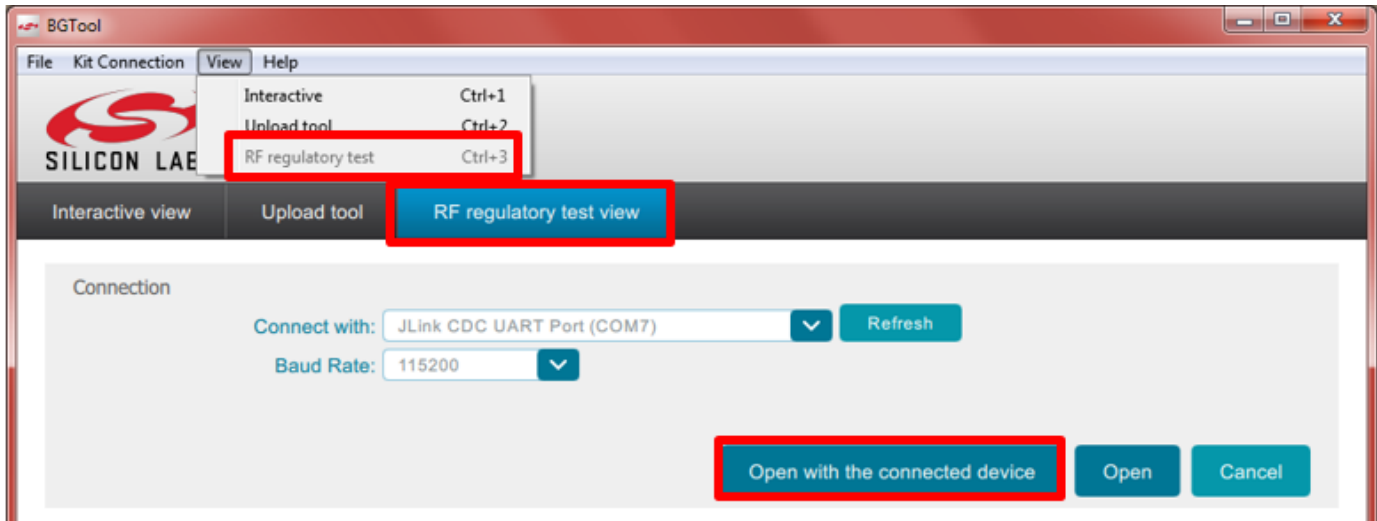


Figure 3.2. Entering the RF Regulatory Test View

The control dialog shown in the following figure opens.

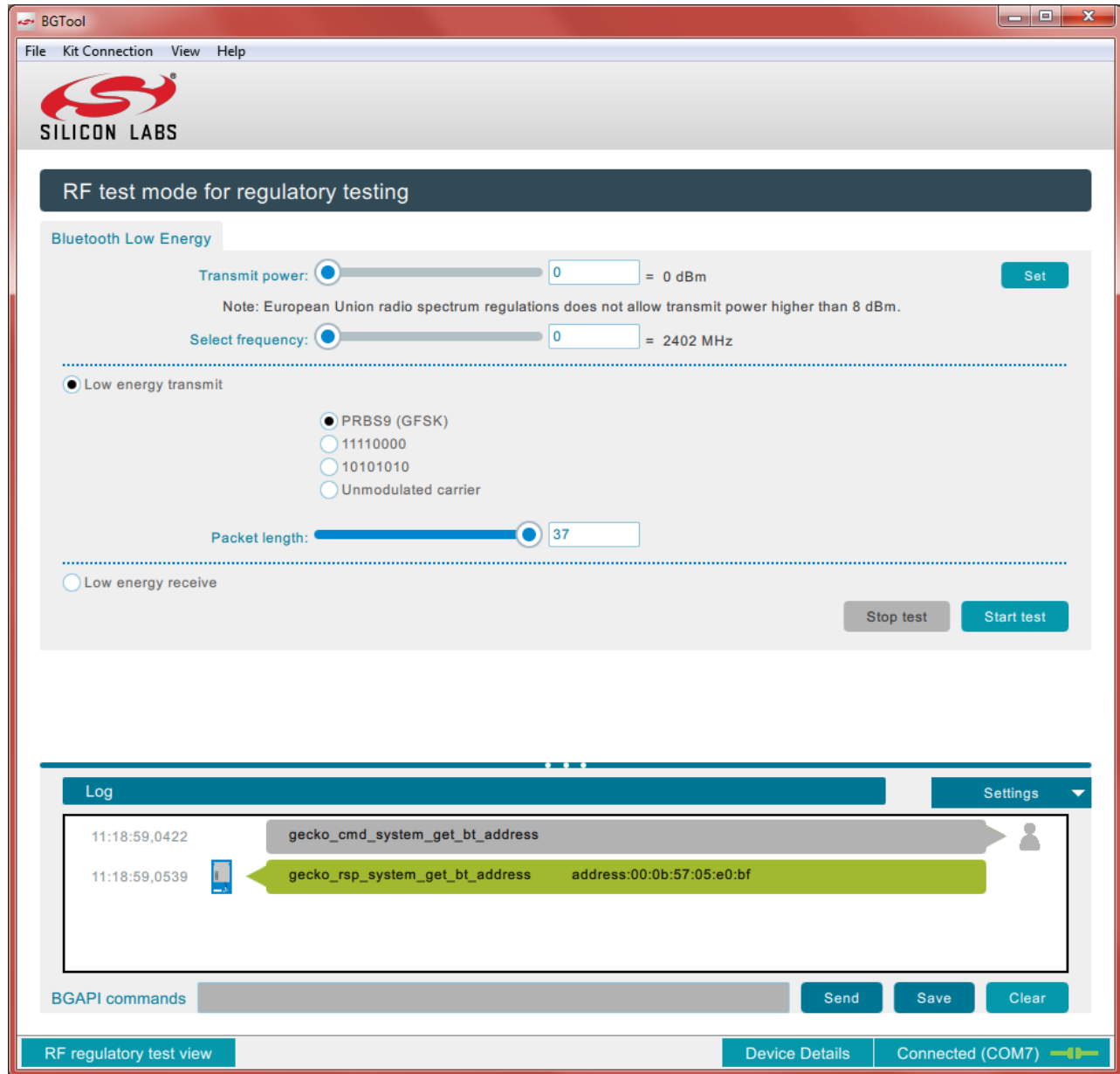


Figure 3.3. RF Regulatory Test Control Dialog

In this dialog you can interact with the device and set the RF test parameters using the sliders and the radio buttons. All the necessary configuration options are provided, namely transmission power level, operational frequency, packet type and length, and whether to perform a transmit or receive test.

If you intend to perform transmit tests using anything other than the default transmit power, change the power and click **Set** next to the Transmit power slider before launching your next test. Normally the default value is the maximum allowed by the firmware for a particular SoC or module. Clicking **Set** executes the BGAPI's `system_set_tx_power` command, which changes the power value.

When the configuration parameters for the test are complete, click **Start test**. The test runs until you click **Stop test**.

Depending on the SDK in use, the BGTool might present different views and contents, such as in the following where no firmware uploading section exists.

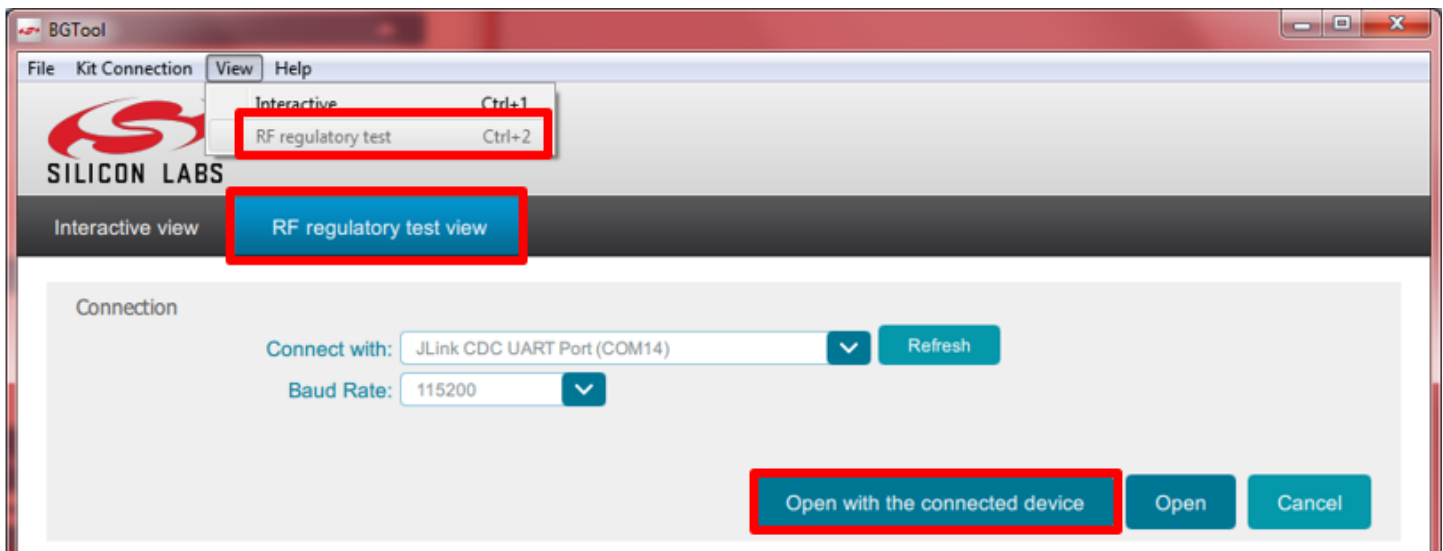


Figure 3.4. Entering the RF Regulatory Test View using the BGTool

The following figure shows the new PHY selection option with the most recent version of the BGTool for devices that support Bluetooth 5.0, together with the new option to select the PN9 continuously modulated carrier, and the possibility to extend the payload to up to 255 bytes.

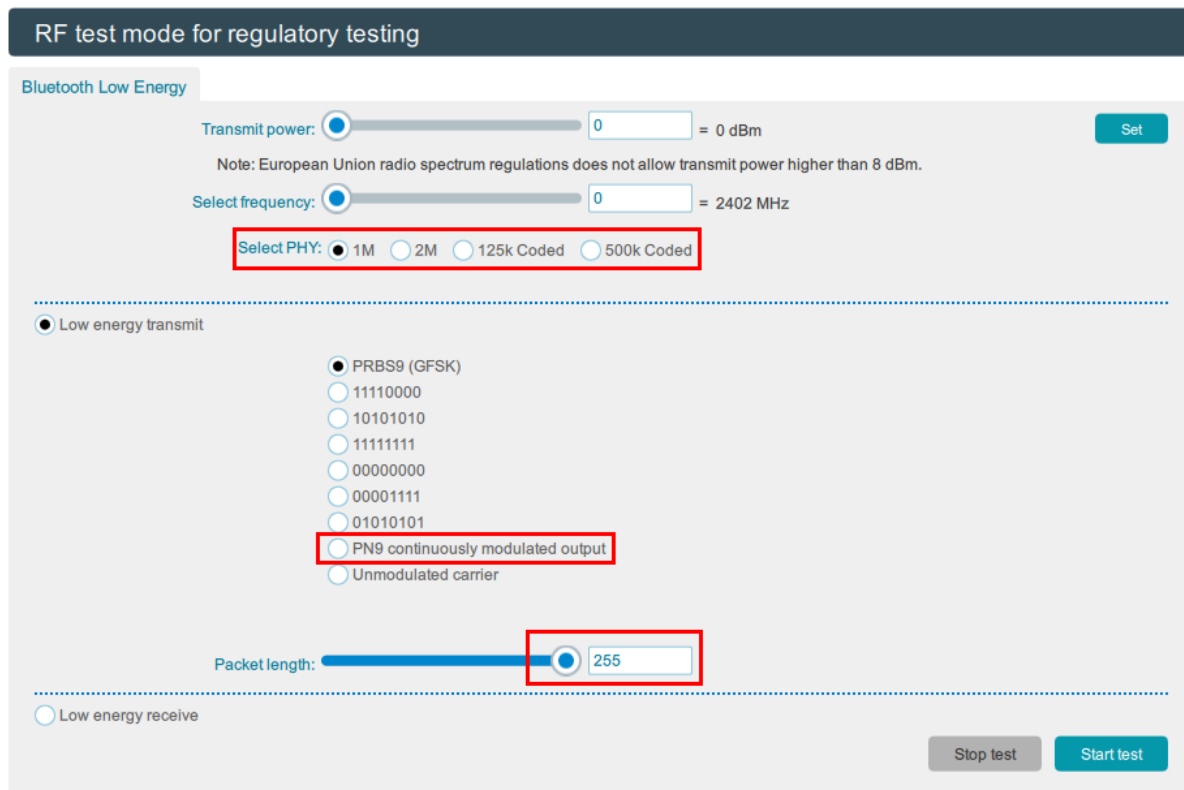


Figure 3.5. Selecting the PHY with the BGTool

When you click the **Start test** button, BGTool sends one of the BGAPI's DTM commands over the host interface of the device. The command parameters correspond to the slider and radio button selections. The API's DTM commands are summarized in the following table.

Table 3.1. DTM Commands

Command	Description
<code>test_dtm_tx(packet_type, length, channel)</code> or <code>test_dtm_tx(packet_type, length, channel, phy)</code>	<p>Starts a transmitter test. The DUT returns a response indicating that the command was received successfully. Shortly after this, a <code>test_dtm_completed</code> event is triggered, indicating that the command was processed by the radio and the actual test mode is started. At this point, the device is sending Bluetooth LE packets continuously at a fixed interval defined in the specification. The test is stopped using the <code>test_dtm_end</code> command, which is also followed by a <code>test_dtm_completed</code> event.</p> <p>Only when a <code>test_dtm_completed</code> event follows the <code>test_dtm_end</code> command, and only with firmware versions 2.4.0 and above, the event's <code>number_of_packets</code> field carries the actual number of packets sent during the test.</p> <p>The type and length of each packet is set by the <code>packet_type</code> and <code>length</code> parameters. The newest firmware versions add a parameter called <code>phy</code> that allows the selection of the PHY among 1M, 2M, 125k Coded, and 500k Coded, when supported by the DUT.</p> <p>Note that a special packet type named <code>test_pkt_carrier</code> exists (enumerating to a value of 3, or 254 beginning with version 2.4.1.0, for the parameter <code>packet_type</code>) that can be used to transmit a continuous unmodulated carrier. The length field is ignored in this mode. Version 2.4.1.0 also introduces yet another special packet type named <code>test_pkt_pn9</code> (enumerating to a value of 253) that can be used to transmit a continuous modulated carrier instead, by means of a PN9 stream offering a 100% duty cycle.</p> <p>In general, for the regulatory testing PRBS9 (<code>packet_type</code> of 0) and/or the continuous modulated carrier are used, whereas the other two packet payloads (<code>packet_type</code> of 1 or 2) are used when testing for the Bluetooth qualification.</p>
<code>test_dtm_rx(channel)</code> or <code>test_dtm_rx(channel, phy)</code>	<p>Starts a receiver test. The procedure is similar to the transmitter test described above. When ending the test with the <code>test_dtm_end</code> command, the expected <code>test_dtm_completed</code> event from the device carries in its <code>number_of_packets</code> field the actual number of packets received during the test.</p>
<code>test_dtm_end()</code>	<p>Can be issued at any time to end a transmitter or a receiver test. When the command is processed by the radio and the test has ended, a <code>test_dtm_completed</code> event is triggered.</p>

The commands with their related responses, and the event mentioned in the table above, are found in the *Bluetooth Software API Reference*.

Note: Once a test is started the normal Bluetooth LE functionality is not available, in other words, advertising and scanning are not possible while a test is running, and similarly no connection can exist.

The following figure shows an example of the commands and responses and events in an actual test.

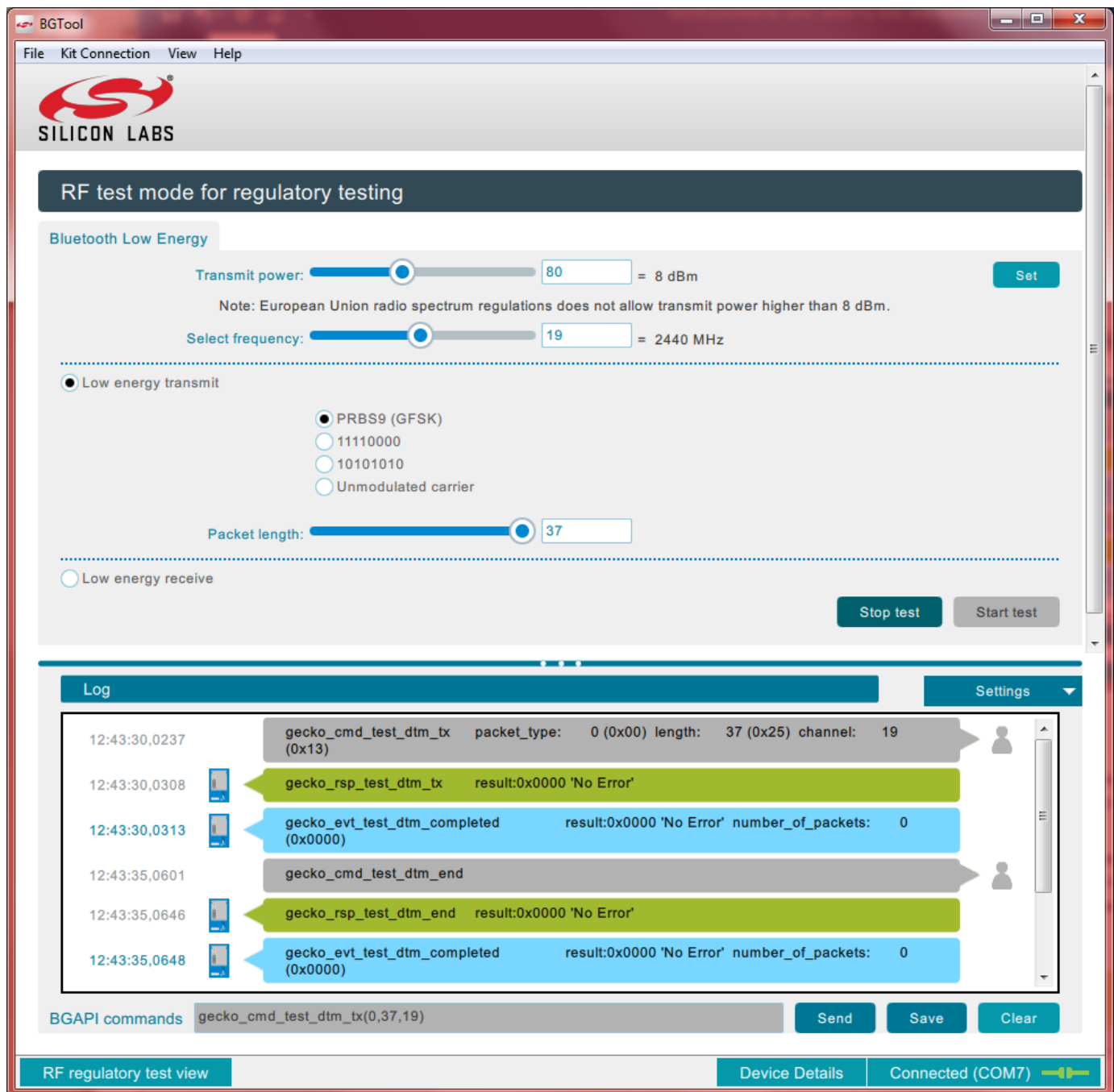


Figure 3.6. Starting and Stopping a Transmission Test

In this example, the test is started by clicking **Start test**. After a DTM test is started, the device will only accept the `test_dtm_end` command, which is entered by clicking **Stop test**. The only other ways to stop a test are by resetting the device or through a power-cycle.

Another way to start and stop tests with BGTool is by entering the commands with the desired parameters in the command field at the bottom of the BGTool window, labeled **BGAPI commands**. Such commands can be copy-pasted from the API reference, for example:

```
gecko_cmd_test_dtm_tx(0,37,19)
```

Using BGTool is just one of the ways to perform the RF PHY tests in the lab. In fact, the DTM commands from the BGAPI protocol are also available to any host MCU capable of issuing the BGAPI commands over the device's host interface, for example when implementing a host program based on the BGLib library.

The commands can also be launched by a DUT operating in standalone mode, by means of a custom C program loaded onto the SoC/module. Users could start with the **SOC-Empty** example project, and customize it to simply have a test command autonomously launched at boot and terminated by a hard reset or after a timer has expired. Alternatively, the program could be designed to allow an incoming Bluetooth LE connection over which a remote device could write a dedicated GATT characteristic. The characteristic's content would define the test command the application should launch and how long this should run until a terminating event such as allowing the next connection or a reset.

Using this programming strategy, customers often prepare multiple firmware images for their test house, each containing the standalone functionality to launch a specific test at bootup, and then simply provide instructions to the test house on how to change firmware images.

Notes and Limitations:

1. The DTM tests discussed in this section are meant for regulatory testing as well as for Bluetooth qualification. All tests are designed to satisfy the guidelines normally set by the test houses that will conduct the regulatory evaluation.
2. During a 1M PHY transmit test where the typical 37 bytes of payload are used, subsequent packet transmissions are started at an interval of 625 μ s. In this case, the packet transmission itself lasts 376 μ s, resulting in a duty cycle of 60.2%. This comes from the fact that the packet used in the test is made of a preamble (8 bit) plus a sync word (32 bit) plus a packet type field (16 bit) plus the payload (296 bit) plus the CRC (24 bit), while the time to transmit one bit is 1 μ s given the air-interface baud rate of 1 Mbit/s. The max payload size that can be configured with the `test_dtm_tx` command is 37 bytes with older firmware versions, but can be up to 128 bytes since firmware version 2.3.0.0, and up to 255 bytes since version 2.6.0.0, according to the LE Data Packet Length Extension introduced in the Core Specification version 4.2. Given all the new possible combinations of PHYs and packet lengths in the newest firmware versions, the duty cycle will actually depend now also on the interval between packets which is not fixed but calculated based on the information found in the Core Specification version 4.2 and 5, in chapter "4.1.6 LE Test Packet Interval" of Volume 6, Part F.
3. In firmware versions 2.3.x.x and earlier, no configuration option exists to output a continuously modulated RF signal. Some of the FCC test procedures might require a modulated output at $\geq 98\%$ duty cycle. Testing with such a duty cycle is not needed when an AVG detector (recommended) is available. But when an AVG detector is not part of the lab testing equipment, and since it is not possible to output the continuously modulated RF signal, then testing might involve measuring the duty cycle in the time domain and then applying a positive correction factor, as discussed in the FCC presentation at:

<https://transition.fcc.gov/bureaus/oet/ea/presentations/files/apr12/2a.-April-12-DTS-Presentation-SJ.pdf>

Starting with firmware version 2.4.0.0, a new packet type is defined for the `test_dtm_tx` command to let the DUT generate a continuously modulated RF signal in addition to the continuous unmodulated carrier. For more information, see [Table 3.1 DTM Commands on page 7](#).

4. As of this document version, no configuration option exists to define a fixed amount of packets that the device would transmit after issuing the `test_dtm_tx` command. One useful use case would be to estimate packets lost: the test setup would have a transmitter sending a number of packets known in advance and a receiver reporting the number of packets received (via the `test_dtm_completed` event). This could evaluate performance changes due to distance or other conditions, or be used during production to validate the quality of a product just manufactured. The workaround for the lack of such a configuration option is to let the unit transmit only for a fixed amount of time, calculated by taking into account the interval at which the packets are transmitted: in the example case of a 1M PHY and 37 bytes payload, having the interval between packets set to 625 μ s, the packet rate is 1600 [packets/s].

Note: Starting with firmware versions 2.4.0 and above, the `test_dtm_completed` event reports the actual packets sent during the test when the test mode launched with the `test_dtm_tx` command is stopped. This is useful for a precise estimation of the PER when comparing the exact number of packets sent by the stack with the actual packets received by the receiver.

4. Testing with the DTM 2-Wire Firmware

If a Bluetooth tester device is available, it should be used to evaluate the RF performance of the DUT, since such dedicated equipment is faster and offers automated and accurate testing. These benefits among others are achieved because the tester can control and configure the DUT in all the tests required for complete RF PHY evaluation. Such control is possible thanks to the DTM 2-wire capability and its related protocol, which are part of the Bluetooth specification.

In order to enable the DTM 2-wire communication between a commercial Bluetooth tester device (that is, the Upper Tester with the included RF PHY measurement capability) and the DUT, the latter needs to run a special firmware where the protocol is included. This special DTM 2-wire-capable firmware was first released with Silicon Labs Bluetooth SDK version 2.1.0.0, and is available through the Simplicity Studio v4, as shown in the following figure.

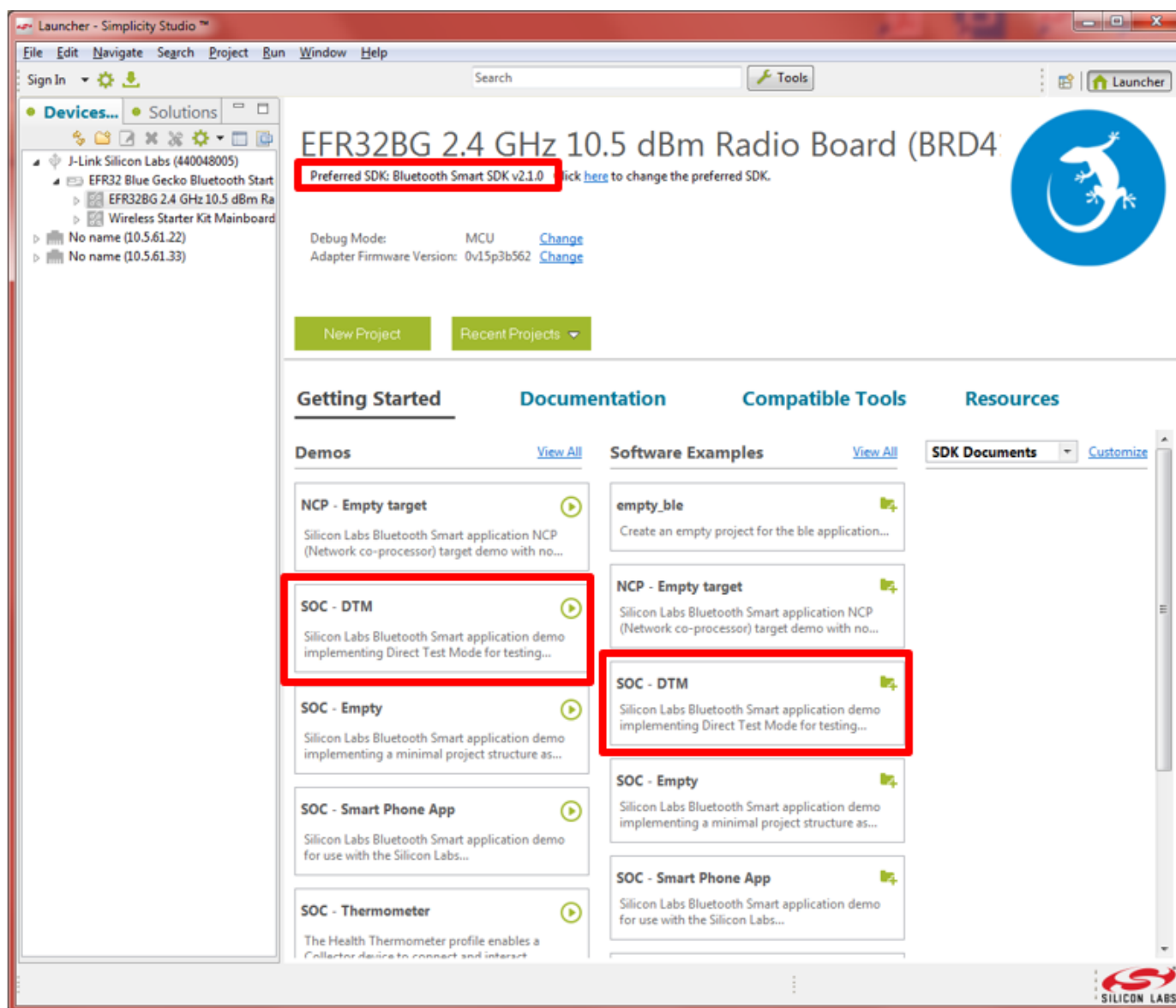


Figure 4.1. DTM 2-Wire Firmware from Simplicity Studio v4 Launcher Perspective

4.1 Using the Precompiled Demo Version

The demo version of the DTM firmware is a ready-to-use solution if the following test configuration is acceptable:

- The hardware link to the Bluetooth tester is enabled over the device's pins that, in its evaluation radio board, are mapped to the WSTK expansion header's UART TX (pin 12) and UART RX (pin 14).
- The link uses UART parameters of 115200, 8N1 with no hardware flow control.

Refer to the documentation of a particular SoC or module and of its evaluation radio board to determine which pins are in use in order to have the DTM signaling routed to the intended expansion header pins.

To program a device with the DTM demo, under the **Demos** column in the Simplicity Studio launcher click the *SOC - DTM* demo. In the next dialog, confirm the demo and mode, and click **Start**. The demo is then loaded onto the device.

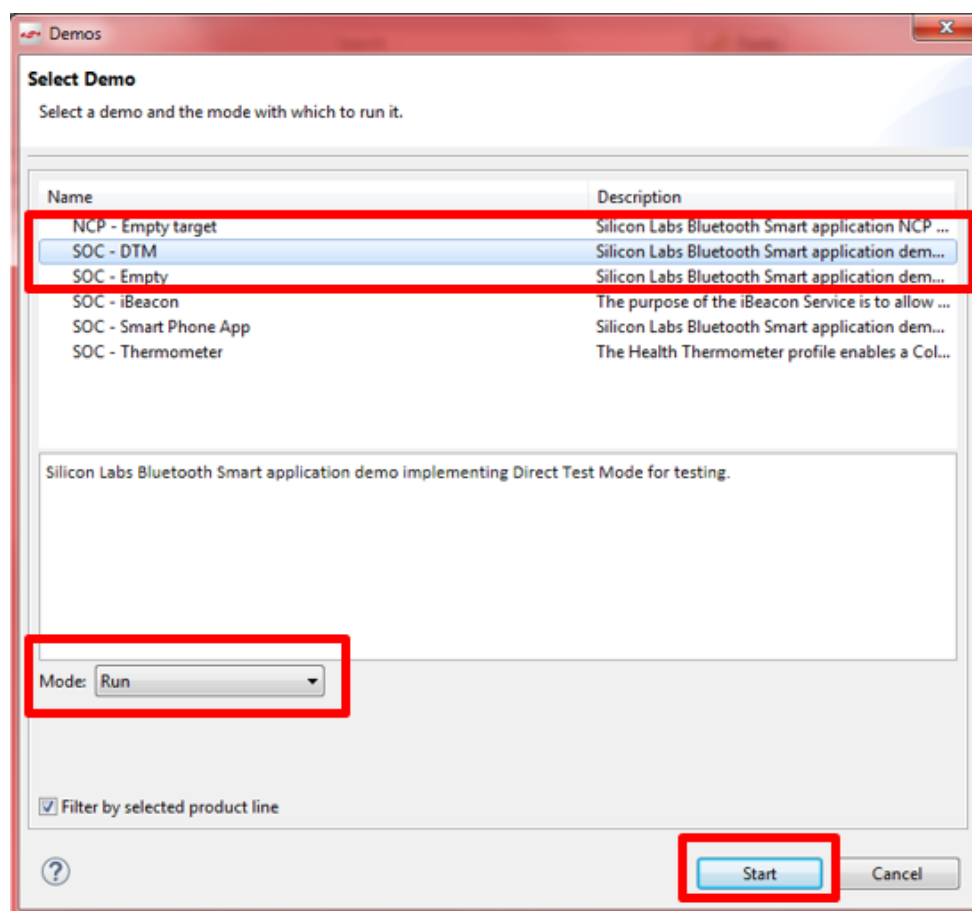


Figure 4.2. Confirming the DTM 2-wire Firmware Demo

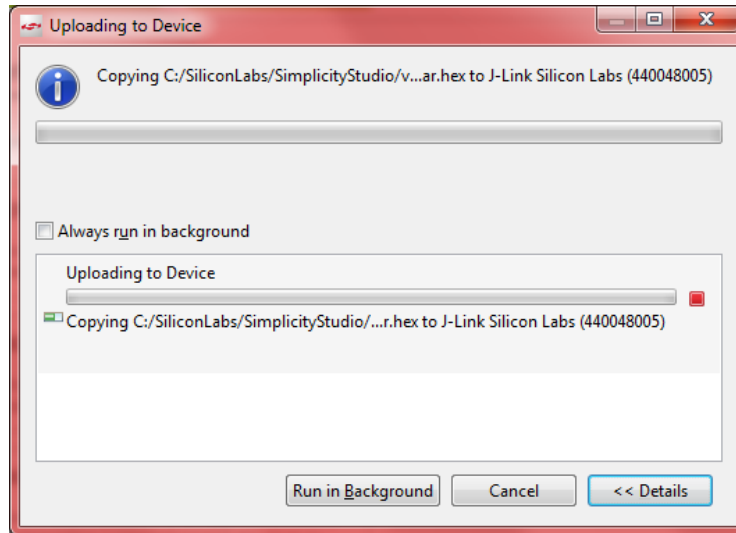


Figure 4.3. Upload in Progress

4.2 Connecting and Testing with the Bluetooth tester

With the demo firmware installed, the DUT is ready to be wired to the Bluetooth tester, as shown in the following figure. Testing can be carried on at the Upper Tester interface, normally through PC software, as shown in the example using Anritsu MT8852B as the Bluetooth tester (Figure 4.5 Connecting the Upper Tester to the DUT on page 13 to Figure 4.7 Receiver Measurements (PER) on page 15).

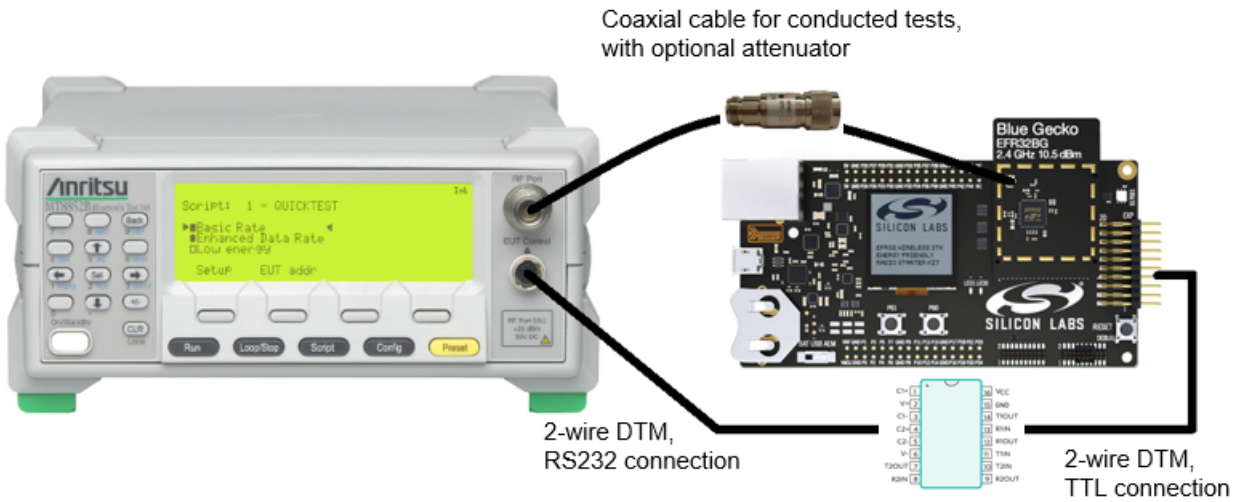


Figure 4.4. Connecting the Bluetooth Tester to the WSTK

First, establish the connection to the DUT with the correct parameters, as highlighted in the following figure.

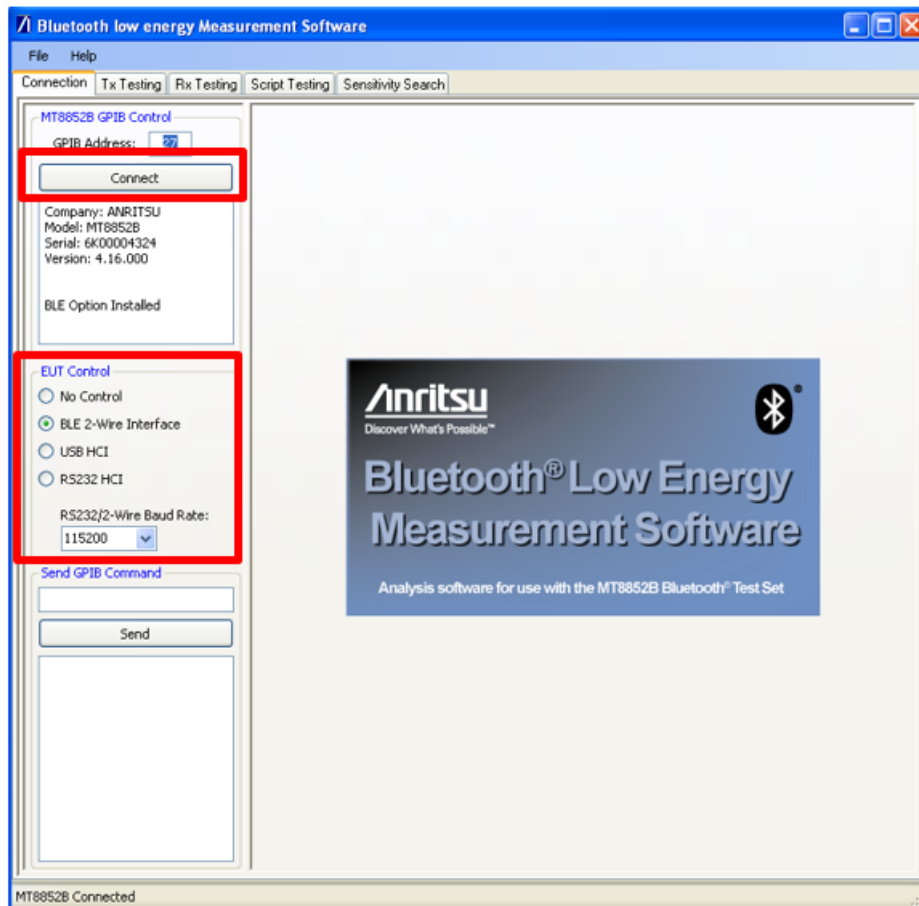


Figure 4.5. Connecting the Upper Tester to the DUT

Next, pre-existing or custom scripts can be used to start a suite of tests, as shown in the following figure. In the same figure the test report is displayed by the tester PC program, after the automated tests have completed, with an overall result of "Passed". Notice also

the **Fixed Offset** field in the **Script Setup** box, which can be used to compensate for power loss, for example over the coaxial antenna cable in the case of conducted RF tests.

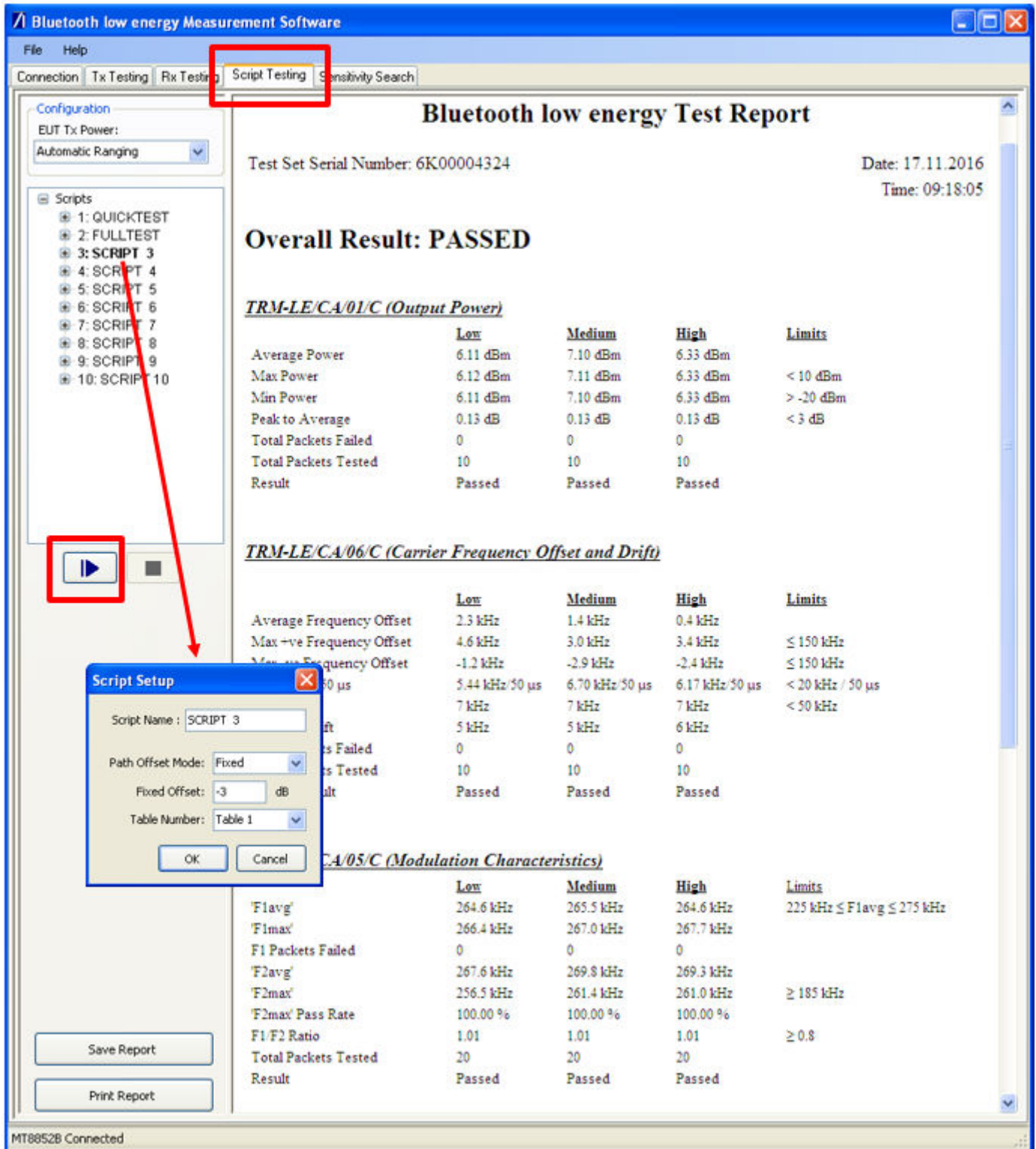


Figure 4.6. Launching a Suite of Tests / Test Results

Any commercial Bluetooth tester should be capable of testing among others the Packet Error Rate (PER). In this test configuration, the Upper Tester first configures the DUT into receiving mode using the appropriate DTM 2-wire command (step 2 in the figure below after the test configuration by the user in step 1), and then the Upper Tester starts sending a defined number of packets at the RF TX power level configured by the user (step 3). When the test is ended by the user (step 4), the corresponding DTM 2-wire command is also sent to the DUT and, much as in the BGAPI `test_dtm_completed` event discussed earlier, the DUT reports over the 2-wire link the number of received packets so that the Upper Tester can calculate the PER, all according to the specification.

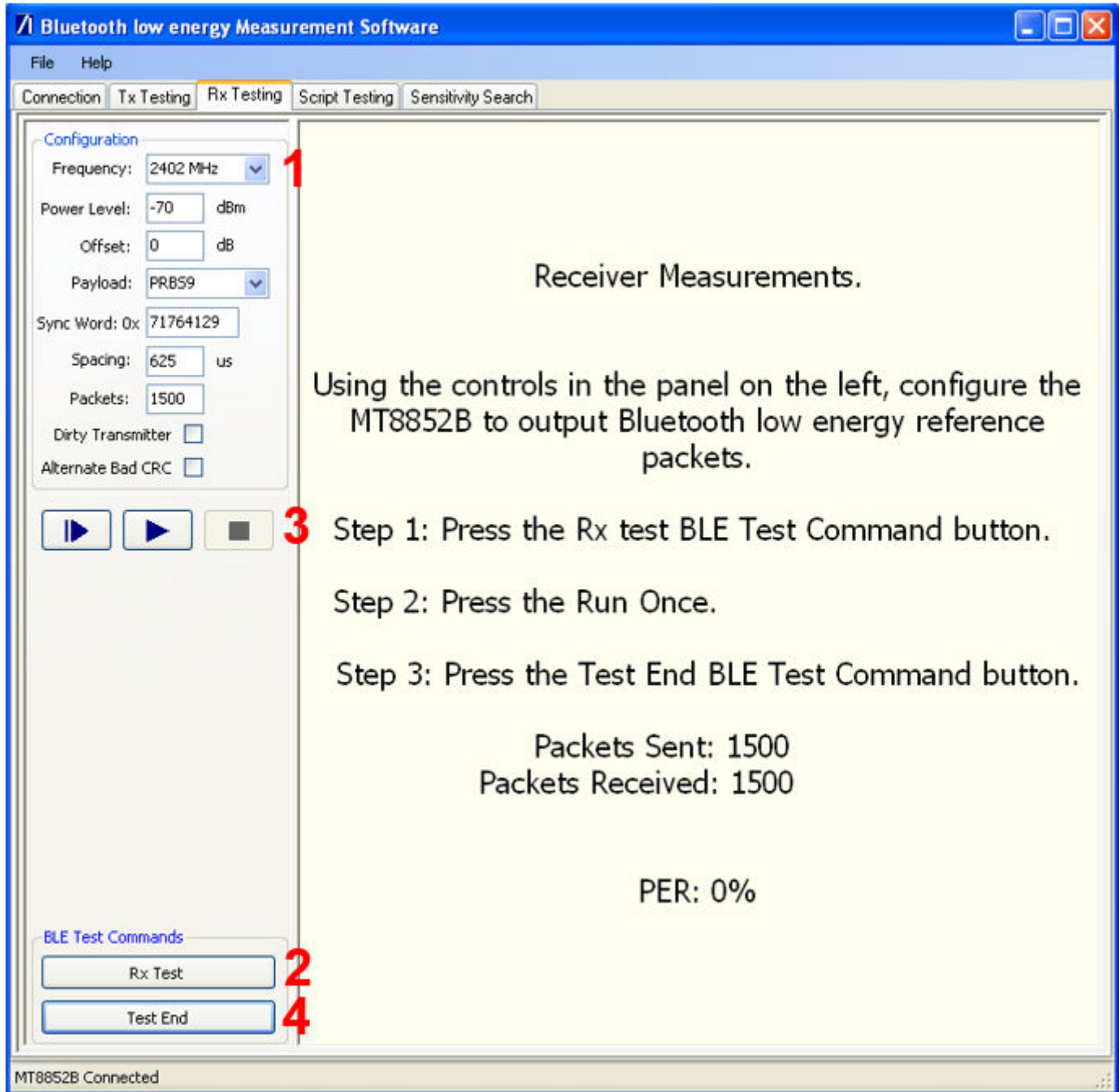


Figure 4.7. Receiver Measurements (PER)

4.3 Testing Equipment Considerations

Certain Bluetooth testers, like the Anritsu MT8852B mentioned in this application note, use RS232 interfaces to connect to a DUT for the DTM 2-wire, meaning that, when testing with the demo firmware and a WSTK, for example, a level shifter is needed in order to interface to the device's TTL logic.

Certain Bluetooth testers have no capability to generate RF signals with a power lower than a certain value, for example -90 dBm in the case of the Anritsu MT8852B mentioned in this application note. Given that modern SoCs/modules have a receiver sensitivity going well below that, an attenuator might be required for appropriate testing, to further decrease the power of a signal directed to the device in receiving test mode.

4.4 Customizing the SOC - DTM Application

To configure the device to use other pins and other settings for the 2-wire UART, instead of selecting the precompiled application under Demos in Simplicity Studio's Launcher perspective, select the source *SOC - DTM* under the Software Examples column. The Simplicity IDE perspective opens and a new project is started, allowing the creation of custom firmware implementing the desired hardware configuration.

Beginning with firmware/SDK version 2.6.0.0 the Hardware Configurator is removed and any hardware re-configuration should be made in accordance to the guidelines in the “Example Project Walkthrough” chapter from *AN1042: Using the Silicon Labs Bluetooth® Stack in Network Co-Processor Mode*.

If you are working in earlier SDK versions (before 2.6.0.0), at this point the Hardware Configurator shown in the following figure can be used to re-configure the UART pin mapping, while parameters such as the baud rate, for example, can be re-configured by editing the `InitDevice.c` source file as shown in [Figure 4.9 Editing the InitDevice.c in the Simplicity IDE on page 18](#), or through the Hardware Configurator's other view, shown in [Figure 4.10 Hardware Configurator in Simplicity Studio v4 / UART Properties on page 19](#).

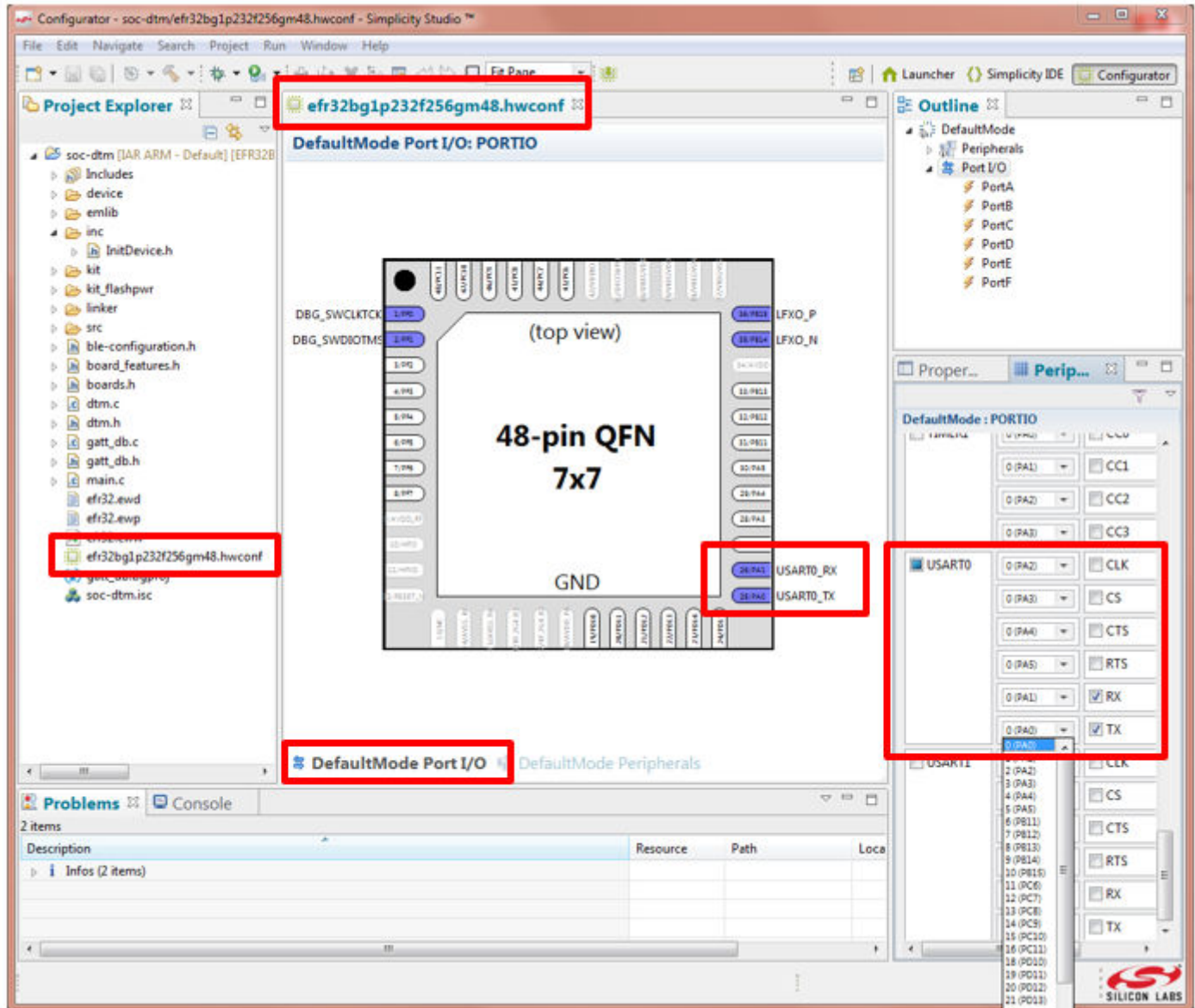


Figure 4.8. Hardware Configurator in Simplicity Studio v4 / UART Pin Mapping

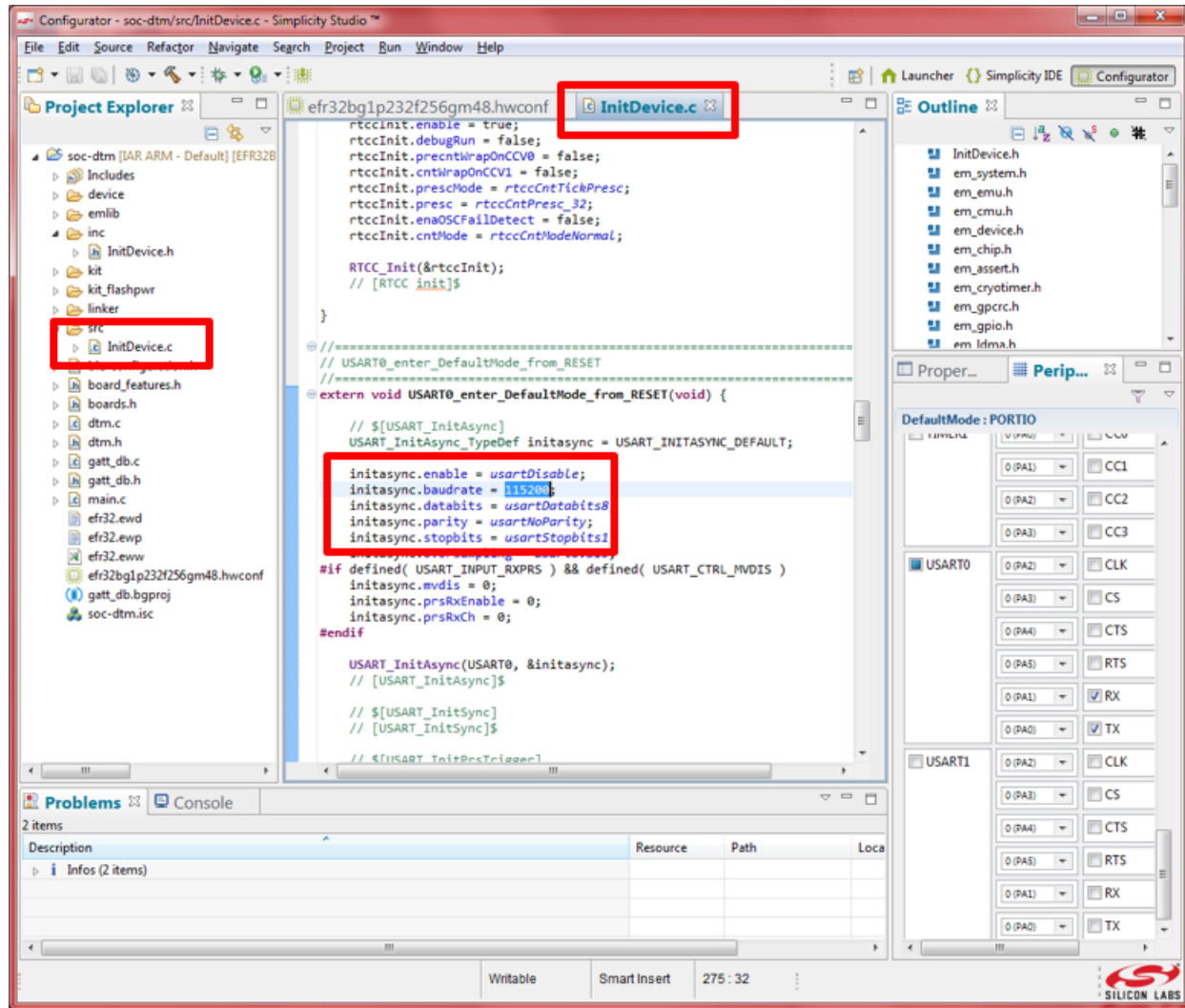


Figure 4.9. Editing the InitDevice.c in the Simplicity IDE

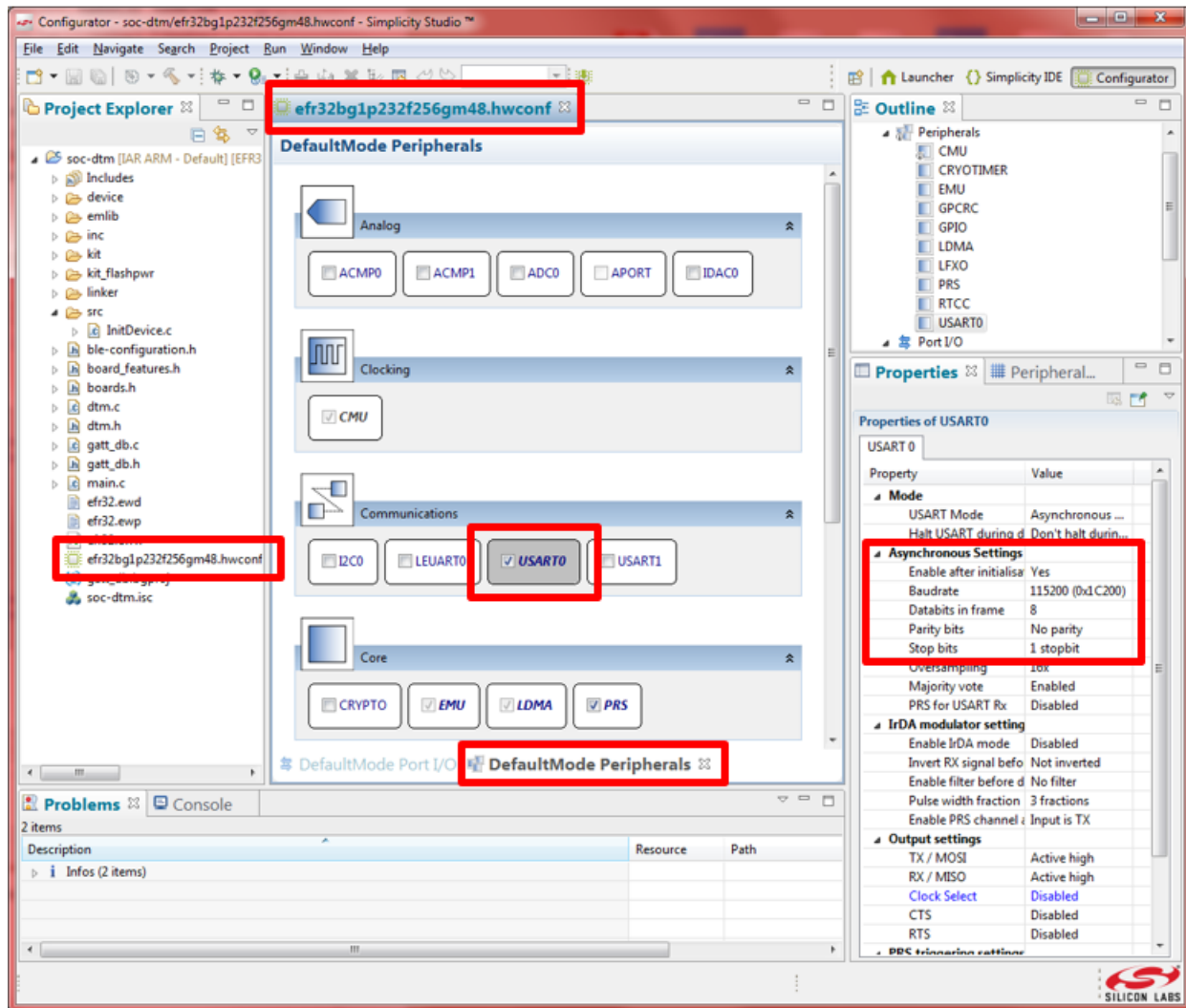


Figure 4.10. Hardware Configurator in Simplicity Studio v4 / UART Properties

In the Simplicity Studio screenshot shown in [Figure 4.1 DTM 2-Wire Firmware from Simplicity Studio v4 Launcher Perspective on page 10](#), a WSTK with a radio board carrying an EFR32BG was attached to the PC. More often a custom design is used instead, and this is obviously not recognized by the Silicon Labs' software. In this case, no demos or software examples will appear in the Simplicity Studio's Launcher perspective. However, the SOC – DTM software example can be used for this case as well, and it can be made available as seen in the following figures.

1. Under My Products, select a product. Start entering a product name to see a matching list of items.

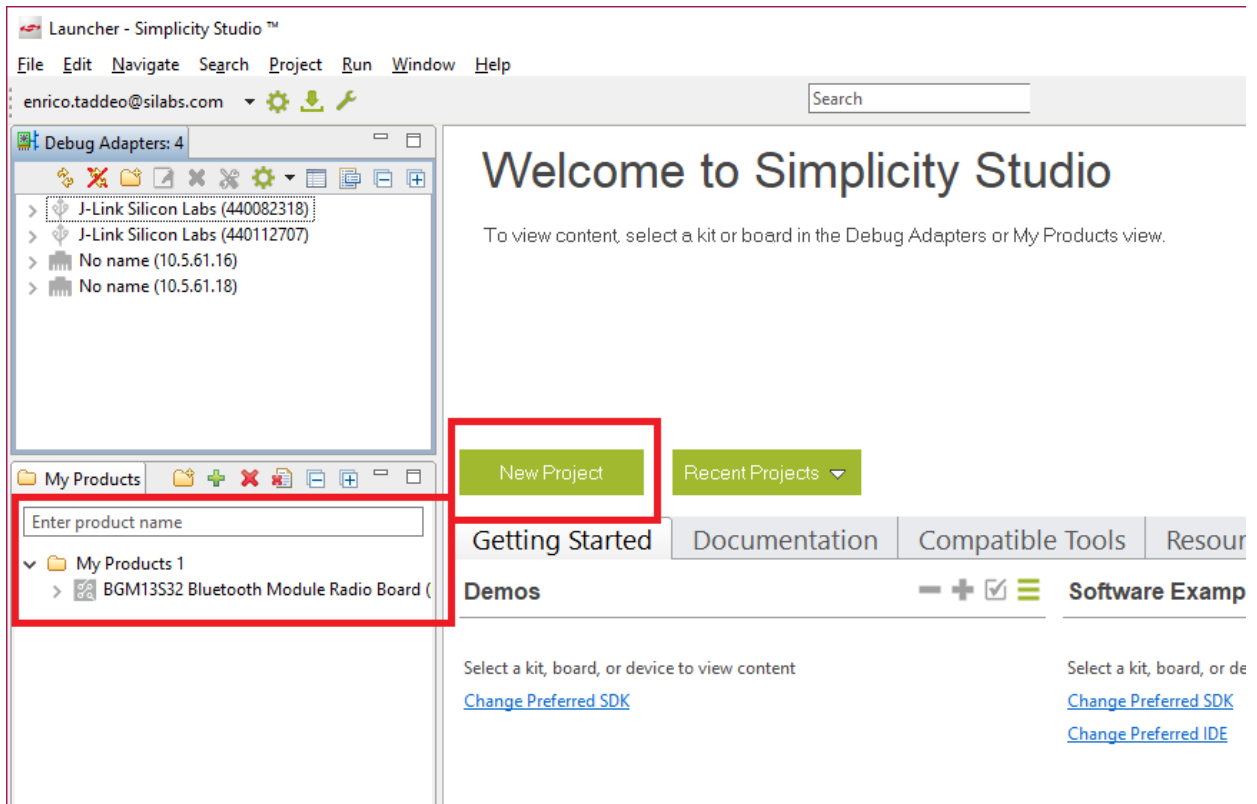


Figure 4.11. Adding the SoC or the Module in a Custom Design

2. Click [New Project].
3. Select the Bluetooth SDK.

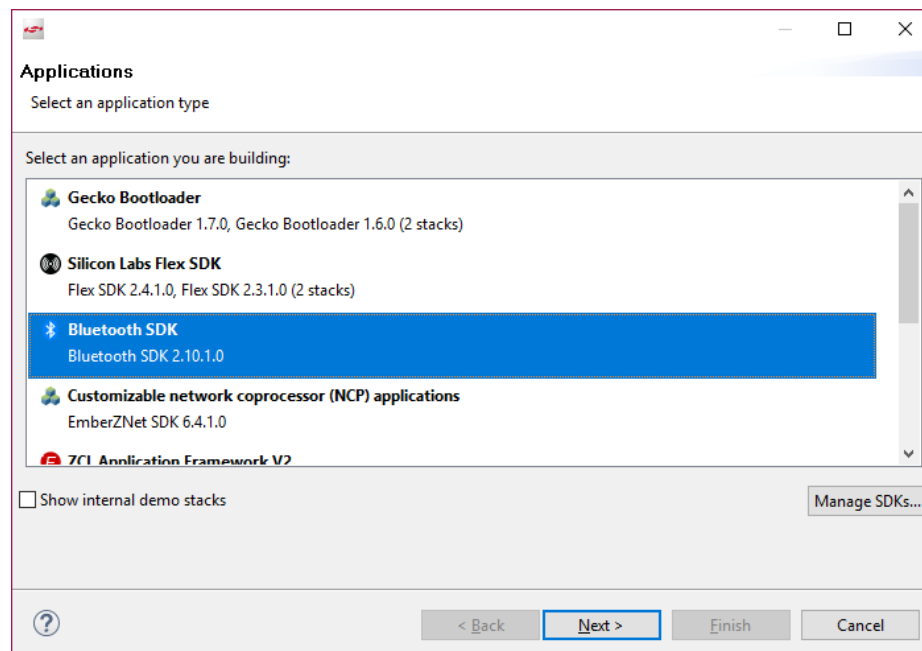


Figure 4.12. Selecting the New Project's Framework or SDK

4. Select the SOC - DTM example.

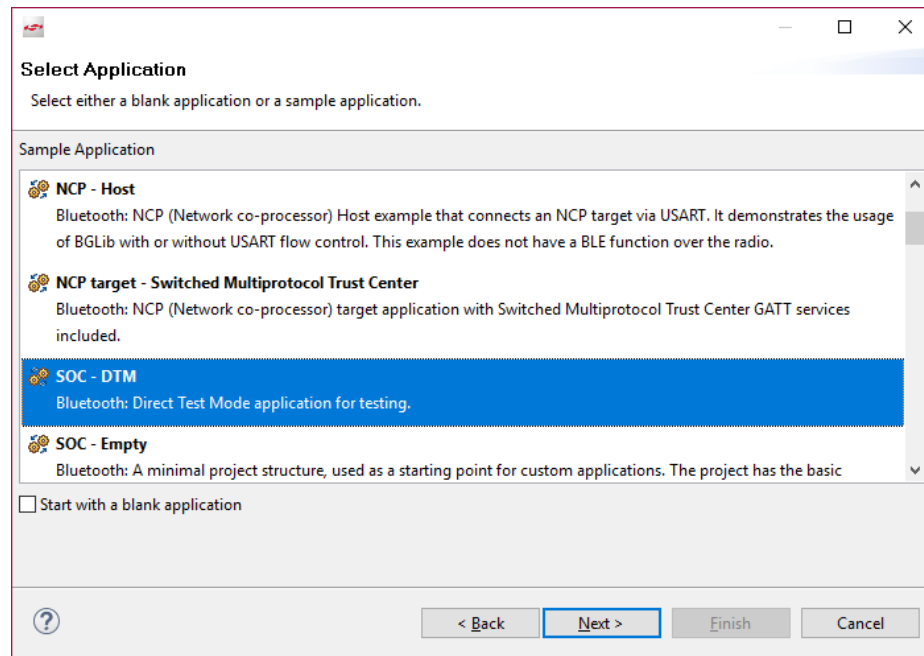


Figure 4.13. Selecting the SOC – DTM Application for a Custom Design

5. You are now in the IDE perspective, with a view similar to the one shown in [Figure 4.9 Editing the InitDevice.c in the Simplicity IDE on page 18](#).

5. Test Examples with the BGAPI Commands `test_dtm_tx` and `test_dtm_rx`

5.1 Output Power—TP/TRM-LE/CA/BV-01-C

The power basic measurement is used to make all of the output power measurements.

In this example, the `test_dtm_tx` command is used.

In this test mode, only the frequency and the output power are configurable parameters.

A spectrum analyzer is used to measure the power of the radio and must be connected through a compatible RF cable to the RF connector of the radio board.

It is also possible to test the output power with a separate Bluetooth tester device when the DTM firmware is installed in the DUT.

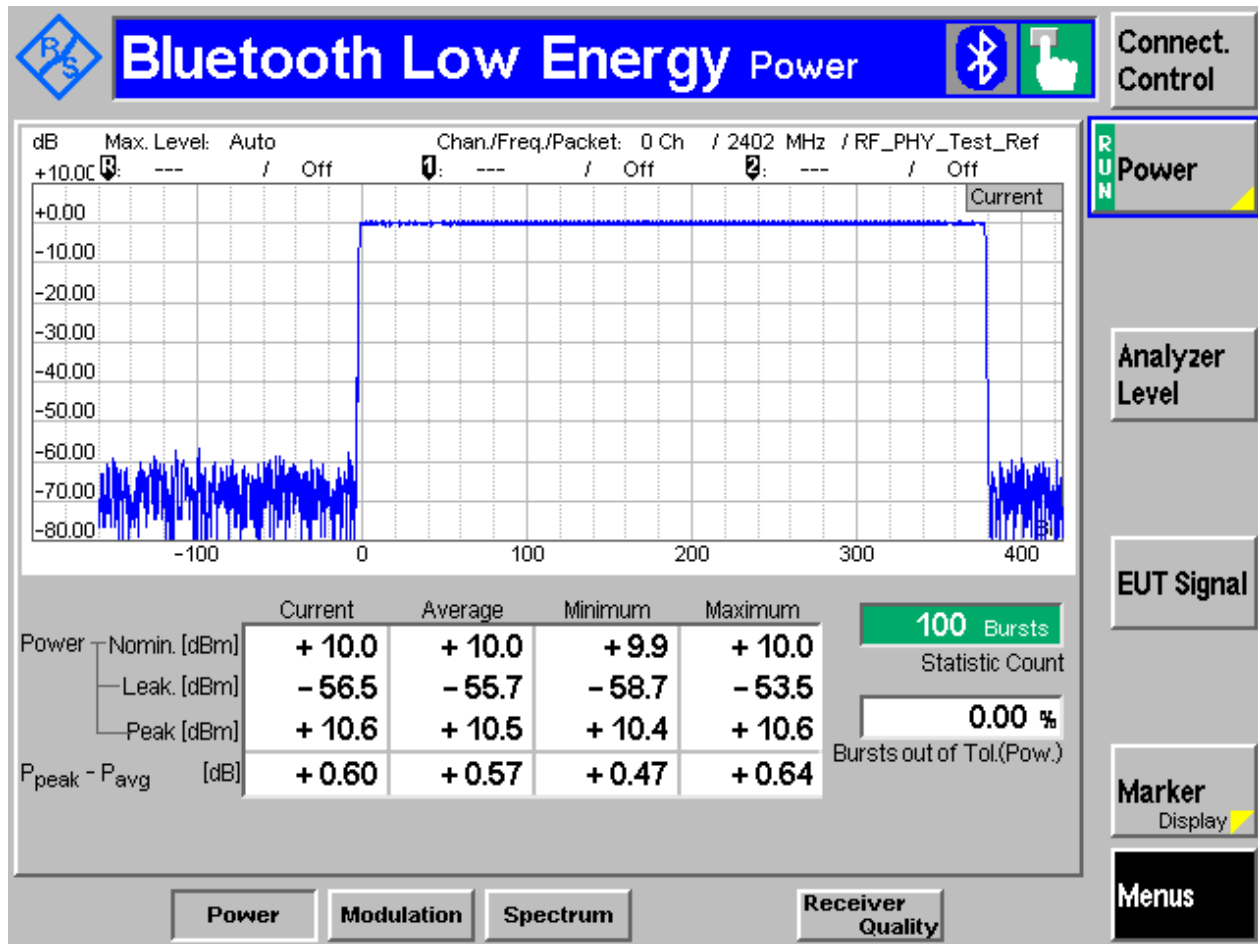


Figure 5.1. Output Power Measurement with the Rohde & Schwarz CBT Bluetooth Tester

5.2 Modulation—TP/TRM-LE/CA/BV-05-C and TP/TRM-LE/CA/BV-06-C

Used to make the modulation, and frequency offset and drift measurements.

In this example, the `test_dtm_tx` command is used.

To follow the test specification, you need to be able to change your payload data pattern (either 1010 pattern or 11110000 pattern).

A spectrum analyzer is used to measure the modulation, frequency offset, and drift measurements of the radio and must be connected through a compatible RF cable to the RF connector of the radio board.

It is also possible to test by using a separate Bluetooth tester device provided that the DTM firmware is installed in the DUT.

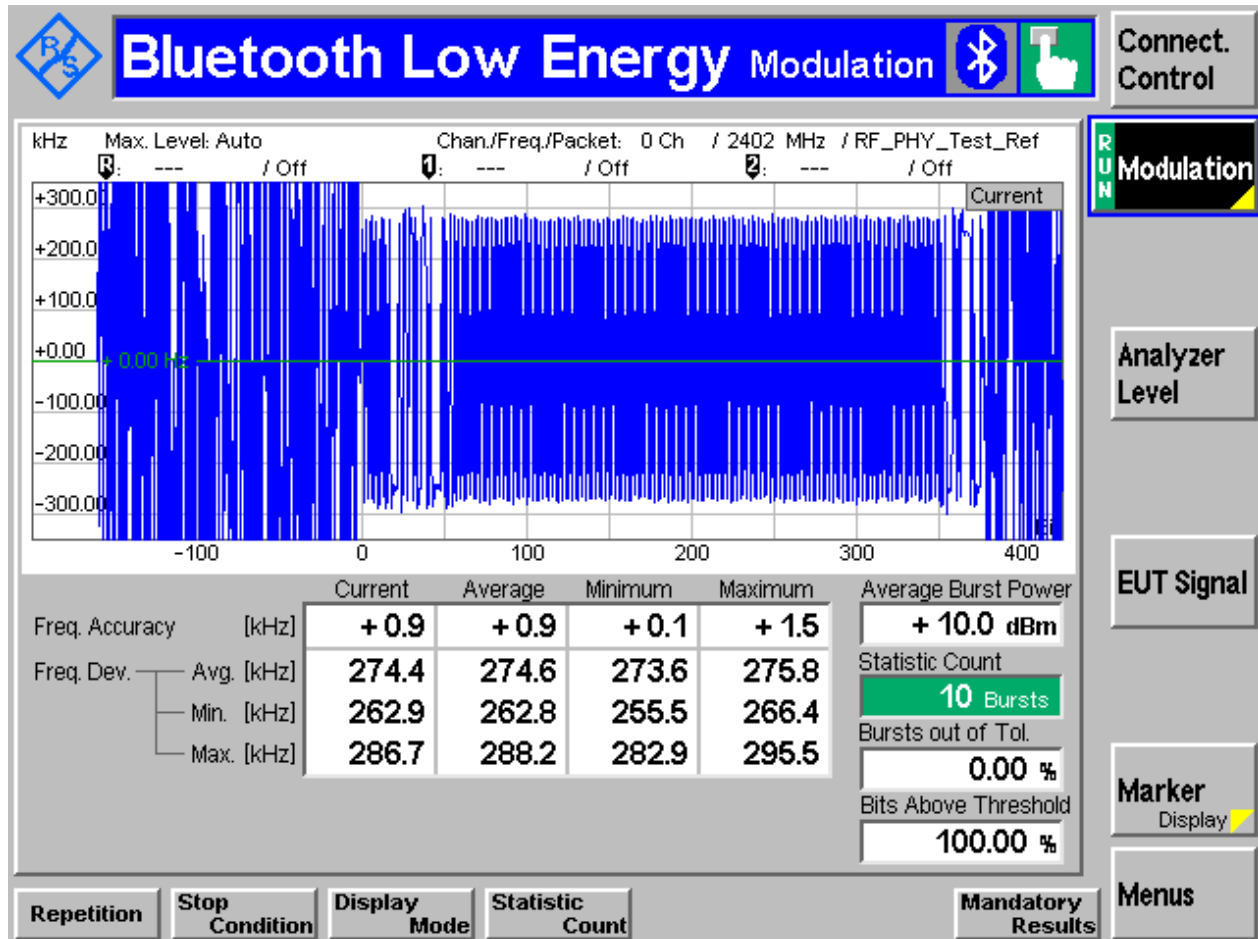


Figure 5.2. Modulation Characteristics

5.3 Spectrum—TP/TRM-LE/CA/BV-03-C

Used for in-band emissions measurements.

In this example, the `test_dtm_tx` command is used.

A spectrum analyzer is used to measure the spectrum of the radio and must be connected through a compatible RF cable to the RF connector of the radio board.

It is also possible to use a separate Bluetooth tester device provided that the DTM firmware is installed in the DUT.

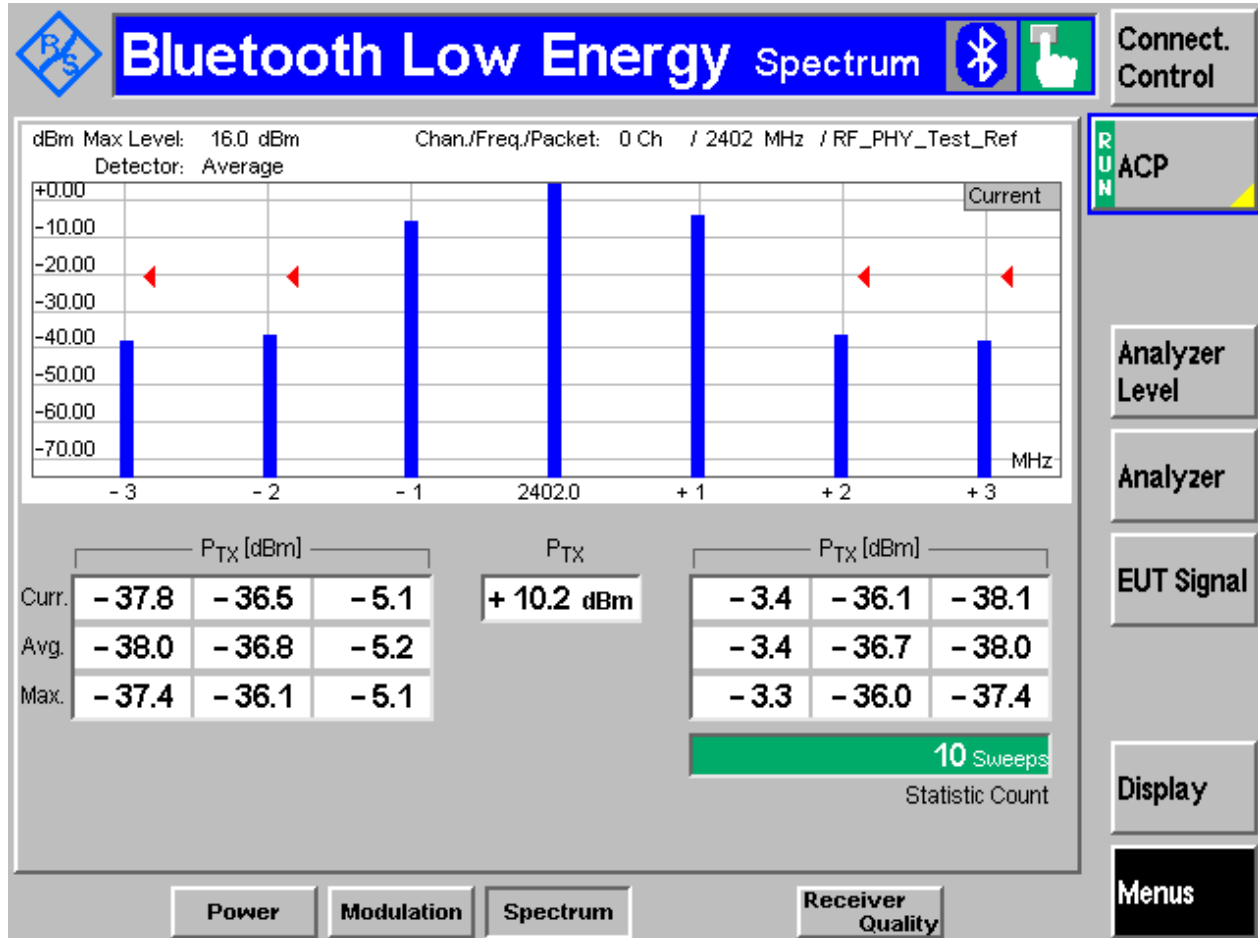


Figure 5.3. Spectrum Test

5.4 Receiver Tests

Used to make all of the sensitivity-based measurements, as well as blocker measurements.

In this example, the `test_dtm_rx` command is used. In BGTool the test is started by selecting **Low energy receive** and then pressing the **Start test** button.

A spectrum analyzer and two RF generators are used to validate the receiver tests and must be connected through a compatible RF cable to the RF connector of the radio board.

A separate Bluetooth tester device can be used, but you might have to consider adding to it an external signal generator to provide the second interferer or blocker signal.

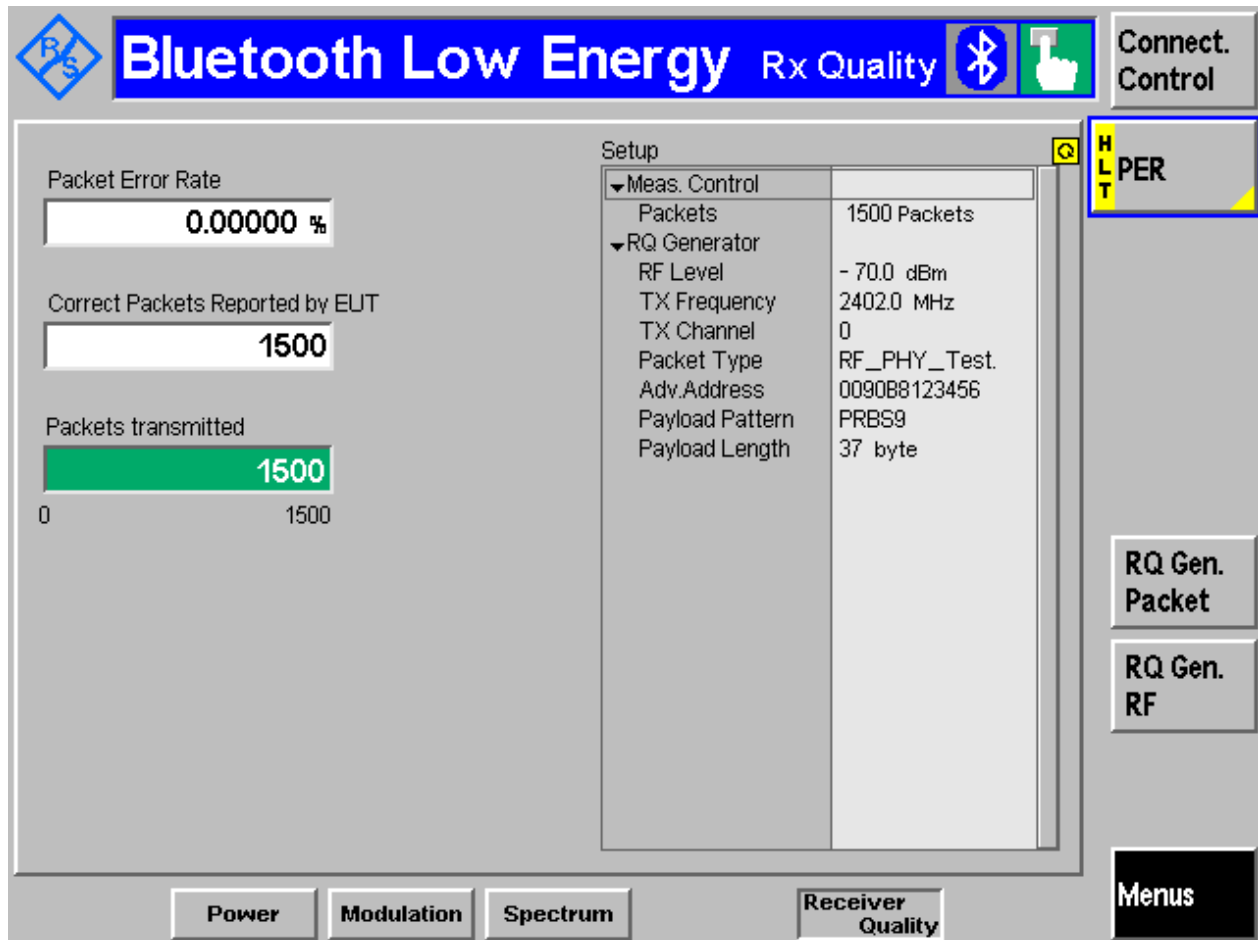


Figure 5.4. Receiver Test

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