DIRECT TEST MODE

This Part describes the Direct Test Mode for RF PHY testing of Bluetooth Low Energy devices.

CONTENTS

1 INTRODUCTION

Direct Test Mode is used to control the Device Under Test (DUT) and provides a report back to the Tester.

Direct Test Mode shall be set up using one of two alternate methods:

1. over HCI (as defined in Section 2) or
2. through a 2-wire UART interface (as defined in Section 3)

Each DUT shall implement one of the two Direct Test Mode methods in order to test the Low Energy PHY layer. Figure 1.1 illustrates the alternatives for Direct Test Mode setup.

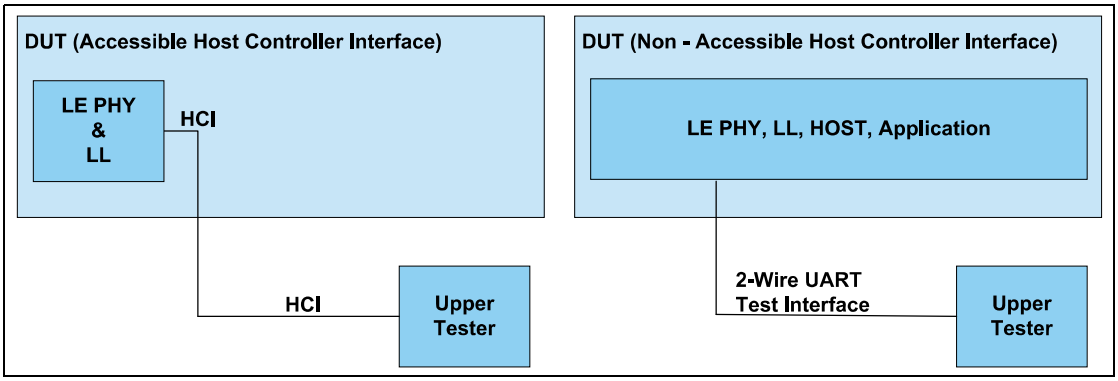

Figure 1.1: Setup alternatives for LE Direct Test Mode: Designs with accessible HCI (left) and designs without accessible HCI (right)

Figure 1.2 illustrates the Bluetooth LE Direct Test Mode setup principle using a 2-wire UART interface.

Figure 1.2: RF PHY test setup for Direct Test Mode (UART control)

2 LOW ENERGY TEST SCENARIOS

2.1 TEST SEQUENCES

These sequences are used as routines and used to control an LE DUT with an accessible HCI or a 2-wire UART interface for RF testing.

The following mapping shall be performed from the RF testing commands to HCI commands and events or 2-wire UART commands and events:

RF Test command / event	HCI command / event	2-wire UART command / event
LE_Transmitter_Test command	HCI_LE_Transmitter_Test command	LE_Transmitter_Test command
LE_Receiver_Test command	HCI_LE_Receiver_Test command	LE_Receiver_Test command
LE_Test_End command	HCI_LE_Test_End command	LE_Test_End command
LE_Status event	HCI_Command_Complete event	LE_Test_Status event
LE_Packet_Report event	HCI_Command_Complete event	LE_Packet_Report event

Table 2.1: Mapping table of HCI / 2-wire UART commands and events

The HCI commands and events used in Direct Test Mode are defined in [Vol 2] Part E, Section 7.8.

2.2 MESSAGE SEQUENCE CHARTS

Transmitter Test

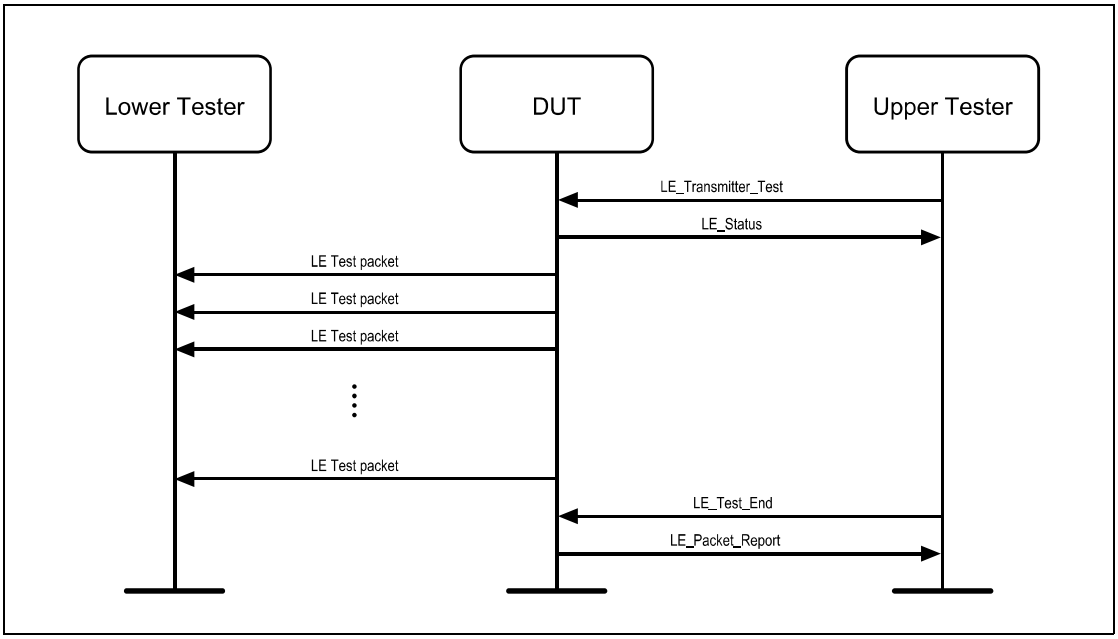

Figure 2.1: Transmitter Test MSC

Receiver Test

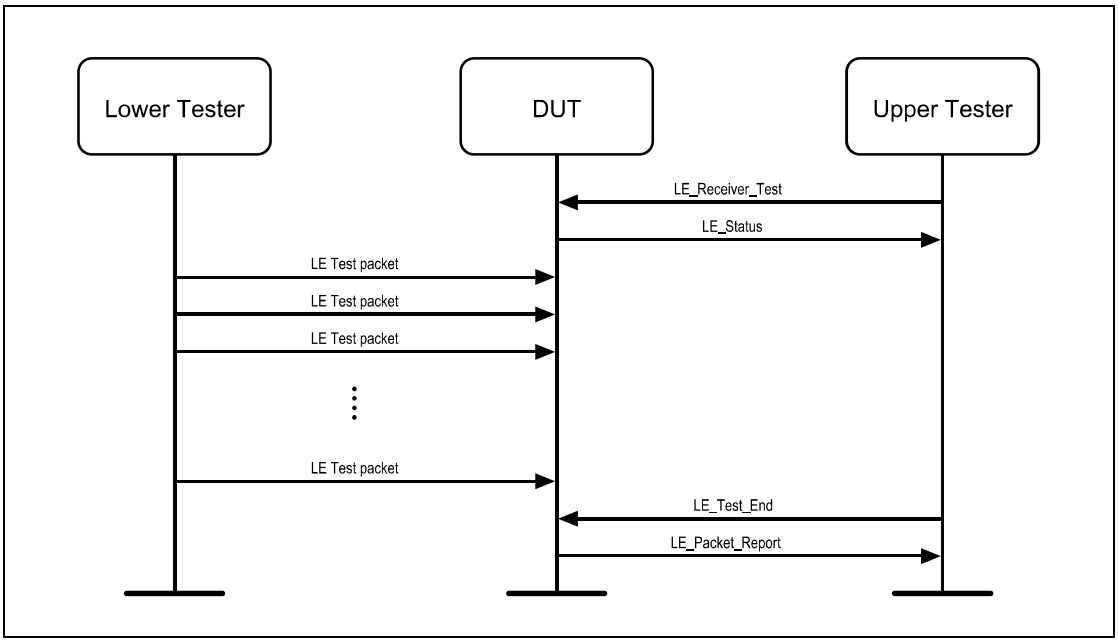

Figure 2.2: Receiver Test MSC

3 UART TEST INTERFACE

3.1 UART INTERFACE CHARACTERISTICS

The UART interface characteristics shall be set to use the following parameters:

- Baud rate: One of the following shall be supported by the DUT:
  1200, 2400, 9600, 14400, 19200, 38400, 57600, 115200
- Number of data bits: 8
- No parity
- 1 stop bit
- No flow control (RTS or CTS)

3.2 UART FUNCTIONAL DESCRIPTION

The Upper Tester shall always initiate any a test scenario using the UART interface. The DUT shall respond to the commands from the Upper Tester.

The Upper Tester sends test commands to the DUT. The DUT shall respond with a test status event or packet report event.

The Upper Tester shall not transmit further commands before it receives a response from the DUT. If the Upper Tester does not receive a response from the DUT within the time $t_{TIMEOUT}$, the Upper Tester shall transmit a reset command (i.e., a test setup command with the control argument set to 0x00) to the DUT and display an appropriate error message. For the reset command, $t_{RESPONSE}$ and $t_{TIMEOUT}$ do not apply.

On reception of a reset command, the DUT shall reset all parameters to their default state.

Definitions

- All commands and events consist of 16 bits (2 bytes).
- The most significant bit is bit number 15.
- The least significant bit is bit number 0.
- The most significant byte is from bit 15 to 8.
- The least significant byte is from bit 7 to 0.
- Commands and events are sent most significant byte (MSB) first, followed by the least significant byte (LSB).

3.3 COMMANDS AND EVENTS

3.3.1 Command and event behavior

Table 3.1 outlines the set of commands which can be received by the DUT and the corresponding response events that can be transmitted by the DUT.

Command (DUT RXD)	Event (DUT TXD)
LE_Test_Setup	LE_Test_Status SUCCESS LE_Test_Status FAIL
LE_Receiver_Test	LE_Test_Status SUCCESS LE_Test_Status FAIL
LE_Transmitter_Test	LE_Test_Status SUCCESS LE_Test_Status FAIL
LE_Test_End	LE_Packet_Report LE_Test_Status FAIL

Table 3.1: 2-Wire command and event behavior

3.3.2 Commands

Command packet formats are shown in Figure 3.1 and Figure 3.2.

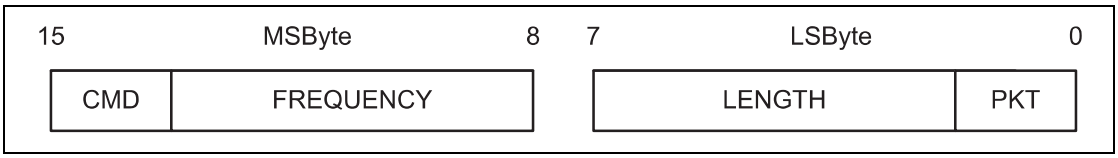

Figure 3.1: Command message format for LE_Transmitter_Test and LE_Receiver_Test commands

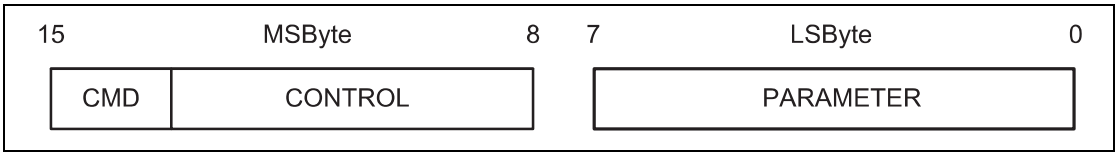

Figure 3.2: Command message format for LE_Test_Setup and LE_Test_End commands

CMD (command): *Size: 2 bits*

Value b_1b_0	Parameter Description
00	LE_Test_Setup command
01	LE_Receiver_Test command
10	LE_Transmitter_Test command
11	LE_Test_End command

Test Setup command: *Size: 14 bits*

Control (6 bits)	Parameter (8 bits)	Description
0x00	0x00 - 0x03	RESET; the upper 2 bits of the data length for any LE_Transmitter_Test or LE_Receiver_Test commands following are set to 00, the PHY is set to LE 1M, the receiver assumes the transmitter has a standard modulation index, and no Constant Tone Extension is present.
	Any other value	Reserved for future use
0x01	0x00 – 0x0F	Set the upper 2 bits of the data length for any LE_Transmitter_Test or LE_Receiver_Test commands following to bits 2 and 3 of the parameter (to enable a length greater than 0x3F to be used)
	Any other value	Reserved for future use
0x02	0x04 - 0x07	PHY set to LE 1M
	0x08 - 0x0B	PHY set to LE 2M
	0x0C - 0x0F	PHY set to LE Coded; transmitter is to use S=8 data coding
	0x10 - 0x13	PHY set to LE Coded; transmitter is to use S=2 data coding
	Any other value	Reserved for future use
0x03	0x00 - 0x03	Receiver assumes transmitter has a standard modulation index
	0x04 - 0x07	Receiver assumes transmitter has a stable modulation index
	Any other value	Reserved for future use
0x04	0x00 - 0x03	Read the test case supported features. The LE_Test_Status event will return the state of the test case supported features as detailed in the LE_Test_Status event (Section 3.4.1).
	Any other value	Reserved for future use

Control (6 bits)	Parameter (8 bits)	Description
0x05	0x00 - 0x03	Read supportedMaxTxOctets (see [Vol 6] Part B, Section 4.5.10)
	0x04 - 0x07	Read supportedMaxTxTime (see [Vol 6] Part B, Section 4.5.10)
	0x08 - 0x0B	Read supportedMaxRxOctets (see [Vol 6] Part B, Section 4.5.10)
	0x0C - 0x0F	Read supportedMaxRxTime (see [Vol 6] Part B, Section 4.5.10)
	0x10	Read maximum length of Constant Tone Extension supported
	Any other value	Reserved for future use
0x06	0x00	No Constant Tone Extension
	Any other value	CTEInfo (see [Vol 6] Part B, Section 2.5.2)
0x07	0x01	Sample Constant Tone Extension with 1 µs slots
	0x02	Sample Constant Tone Extension with 2 µs slots
	Any other value	Reserved for future use
0x08	Bits 0 to 6: 0x01 – 0x4B	Number of antennae in the antenna array
	Any other value	Reserved for future use
	Bit 7: 0	Antenna switching pattern A: 1, 2, 3, …, n, 1, 2, 3, …, n, … (where n is the number of antennae in the antenna array)
	1	Antenna switching pattern B: 1, 2, 3, …, n, n-1, n-2, …, 1, … (where n is the number of antennae in the antenna array)

If an AoD Constant Tone Extension is selected when transmitting, Control 0x08 shall be used before starting the test. If an AoA Constant Tone Extension is selected when receiving, Controls 0x07 and 0x08 shall be used before starting the test.

Control 0x07 does not affect receiving AoD Constant Tone Extensions or any transmissions. Control 0x08 does not affect transmitting AoA Constant Tone Extensions or receiving AoD Constant Tone Extensions.

In the receiver test, the CTEInfo field specified using Control 0x06 indicates the expected type and length of the Constant Tone Extension. If either the length or type of the Constant Tone Extension in a received LE Test packet does not match the expected value, then the DUT shall discard that packet.

LE_Test_End command: *Size: 14 bits*

Control (6 bits)	Parameter (8 bits)	Description
0x00	0x00 - 0x03	LE_Test_End command
0x00	Any other value	Reserved for future use
0x01 – 0x3F	Any value	Reserved for future use

LE_Transmitter_Test and LE_Receiver_Test commands:

Frequency: *Size: 6 bits*

Value	Parameter Description
0x00 – 0x27	The frequency to be used; a value of N represents a frequency of (2N+2402) MHz (the available range is therefore even MHz values from 2402 to 2480 inclusive)
0x28 – 0x3F	Reserved for future use

Length: *Size: 6 bits*

Value	Parameter Description
0x00 - 0x3F	The lower 6 bits of the packet length in bytes of payload data in each packet (the top two bits are set by the LE_Test_Setup command)

PKT (Packet Type): *Size: 2 bits*

Value b_1b_0	Parameter Description
00	PRBS9 Packet Payload
01	11110000 Packet Payload
10	10101010 Packet Payload
11	On the LE Uncoded PHYs: Vendor Specific On the LE Coded PHY: 11111111

3.4 EVENTS

There are two types of events sent by the DUT:

1. LE_Test_Status event
2. LE_Packet_Report event

The event packet format is shown in Figure 3.3. This packet format is used for both LE_Test_Status events and LE_Packet_Report events.

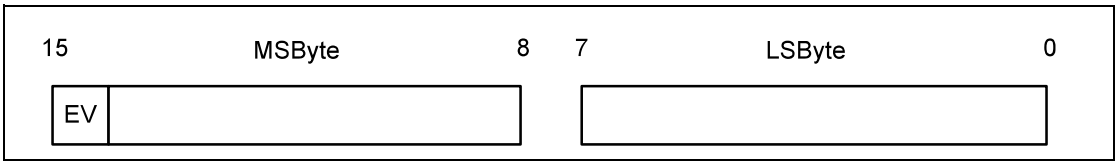

Figure 3.3: Event packet format

EV (event): *Size: 1 bit*

Value	Parameter Description
0	LE_Test_Status event
1	LE_Packet_Report event

3.4.1 LE_Test_Status event

The LE_Test_Status event packet format is as shown in Figure 3.4.

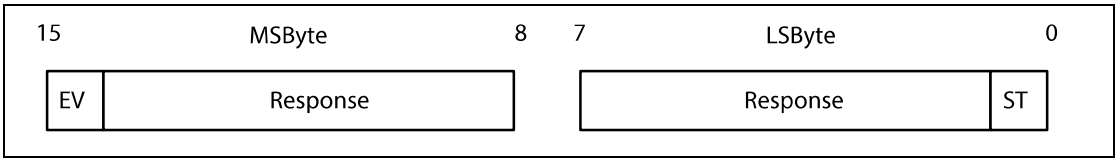

Figure 3.4: LE_Test_Status event

ST (status): *Size: 1 bit*

Value	Parameter Description
0	Success
1	Error

Response[1] *Size: 14 bits*

LE_Test_Setup command control parameter	Value bits 1 to 14[2]	
0x04	Bit 1	LE Data Packet Length Extension feature supported
	Bit 2	LE 2M PHY supported
	Bit 3	Transmitter has a Stable Modulation Index
	Bit 4	LE Coded PHY supported
	Bit 5	Constant Tone Extension supported
	Bit 6	Antenna switching supported
	Bit 7	1 µs switching supported for AoD transmission
	Bit 8	1 µs sampling supported for AoD reception
	Bit 9	1 µs switching and sampling supported for AoA reception
	Bits 10 to 14	Reserved for future use

LE_Test_Set up command control parameter	Value bits 1 to 14[2]	
0x05	Bits 1 to 14	One of the following values (depending on the parameter in the original query): • Maximum transmit or receive time, in microseconds, that the local Controller supports for transmission of a single Link Layer Data Physical Channel PDU, divided by 2. • Maximum number of payload octets that the local Controller supports for transmission of a single Link Layer Data Physical Channel PDU. • Maximum length of the Constant Tone Extension that the local Controller supports for transmission in a Link Layer packet, in 8 µs units. Range: • 0x00A4-0x2148 for times or • 0x001B-0x00FF for number of octets. • 0x02-0x14 for the maximum Constant Tone Extension length All values outside the range are reserved for future use.
All other values		Reserved for future use

1 If the event has a status of "Error" or was generated in response to a command other than LE_Test_Setup, then this field is Reserved for future use.

2 This field is described as having bits 1 to 14 rather than 0 to 13 to avoid confusion.

3.4.2 LE_Packet_Report event

The LE_Packet_Report event packet format is shown in Figure 3.5. The *Packet Count* parameter indicates the number of received LE Test packets. The *Packet Count* in the LE_Packet_Report event ending a transmitter test shall be 0.

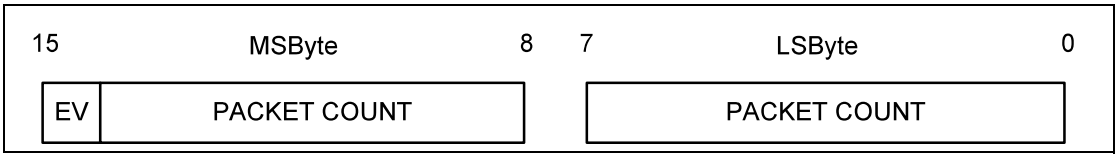

Figure 3.5: LE_Packet_Report event

PACKET COUNT: *Size: 15 bits*

Value	Parameter Description
N	N is the number of packets received Range = 0 to 32767.

Note: The DUT is not responsible for any overflow conditions of the packet count. That responsibility belongs with the RF PHY Tester or other auxiliary equipment.

3.5 TIMING – COMMAND AND EVENT

The timing requirements are as shown in Table 3.2.

Symbol	Parameter	Min.	Max.	Unit
b_{ERR}	Baud rate accuracy		±5	%
t_{MIN}	The time between the first and second byte of the command (end of stop bit to start of start bit)	0	5	ms
$t_{RESPONSE}$	The time from a DUT receiving a command (end of stop bit) until the DUT responds (start of start bit)	0	50	ms
$t_{TURNAROUND}$	The time from when the tester receives a response (end of stop bit) until the tester sends another command (start of start bit)	5	-	ms
$t_{TIMEOUT}$	The time from when a tester sends a command (end of stop bit) until the tester times out (not having received end of the stop bit in the response)	51	100	ms

Table 3.2: Parameter requirements table for 2-wire UART interface

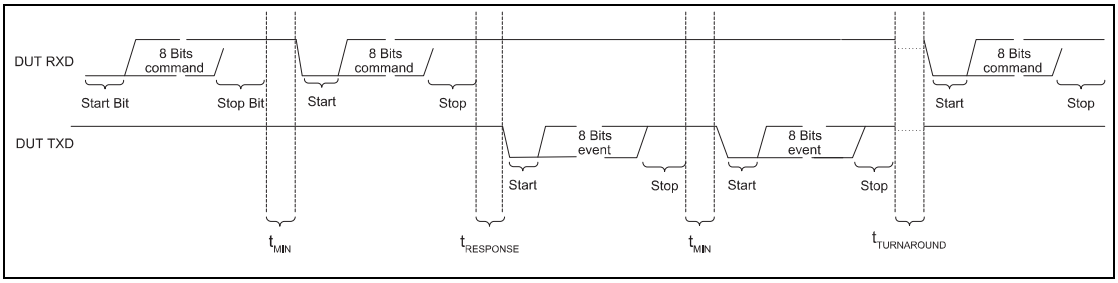

Figure 3.6: Command and event timing on 2-wire UART interface

The commands and events shall be transmitted with two 8-bit bytes with a maximum time between the 2 transmissions. A timeout is required for no response or an invalid response from the DUT.

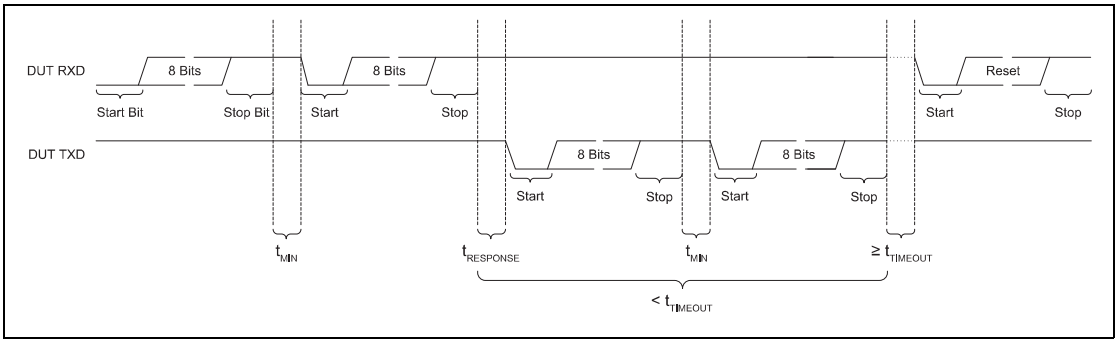

Figure 3.7: Command and event timing on 2-wire UART interface showing timeout

4 LE TEST PACKET DEFINITION

4.1 LE TEST PACKETS FORMAT

The LE Test packet format for the LE Uncoded PHYs shall be as shown in Figure 4.1. The LE Test packet format for the LE Coded PHY shall be as shown in Figure 4.2. LE test packets are required for LE RF PHY conformance testing using Direct Test Mode. Except as modified by this section, the LE Test packet formats shall be identical to the formats specified in [Vol 6] Part B, Section 2.1 and [Vol 6] Part B, Section 2.2.

Depending on the test, the packet payload content may vary

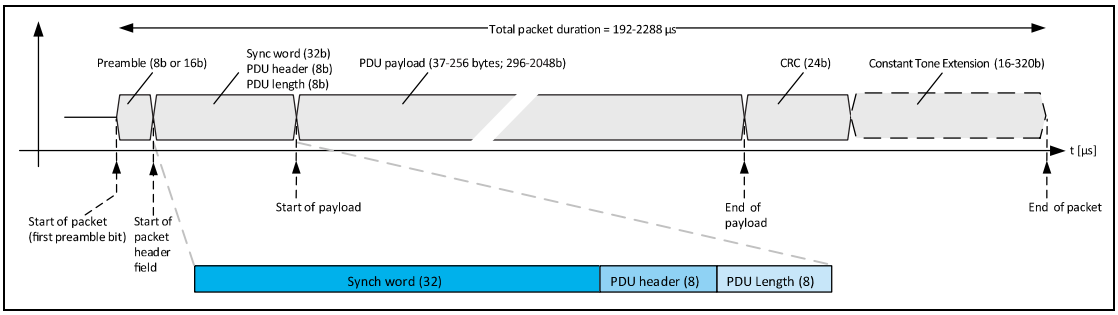

Figure 4.1: LE Test packet format for the LE Uncoded PHYs

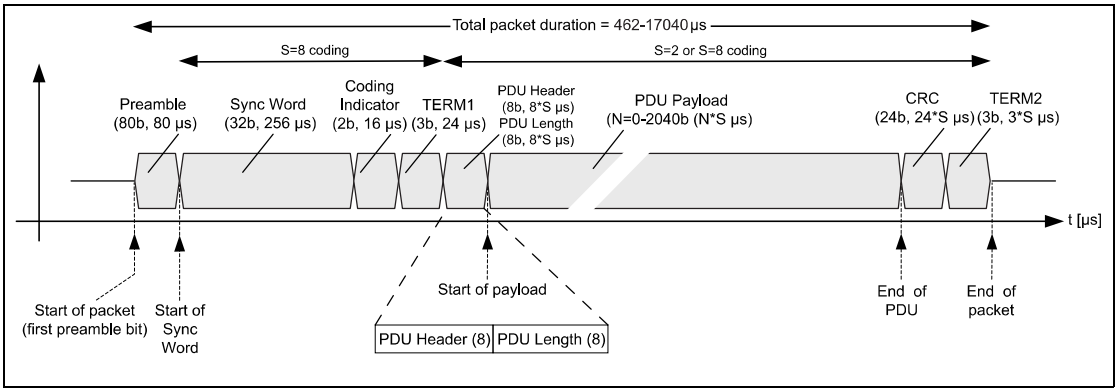

Figure 4.2: LE Test packet format for the LE Coded PHY

4.1.1 Whitening

LE test packets shall not use whitening.

4.1.2 Preamble and synchronization word

LE test packets shall have ‘10010100100000100110111010001110’ (in transmission order) as the synchronization word. The preamble for all LE test packets is thus ‘10101010’ (in transmission order) when the device under test is configured for the LE 1M PHY, ‘1010101010101010’ (in transmission order)

if the device under test is configured for the LE 2M PHY, and the preamble described in [Vol 6] Part B, Section 2.2.1 if the device under test is configured for the LE Coded PHY.

4.1.3 CRC

The CRC shift register shall be preset with 0x555555 for every LE test packet.

4.1.4 LE Test packet PDU

The LE test packet PDU consists of an 8-bit header, an 8-bit length field, an optional 8-bit CTEInfo field, and a variable size payload. Its structure is as shown in Figure 4.3.

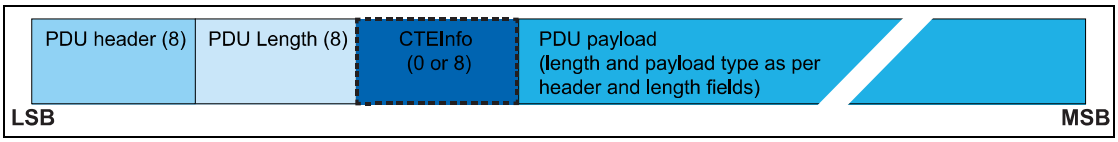

Figure 4.3: LE Test packet PDU structure

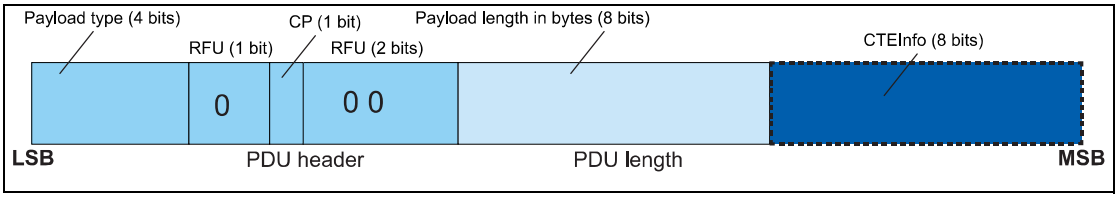

Figure 4.4: LE Test packet header and length field structure

The first four bits of the PDU header field indicate the payload content type as defined in Table 4.1. The CTEInfo Present (CP) field of the PDU header indicates whether the CTEInfo field is present and therefore whether the test packet has a Constant Tone Extension. If the CP field is 0, then no CTEInfo field is present and there is no Constant Tone Extension in the test packet. If the CP field is 1, then the CTEInfo field is present and the test packet includes a Constant Tone Extension. The CTEInfo field is defined in [Vol 6] Part B, Section 2.5.2. The length field expresses the Payload length in bytes.

Note: On the LE Coded PHY, this section defines the PDU contents before coding.

Payload type $b_3b_2b_1b_0$	**Payload description**
0000b	PRBS9 sequence '11111111100000111101…' (in transmission order) as described in Section 4.1.5

Table 4.1: LE Test packet PDU header's Type field encoding

Payload type $b_3b_2b_1b_0$	Payload description
0001b	Repeated '11110000' (in transmission order) sequence as described in Section 4.1.5
0010b	Repeated '10101010' (in transmission order) sequence as described in Section 4.1.5
0011b	PRBS15 sequence as described in Section 4.1.5
0100b	Repeated '11111111' (in transmission order) sequence
0101b	Repeated '00000000' (in transmission order) sequence
0110b	Repeated '00001111' (in transmission order) sequence
0111b	Repeated '01010101' (in transmission order) sequence

Table 4.1: LE Test packet PDU header's Type field encoding

Example: For LE test packets with 0x0F payload contents ('11110000' in transmission order) and with an LE test packet payload length of 37 bytes (296 bits), the LE test packet header and length type field will be '1000000010100100' in transmission order.

4.1.5 LE Test packet payload description

The LE test packet payload content alternatives required for the Bluetooth low energy RF PHY conformance tests are:

PRBS9:

A 9-bit pseudorandom binary sequence used for wanted signal payload content. The PRBS9 sequence repeats itself after the (2^9 -1 = 511) bit. The PRBS9 sequence may be generated in a nine stage shift register whose 5^{th} and 9^{th} stage outputs are added in a modulo-two addition stage (see Figure 4.5) and the result is fed back to the input of the first stage. The sequence begins with the first ONE of 9 consecutive ONEs (i.e. the shift register is initialized with nine ONEs).

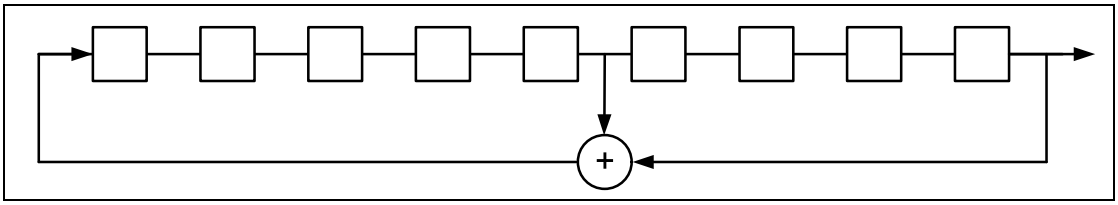

Figure 4.5: Linear feedback shift register for generation of the PRBS9 sequence

The same pseudorandom sequence of bits shall be used for each transmission (i.e. the packet is repeated).

PRBS15:

A 15-bit pseudorandom binary sequence that is used for the interfering signal and can optionally be used for wanted signal payload content. The PRBS15 sequence repeats itself after the (2^{15} -1 = 32767) bit. The PRBS15 sequence may be generated in a fifteen stage shift register whose 14th and 15th stage outputs are added in a modulo-two addition stage (See Figure 4.6) and the result is fed back to the input of the first stage. The sequence begins with the first ONE of 15 consecutive ONEs (i.e., the shift register is initialized with fifteen ONEs).

This PRBS15 definition is consistent with ITU T-REC-01 150-199605-I. SERIES O: SPECIFICATIONS OF MEASURING EQUIPMENT - Equipment for the measurement of digital and analogue/digital parameters.

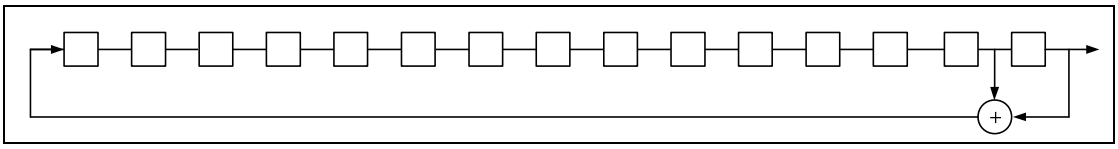

Figure 4.6: Linear feedback shift register for generation of the PRBS15 sequence

The same pseudorandom sequence of bits shall be used for each transmission (i.e. the packet is repeated).

10101010:

Repeated sequence of alternating 1's and 0's, starting at the first payload bit and ending at the start of the first bit in the CRC. This pattern is used to verify the frequency deviation and the Gaussian filtering properties of the transmitter modulator.

11110000:

Repeated sequence of alternating 0's and 1's in groups of four (i.e. 1111000011110000…), starting at the first payload bit and ending at the start of the first bit in the CRC. This pattern is used to verify the frequency deviation and the Gaussian filtering properties of the transmitter modulator.

4.1.6 LE Test packet interval

While in LE direct TX mode, LE test packets shall be transmitted from the EUT with a packet interval I(L) as defined below; see the top half of Figure 4.7 for reference.

While in LE direct RX mode, the nominal packet interval of the LE test packets transmitted from the tester is I(L), but the tester packet interval may be extended to a maximum of T(L) upon change of the dirty transmitter parameter settings and during verification of the EUT PER reporting functionality. See the bottom half of Figure 4.7 for reference.

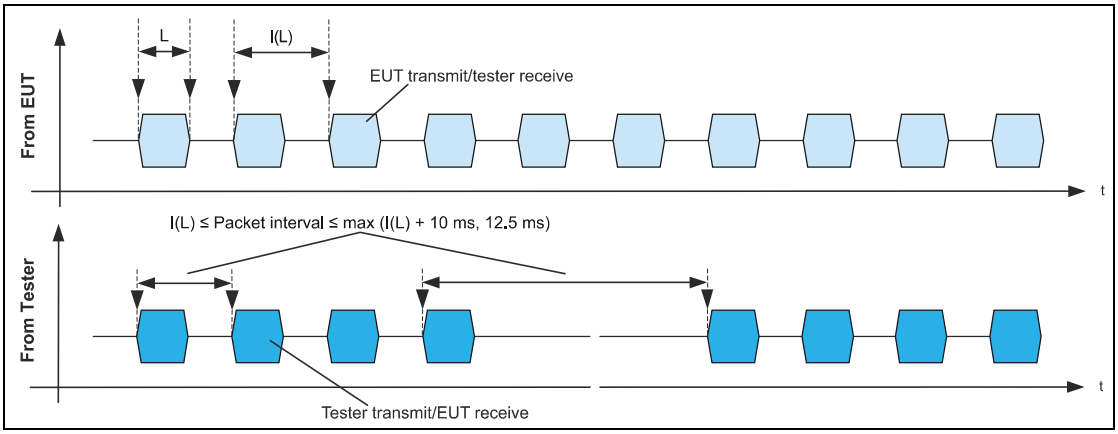

Figure 4.7: LE Test packet interval in LE Direct Test mode

For an LE Test packet length of L µs, l(L) = ceil((L + 249) / 625) * 625 µs, where ceil(x) is the smallest integer greater than or equal to x, and T(L) = max (l(L) + 10 ms, 12.5 ms).

4.1.7 Constant Tone Extension

The Constant Tone Extension is an optional field that consists of a constantly modulated series of unwhitened 1s. It is 16-160 bits when operating at 1 Msym/s modulation or 32-320 bits when operating at 2 Msym/s modulation. The Constant Tone Extension is not included in CRC or MIC calculations. The Constant Tone Extension shall only be present on the LE Uncoded PHYs.

If Direct Test Mode is being used over HCI and a Constant Tone Extension is present in a received packet, the Controller may generate events containing IQ samples of the Constant Tone Extension (see [Vol 2] Part E, Section 7.7.65.21).

Core System Package [Wireless Coexistence volume]

Specification of the **Bluetooth**® System

Specification Volume 7

Covered Core Package Version: 5.1
Publication Date: 21 January 2019