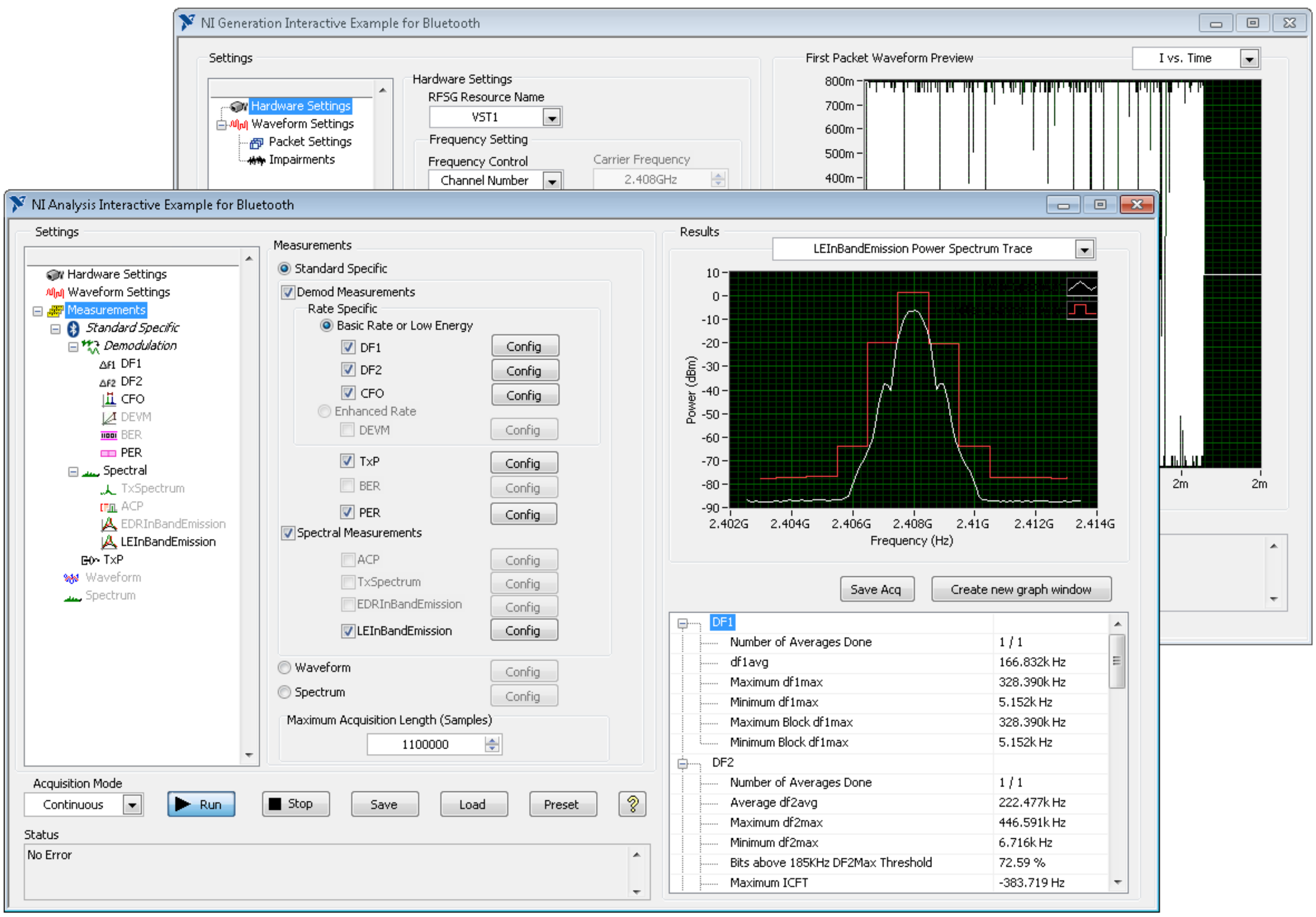
Introduction to Bluetooth Device Testing

From Theory To Transmitter and Receiver Measurements



September 2016

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1. Overview

Introduction

Bluetooth is a global wireless standard that enables connectivity for a wide range of electronic devices ranging from mobile phones to medical devices, computers, and even toothbrushes. Bluetooth technology eliminates the need for a cable connection between devices by connecting them over short distances (up to 100m) using short-wavelength radio transmissions in the unlicensed industrial, scientific, and medical (ISM) band from 2.4000 to 2.4835 GHz.

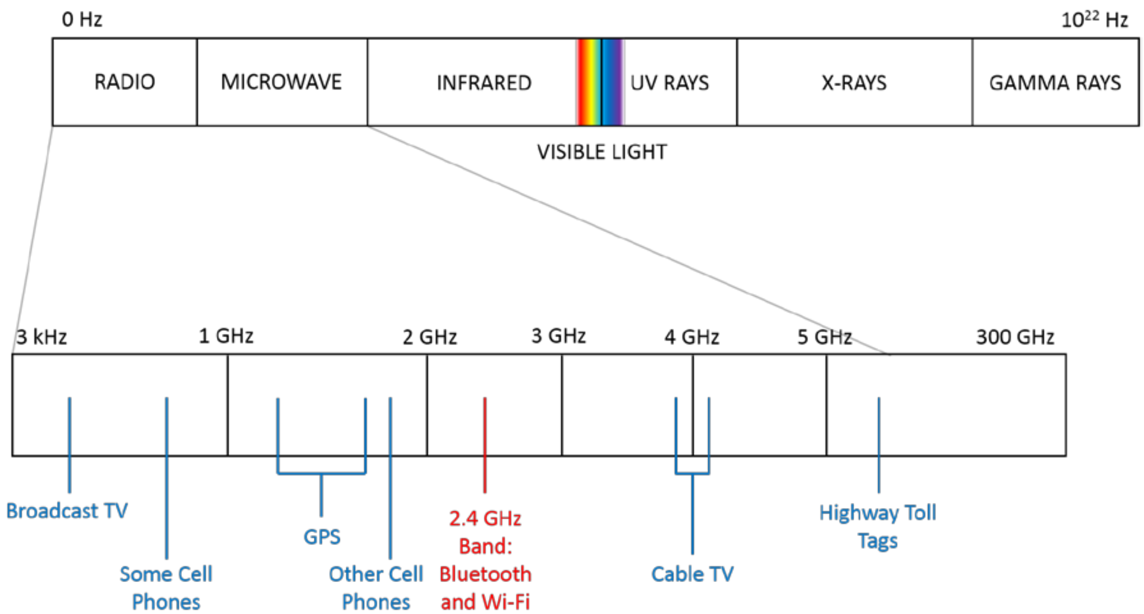


Figure 1 Bluetooth Operating Spectrum

While other protocols like Zigbee and RFID can be used to connect networks of sensors and build connectivity across devices, Bluetooth is pre-existing in common consumer electronics. The accessibility of Bluetooth makes it a perfect standard for connecting devices within personal area network (PAN) space. Up to seven devices can be connected over Bluetooth to form a piconet. WLAN, commonly known as Wi-Fi, can also be used for some of the Bluetooth applications like streaming audio, however, Bluetooth's ability to utilize the entire spectrum of 2.4 GHz to 2.4835 GHz makes it ideal for robust, short-range wireless transmission in congested radio environments where WLAN devices can run into performance issues. To ensure robust operation in the interference-dominated ISM band, Bluetooth uses spread spectrum, frequency hopping, full-duplex signal at a nominal rate of 1600 hops per second for basic and enhanced data rate transmissions.

Bluetooth allows for high-quality data and audio streaming between devices, as well as the creation of sensors smaller than ever before. Bluetooth Smart, or Bluetooth Low-Energy, has allowed for coin-cell battery, solar, and kinetic powered sensors to be placed almost anywhere. The combination of Bluetooth BR/EDR and Bluetooth LE lets devices communicate to applications in an ultra-power efficient way which makes it a prime technology for the Internet of Things, IoT.

A typical Bluetooth module consists of four main components: radio transceiver, baseband/link controller, link manager and a host controller interface (HCI). HCI connects a Bluetooth system with the host system and provides a uniform interface method of accessing the Bluetooth hardware capabilities by the host system.

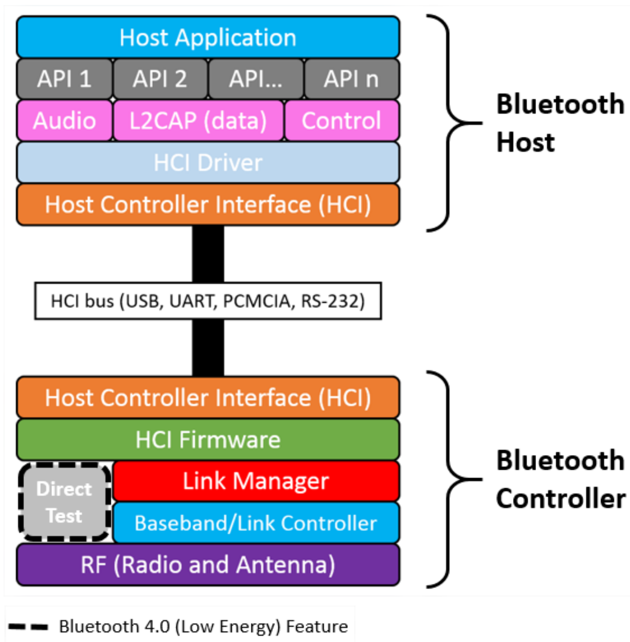


Figure 2 Bluetooth System Stack

This document provides a brief summary of major baseband and radio (physical layer) characteristics of the Bluetooth standard and then discusses some of the typical measurements required for device certification according to Bluetooth standard. The following versions of the standard will be covered V1.0, V1.2, V2.0, V2.1, V3.0, V4.0 and V4.2.

History of Bluetooth

Bluetooth technology was invented in 1994 by a group of engineers at Ericsson. The name "Bluetooth" originates from the name of the 10th century Danish King Harald Blåtand or Harold Bluetooth in English. During his reign, King Bluetooth united dissonant tribes in Sweden, Norway, and Denmark into a single kingdom. Similarly, Bluetooth technology provides a method of uniting electronic devices through a wireless communications link.

There are several versions of the Bluetooth standard. The first version of Bluetooth standard was V1.0 which was released in 1999 by Bluetooth Special Interest Group (SIG). Bluetooth SIG oversees the development of the Bluetooth standard as well as licensing of the Bluetooth technology to the manufacturers. Manufacturers of Bluetooth-compliant devices can pursue the Bluetooth certification with Bluetooth SIG, which allows them to use the Bluetooth logo, shown in **Figure 3**, on Bluetooth-compliant devices.

Figure 3. Bluetooth logo

Year	Bluetooth Standard	Data Rate	Modulation	Notes
1999	V1.0	1 Mb/s	GFSK	• The Bluetooth 1.0 Specification is released by the Bluetooth SIG
2003	V1.2	1 Mb/s	GFSK	• First FDA-approved Bluetooth medical system. Bluetooth product shipments grow to 1 million/week
2004	V2.0 + EDR	1 Mb/s 2 Mb/s 3 Mb/s	GFSK π /4–DQPSK 8-DPSK	• Introduction of Enhanced Data Rate (EDR) for faster data transfer. • Bluetooth product shipments surpasses to 3 million/week
2007	V2.1 + EDR	1 Mb/s 2 Mb/s 3 Mb/s	GFSK π /4–DQPSK 8-DPSK	• Introduction of secure simple pairing (SSP) and extended inquiry response (EIR) for Bluetooth devices
2009	V3.0+HS	1 Mb/s 2 Mb/s 3 Mb/s	GFSK π /4–DQPSK 8-DPSK	• Introduction of AMP (Alternative MAC/PHY) and the addition of 802.11 as a high-speed transport with data transfer speeds up to 24 Mbit/s.
2010	V4.0 (Smart)	1 Mb/s 2 Mb/s 3 Mb/s	GFSK π /4–DQPSK 8-DPSK	• Introduction of Bluetooth Low Energy protocol and AES encryption
2013	V4.1	1 Mb/s 2 Mb/s 3 Mb/s	GFSK π /4–DQPSK 8-DPSK	• MWS (Mobile Wireless Standard) Coexistence • SIG membership surpasses 20,000 companies

Year	Bluetooth Standard	Data Rate	Modulation	Notes
2014	V4.2	1Mb/s 2Mb/s 3Mb/s	GFSK π /4–DQPSK 8-DPSK	• Smart sensor allows flexible internet connectivity • Increased privacy (Le Privacy 1.2 and LE Secure Connections) • LE Data Length Extension increases data throughput with packet capacity increase of 10x compared to previous versions.

Table 1 History of Bluetooth Standard

Bluetooth Physical Layer (PHY) Radio Characteristics

In this section, the fundamental theory behind the Bluetooth physical layer's radio and its key characteristics are explained.

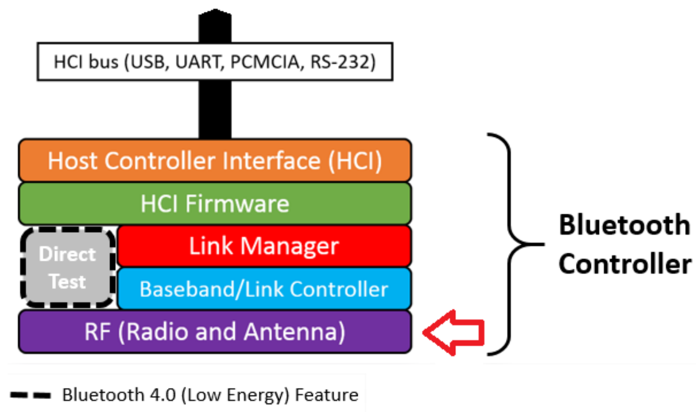


Figure 4. Location of RF Physical Layer in Bluetooth Protocol Stack

This section will cover operating frequencies, modulation, and frequency hopping, transmit power, and receiver power. First, the channel arrangement topic discusses spacing between channels and the number of channels that are used. The data is transmitted on these channels via a modulation scheme. While the data is being transferred per the given modulation scheme, the signal will "hop" on multiple channels to avoid interference from other devices. Additionally, the Tx and Rx devices have power requirements that they should follow to be in compliance with regulatory specifications. The concepts in this section are building blocks for understanding the Bluetooth physical layer measurements that are discussed in this application note.

Radio Characteristic	**Bluetooth Specification**	**Additional Details**
Frequency bands	2400 to 2483.5 MHz	• BR/EDR: f=2402+k MHz, k=0,…,78 with 1MHz channel spacing • LE: f=2402+k*2 MHz, k=0, … ,39 with 2MHz channel spacing
Modulation	Basic Rate: -Binary GFSK at 1 Msymbol/s -Bandwidth bit period product BT=0.5 -Modulation index: 0.28 to 0.35 (0.32 nominal) Enhanced Date Rate: - p/4-DQPSK at 2 Msymbol/s -Bandwidth bit period product BT=0.4 -8DPSK at 3 Msymbol/s -Bandwidth bit period product BT=0.4 Low Energy: -Binary GFSK with at 1 Msymbol/s -Bandwidth bit period product BT=0.5 -Modulation index: 0.45 to 0.55 (0.5 nominal)	• Minimum frequency deviation shall never be smaller than 115kHz (BR/EDR) and 185kHz (LE).
Frequency hopping	Standard hop rate = 1600 hops/s.	• Hop rate varies based on the device state. For example, when the device is in PAGE mode, the hop rate is 3200 hops/s since the paging message is a very short packet.
Transmit Power and Operating Range	Power class 1: 1 mW (0 dBm) to 100 mW (20 dBm) Power class 2: 0.25 mW (–6 dBm) to 2.5 mW (4 dBm) Power class 3: 1 mW (0 dBm) max power	• A power class 1 device shall support received power control requests. Support of received power control requests is optional for class 2 and class 3 devices

Radio Characteristic	Bluetooth Specification	Additional Details
Receiver Sensitivity	BR: - 70 dBm (at 0.1% BER) EDR: - 70 dBm (at 0.01% BER) LE: - 70 dBm (at 0.1%* BER)	• Sensitivity is the lowest power level that a receiver is expected to operate at the specified Bit Error Rate (BER)
Maximum data throughput	BR: During symmetric link (same packets in both directions), the rate of 433.9 kb/s can be achieved. During asymmetric link, a rate of 723.2 kb/s can be achieved with 5 slot packets in one direction and single-slot packets in the reverse direction at 57.6kb/s [1] EDR: For EDR, the maximum throughput is increased to 2.1 Mbit/s	• The actual data throughput for a given packet type will depend on the quality of the RF channel.

*- For Bluetooth Low Energy the BER limit will vary based on the payload length. Refer to Table 50 in Appendix.

Table 2. Summary of Bluetooth Radio Characteristics

Frequency bands and channel arrangement

Bluetooth, operating in 2.4 GHz ISM band, employs 79 RF channels with 1 MHz spacing for Basic and Enhanced Data Rates (BR/EDR) transmissions and 40 RF channels with 2 MHz spacing for Low Energy (LE) transmissions. Each RF channel is ordered in channel number k as follows: f=2402+k MHz, k=0,…,78 (BR/EDR) and f=2402+k*2 MHz, k=0, … ,39 (LE).

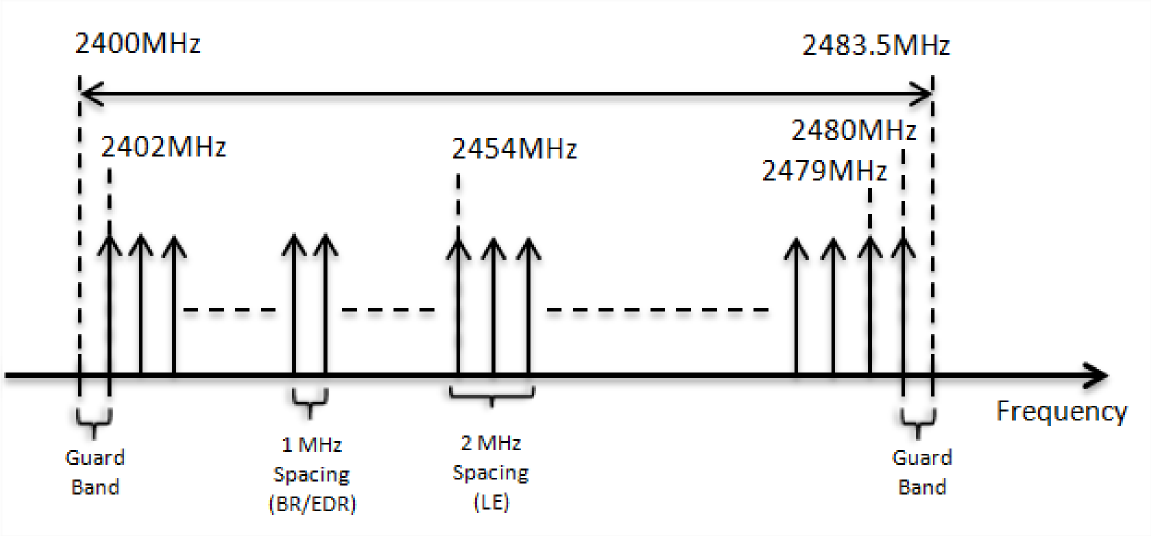


Figure 5. Bluetooth Frequency Bands and RF Channels

Frequency Hopping

To combat narrowband interference and fading in the 2.4GHz ISM band, Bluetooth employs frequency hopping spread spectrum (FHSS). The frequency hops occur at a standard hop rate of 1600 hops/s. The frequency hops follow pseudo-random pattern with uniform probability across all 79 Bluetooth channels (BR/EDR), or optionally fewer channels when Adaptive Frequency Hopping (AFH) is in use. During the active Bluetooth connection both the transmitter and the receiver know the pseudorandom pattern which is calculated based on the clock of the master device within the piconet and certain fields in the Bluetooth address.

Modulation

For basic rate (BR) transmission, Bluetooth uses binary Gaussian frequency shift keying (GFSK) modulation scheme with a bandwidth bit period product BT=0.5[1] and 0.32 as nominal modulation index. The BT = 0.5 specification sets the bandwidth of the data filter to 500kHz to reduce the occupied RF spectrum.

The modulation index is proportional to peak frequency deviation, which is +/-175 kHz for classical (BR/EDR) Bluetooth devices. Binary GFSK is similar to binary FSK modulation scheme in which the modulated carrier shifts between two frequencies that represent "1" and "0" respectively. In addition, in GFSK modulation, a pulse-shaping Gaussian filter is applied to the baseband waveform before applying it to a carrier, to reduce the spectral width of the modulated signal. The following figure illustrates time and frequency domain representations of FSK-modulated signal with two discrete frequencies.

[1] The RF bandwidth is controlled by the Gaussian low-pass filter. The degree of filtering is expressed by multiplying the filter 3dB bandwidth (B) by the bit period of the transmission (T), i.e. BT = (f_{-3dB} /Bit Rate) (in comparison, BT = 0.3 for GSM networks). For example, for a bit rate of 1Mbps and BT=0.5, the Gaussian filter cutoff frequency is 500kHz.

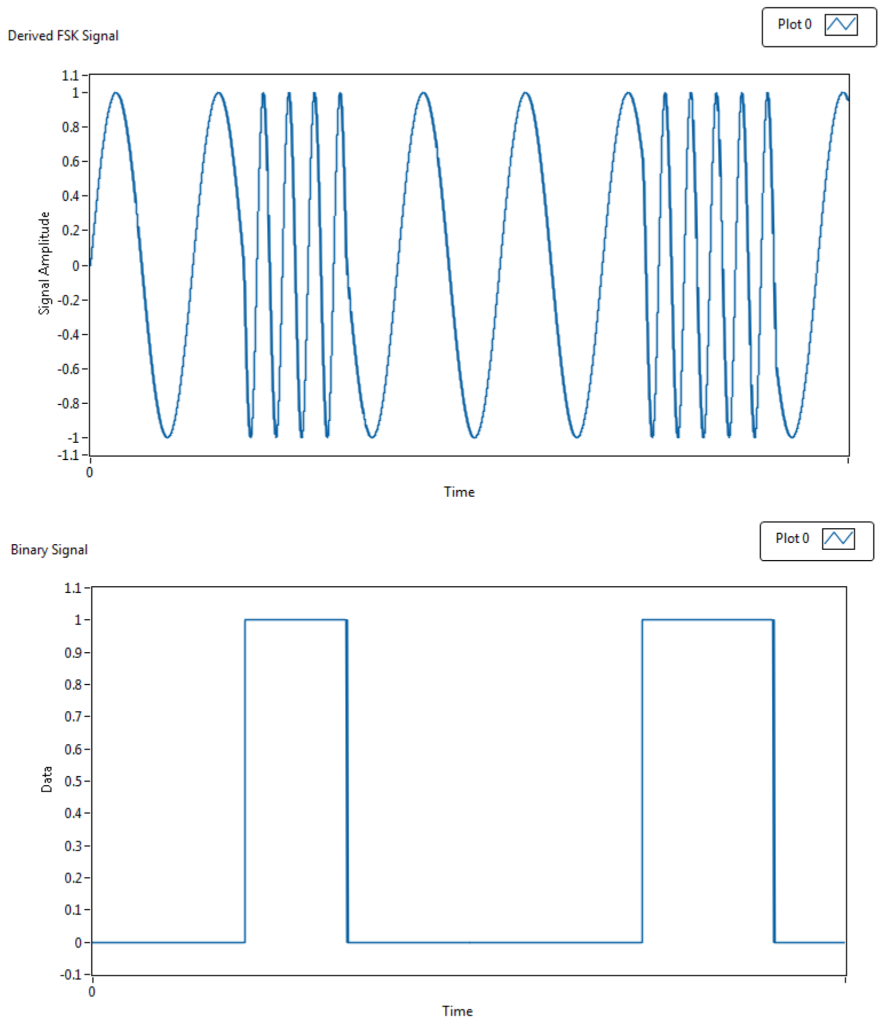


Figure 6. Bits to Waveform Mapping: 2FSK

The next two figures display the power vs. time and power vs. frequency relationships.

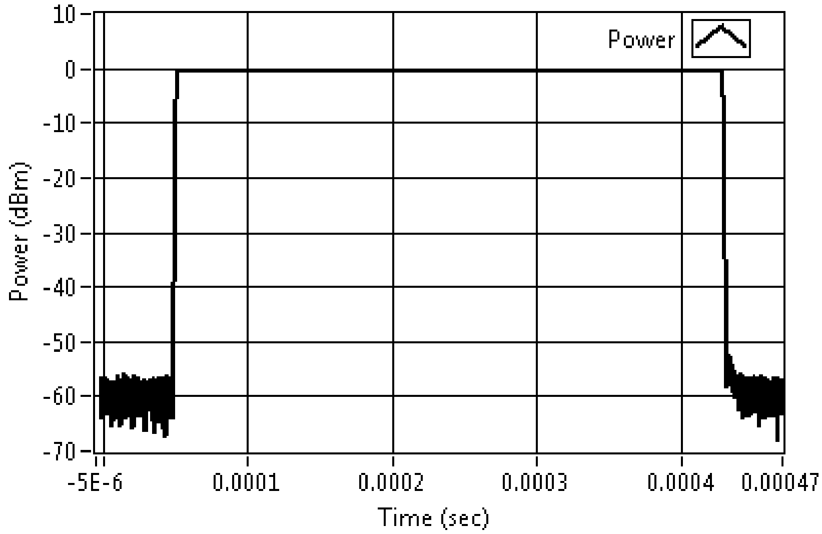


Figure 7. Time Representation of GFSK Modulated Signal (HV1 burst with 10 bytes payload at 0dBm)

As it can be observed from the figure above, since only the frequency varies in the GFSK-modulated signal while the amplitude stays constant, the power is flat (0 dBm) across the duration of the GFSK-modulated packet. Looking at the GFSK signal in frequency domain reveals two peaks at deviation frequencies ±166 kHz away from the carrier, each representing transmission of “0” or “1” bits respectively.

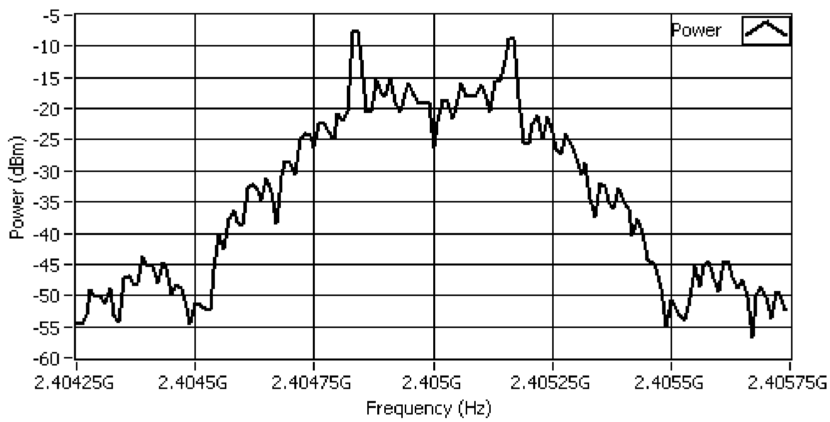


Figure 8 Frequency Representation of the GFSK Modulated Signal (HV1 burst with 10 bytes payload, 10 averages)

When a Bluetooth device transmits at a basic rate using GFSK modulated signal, one symbol represents one bit, which gives a symbol rate of 1 Megasymbol per second (1 MSym/s) and a gross air data transfer rate of 1 Mbit/s.

For enhanced data rate (EDR), Bluetooth uses PSK modulation with 1 Msym/s symbol rate. Based on the final data rate, two different PSK modulation schemes are used: pi/4-DQPSK for 2 Mb/s and 8-DPSK is used for 3 Mb/s air data transmissions. Note the eight distinct points with the differentiated I/Q patterns for the π/4-DQPSK Symbol Map. The π/4-DQPSK differential map is obtained by rotating the normal QPSK map by π/M (M=4 and represents the number of states on the map). The following figures illustrate pi/4-DQPSK and 8-DPSK constellation plots.

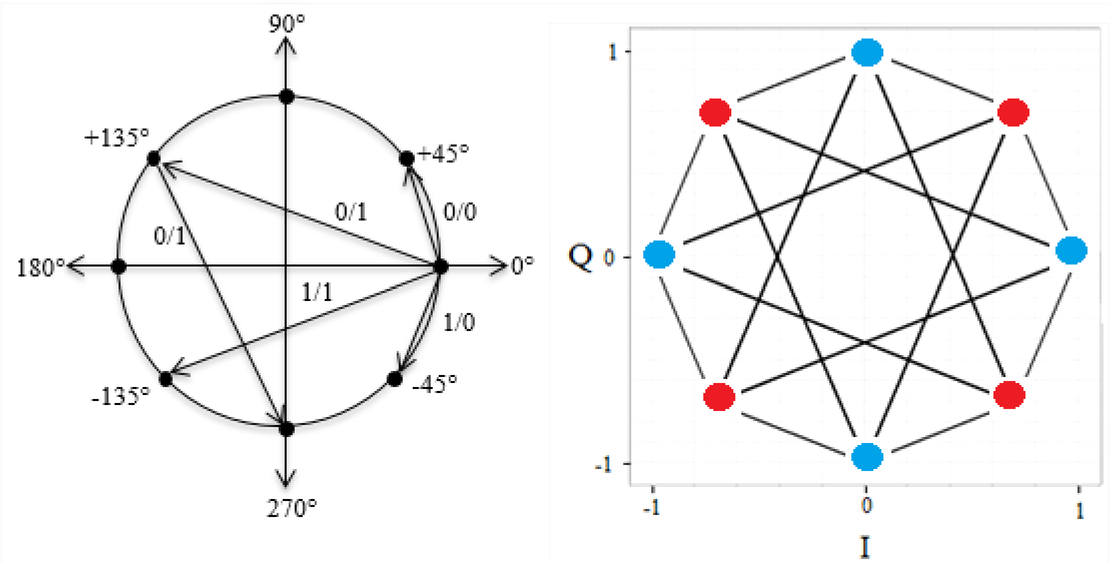


Figure 9 π/4-DQPSK Symbol Map and Constellation Plot

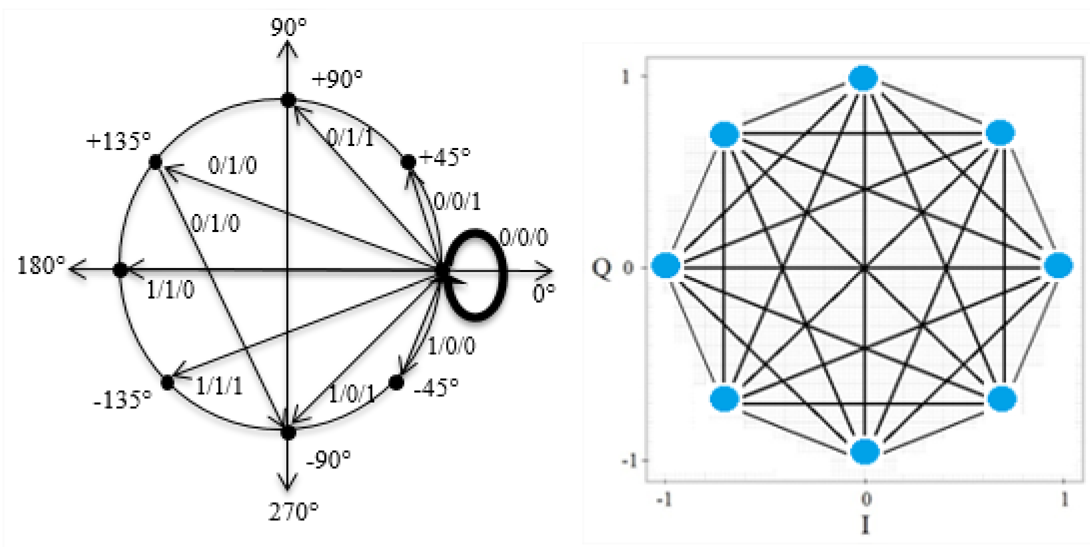


Figure 10. 8-DPSK Symbol Map and Constellation Plot

As seen from the figures above, the pi/4-DQPSK modulation scheme uses 2 bits per symbol and the 8-DPSK scheme uses 3 bits per constellation symbol, which ultimately enables 3Mb/s data transmissions.

Similar to BR radio, Bluetooth Low Energy (LE) uses the GFSK modulation for transmission of data. The symbol rate is 1 Megasymbol per second (Ms/s) supporting the bit rate of 1 Megabit per second (Mb/s).

Transmit power

Bluetooth products are divided into three main power classes based on the maximum output power and low energy power class.

Power Class	Maximum Output Power (Pmax)	Minimum Output Power [1]	Power Control	Operating Range
1	100 mW (20 dBm)	1 mW (0 dBm)	P_{min} < +4 dBm to P_{max} Optional: P_{min2} to P_{max}	100 m
2	2.5 mW (4 dBm)	0.25 mW (-6 dBm)	Optional: P_{min2} to P_{max}	10 m
3	1 mW (0 dBm)	N/A	Optional: P_{min2} to P_{max}	1 m
Low Energy	10 mW (10dBm)	0.01 mW (-20 dBm)	N/A	50 m

1. Minimum output power at maximum power setting.
2. Suggested (not-mandatory) lower power limit is P_{min} < -30 dBm

Table 3. Bluetooth Power Classes

Receiver Sensitivity

Receiver sensitivity is defined for Basic Rate, Enhanced Data Rate, and Low Energy:

Basic Rate: For BR, the sensitivity level is defined to have a bit error rate (BER) of 0.1% or better at a power greater or equal to -70 dBm, where the transmit power specifications of the transmitter are also met.

Enhanced Data Rate: For EDR, the sensitivity level has to meet a lower BER of 0.01%. Bluetooth π/4-DQPSK and 8-DPSK receivers shall meet the same -70 dBm requirement as BR or better. Once again, this is considering the transmitter meets the EDR transmitter specifications as well.

Low Energy: For LE, the sensitivity level is also defined to be a BER of 0.1% or better, like BR. Similarly, the power should be greater than or equal to -70 dBm, considering the transmitter power specifications are met. However, the initial frequency offset, frequency drift, symbol rate, or frequency deviation can vary. In addition, as of Bluetooth 4.2 specification the BER requirement will vary based on the payload length of the low energy packet. Refer to Table X in the Appendix for more details.

The following table summarizes and compares some of the key characteristics of Bluetooth BR/EDR/HS vs. Low Energy.

Characteristic	**BT BR/EDR/HS**	**BT LE**
Radio Frequency	2.4GHz ISM (2400MHz ~ 2483.5MHz)	2.4GHz ISM (2400MHz ~ 2483.5MHz)
RF Channels	79 (f=2402+k MHz, k=0,…,78) 1MHz separation	40 (f=2402+k*2 MHz, k=0, … ,39) 2 MHz separation
Range	10m~100m	10m~50m
Modulation	GFSK (BR) π/4-DPSK, 8DPSK (EDR)	GFSK
Modulation Index	0.28~0.35	0.5
Bandwidth Period	0.5 (BR) 0.4 (EDR)	0.5
Max Tx P_{AVG}	+20 dBm (Class 1) +4 dBm (Class 2) 0 dBm (Class 3)	+10 dBm
Symbol Rate	1 MS/s (BR) 2 MS/s π/4-DPSK (EDR) 3MS/s 8DPSK (EDR)	1 MS/s
Application Throughput	0.7 – 2.1 Mbit/s	0.27 Mbit/s
Access Scheme	TDMA	FDMA, TDMA
Packets	16 types	2 types
Data Rate	1-3 Mbps > 400Mbps (AMP)	1 Mbps
Security	56-bit E0 (classic)/128-bit AES (AMP) and applications layer user defined	128-bit AES and applications layer user defined

Characteristic	BT BR/EDR/HS	BT LE
Robustness	Adaptive frequency hopping and FEC, fask ACK	Adaptive frequency hopping, 32-bit Message Integrity Check, 24-bit CRC, Lazy Acknowledgement
Latency	100ms	3ms
Voice Capable	YES	NO
Network Topology	Scatternet	Star-bus
Power Consumption	1 as the reference, x10 for AMP	0.01 ~ 0.05 (user case dependent)
Peak Current Consumption	< 30mA	< 20mA
Connection Time	20ms	2.5ms

Table 4 BT BR/EDR/HS vs Low Energy Key Characteristics Comparison

Bluetooth Baseband Characteristics

The main purpose of the Baseband physical layer is to convert the received radio signals into digital form and vice versa. The Baseband layer is located just above the RF layer which acquires Bluetooth radio signals and downconverts them to baseband. Refer to the figure below.

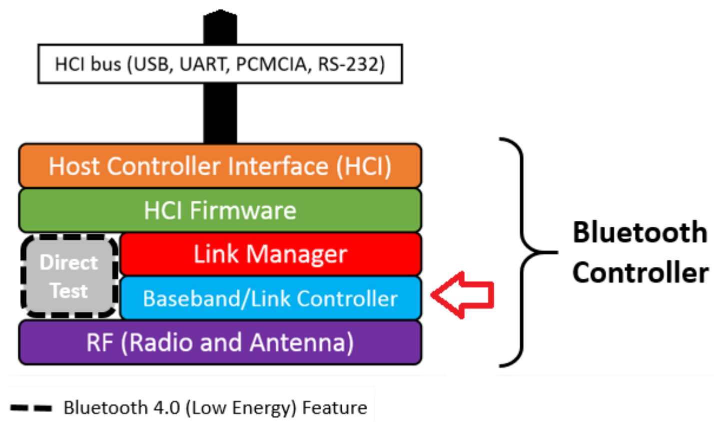


Figure 11 Location of Baseband Physical Layer in Bluetooth Protocol Stack

Once the radio signals are demodulated and converted into digital form, the digital data is then passed to higher layers of Bluetooth protocol stack for further processing. When transmitting a Bluetooth signal, the process described above is reversed. The baseband layer formats the digital data into packets and passes them on to the RF layer for radio transmission. Refer to Table 4 for the summary of Bluetooth packets.

Controller Type	**Packet Type**	**Description**	**Data Rate**
Basic Rate	NULL, POLL, ID, FHS	System packets (both ACL &SCO)	1 Mb/s packets
	DM1, DM3, DM5	Data-Medium rate (ACL)	
	DH1, DH3, DH5	Data-High rate (ACL)	
	HV1, HV2, HV3	voice packet (SCO)	
	DV	Mixed data/voice (SCO)	
	AUX1	Other uses	
Enhanced Data Rate	2-EV3, 2-EV5	Voice packet, π/4-DQPSK (eSCO)	2 Mb/s packets
	2-DH1, 2-DH3, 2-DH5	modulatedusing π/4-DQPSK (eACL)	
	3-EV3, 3-EV5	Voice packet, 8DQPSK (eSCO)	3 Mb/s packets
	3-DH1, 3-DH3, 3-DH5	modulated using 8DQPSK (eACL)	
Low Energy	LE-TP	FDMA & TDMA	1 Mb/s packets

Table 5 Bluetooth Packet Types

The physical layer also contains a link manager that is responsible for interpreting host level interface, (HCI) commands and translating them into baseband-level operations. In addition, it's responsible for establishing and maintaining links between the Bluetooth devices, as well as regulating power efficiency, link encryption and authentication. When a link is established between two Bluetooth devices one device operates a master and the other as a slave. In the next section, more details on the Bluetooth's master/slave model will be presented as well as the Bluetooth network topology will be discussed.

Network Topology

To connect Bluetooth devices together, Bluetooth standard uses a master/slave model that allows up to eight devices to be connect together in a group called a piconet. Different piconets can be linked into scatternets, however the data rate between scatternets will be lower than the data rate within a single piconet [3]. The network topology for basic rate and enhanced data rate can be seen in Figure 12. Each master device is responsible for initiating a connection and can communicate with up to seven slave devices. Additional slaves can be connected to the piconet but they have to be in a "parked" state. If a slave is shared between two masters, then it is also shared between two piconets. Slaves can be a part of multiple piconets. A scatternet comprises of all of interconnected piconets. The image below shows three masters, with three piconets, that are controlling eleven slave devices in the scatternet.[4]

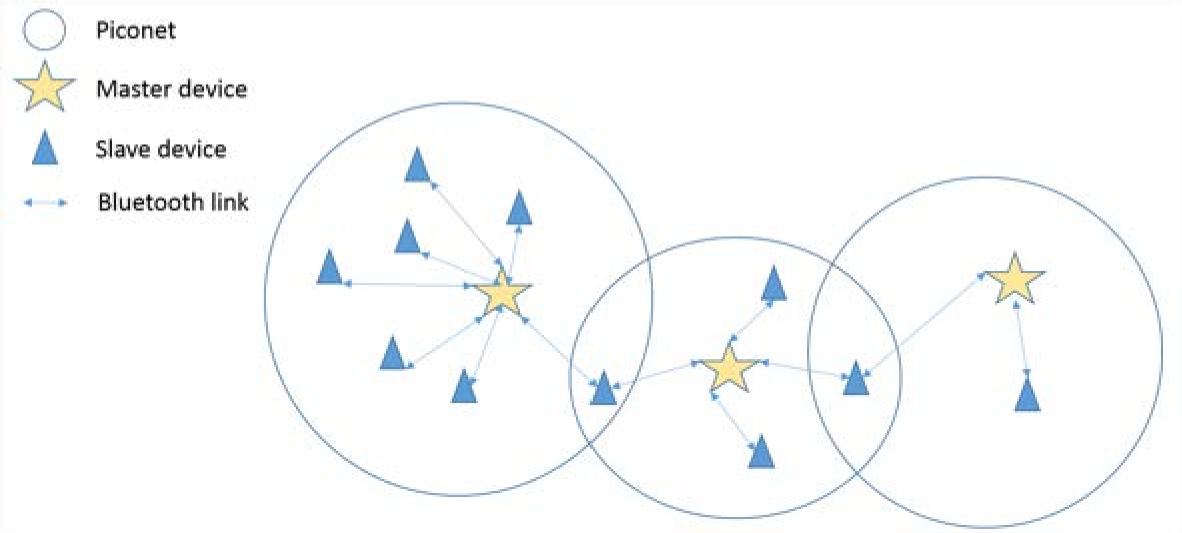


Figure 12 Bluetooth Scatternet Network Topology

Bluetooth low energy follows a different network topology than basic rate and enhanced data rate. Its architecture is referred to as a star-bus topology. This means that each slave has a direct connection to the master. Each connection is linked by a physical channel. One differentiating factor for low energy is that the slaves invite connections instead of listening for the connection, as done in basic rate and enhanced data rate. This is what allows it to conserve energy, hence low energy. Also, the number of slaves that are active is dependent on the application and is not limited to seven, like it is for the other data transmission rates. The figure below displays the star-bus topology.

Figure 13 Bluetooth Low Energy Star-Bus Topology

The physical links that are shown in Figure 6xx and 7xx can be categorized as either Synchronous Connection Oriented (SCO) or Asynchronous Connection-Less (ACL). When an application is time critical, such as transmitting voice information, the SCO link is utilized. However, when other data packets that aren't limited by time are being transmitted, ACL is utilized. The symmetry of the links also plays a factor between SCO and ACL. SCO has a data rate of 64kbps and only supports symmetric links. However, ACL can achieve data rates up to 2178 kbps and is capable of both symmetric and asymmetric links.

The Bluetooth connections have different modes for communication. First, one of the devices will send an inquiry to the other device to better understand it. Next, the paging mode, or connecting mode, is used to build the connection between the devices. After two Bluetooth devices have performed the inquiry and paging steps, they begin the connection state. This connection state includes the following modes: active, sniff, hold, and park. Each of these modes is initiated by the master and is performed by the slave device.

Active mode is the standard connection where data is being sent and received. The sniff, hold, and park modes are all used to conserve energy. Sniff mode will listen for transmissions at a set interval and will "sleep" the remainder of the time. Hold mode will sleep for a determined amount of time and then it returns back to the standard active mode. Park mode makes the slave device sleep until it is forced to wake up.

Packet types

The physical RF channel is divided into time slots where each slot is associated with a particular hop frequency. Basic time slot is 625us (1s/1600hops/s=625us) in length. Within a piconet, data is transmitted between the Bluetooth devices via packets which are located in their respective time slots.

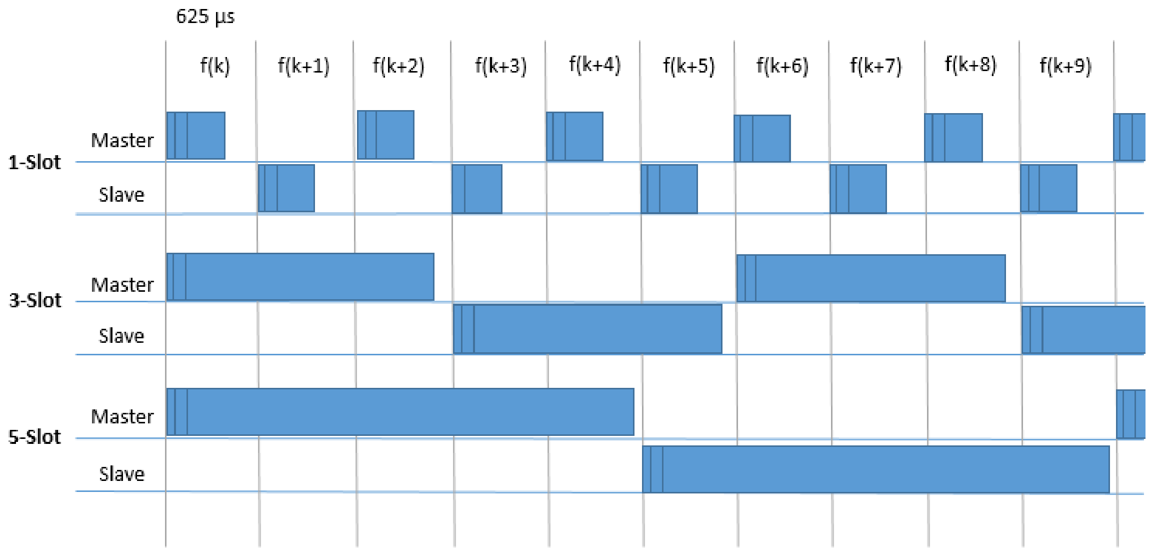


Figure 14 Packet Slot and Timing Structure

The transmitted packets can span one, three, or five time slots. A Basic Rate Bluetooth packet, shown in Figure 12, consists of three sections: an access code, a header, and a payload.

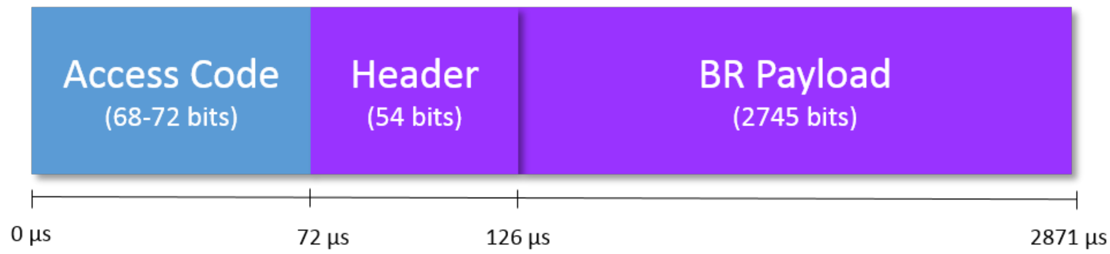


Figure 15. Basic Rate Packet Structure

The Access Code section of the packet carries the physical channel access code. The header contains the logical transport identifier, the logic link identifier, and the link control protocol. Lastly, the payload section will include the data that is being transmitted. For additional details about these sections, refer to the *Core Bluetooth Protocol V. 4.2*.

The structure of the EDR packet is depicted in the following figure:

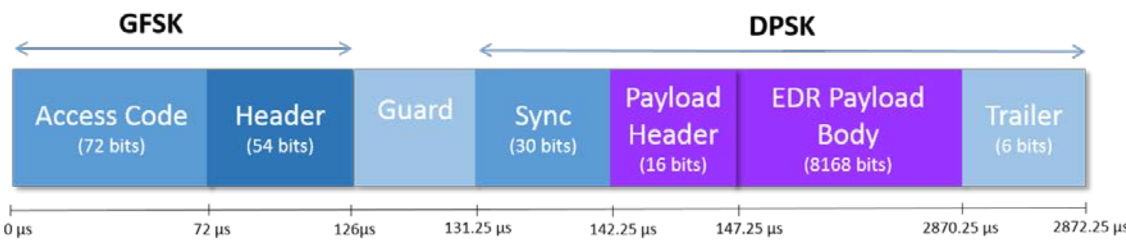


Figure 16a. EDR Packet Structure (3-DH5 with full max payload and 5.25 µs guard band)

One key feature of the EDR packet is that the modulation scheme is changed within a packet. The first two sections of the packet - access code and header, are transmitted using GFSK modulation and the remaining sections of the packet after the guard band are transmitted using pi/4-DQPSK or 8-DPSK depending on the data rate of the link. The guard band will be a value between 4.75 µs and 5.25 µs. The following figure further illustrates the multi-coding structure of a typical EDR packet.

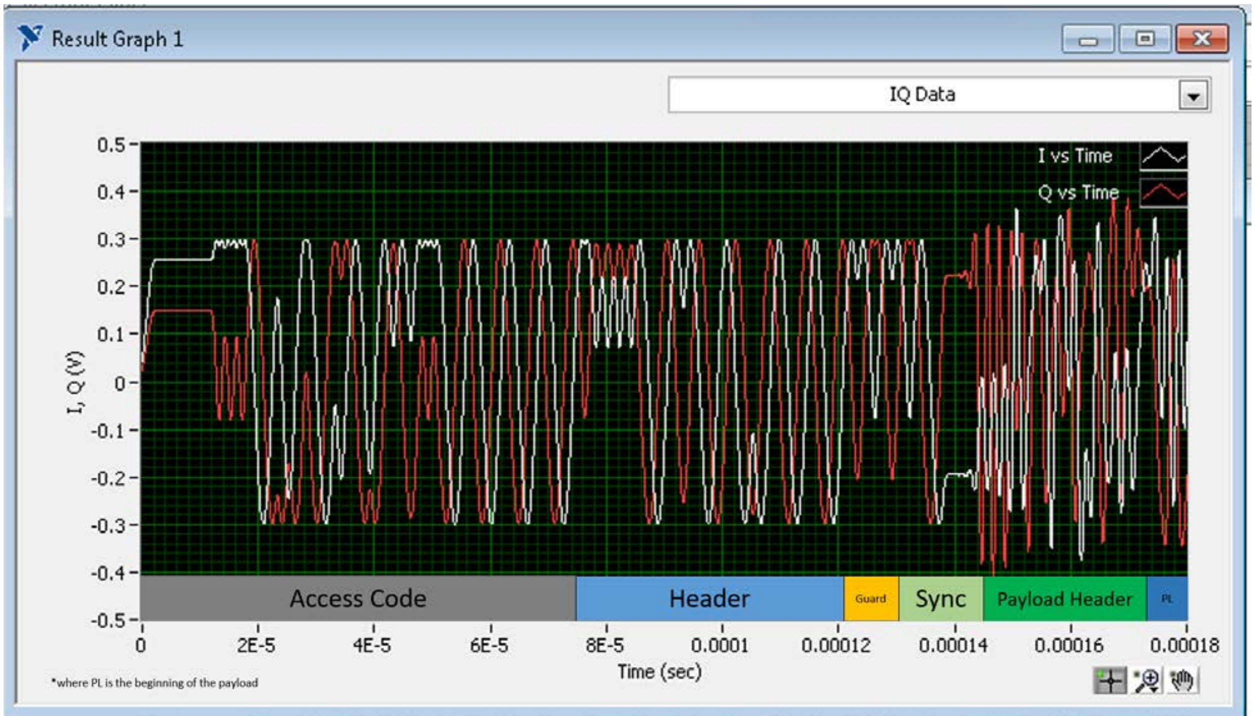


Figure 17b. 3-DH5 Packet Structure and Timing

As it can be observed from the IQ data shown in the figure above, the GMSK portion of the 3-DH5 EDR packet has a constant amplitude, whereas the amplitude of the DPSK portion pf the packet, which starts with payload, varies in time according to the amplitude of the symbols in the DPSK constellation map.

The packet for BT LE transmission varies from the BR and EDR packets. The BT LE packet structure and timing scheme can be found in Figure 17.

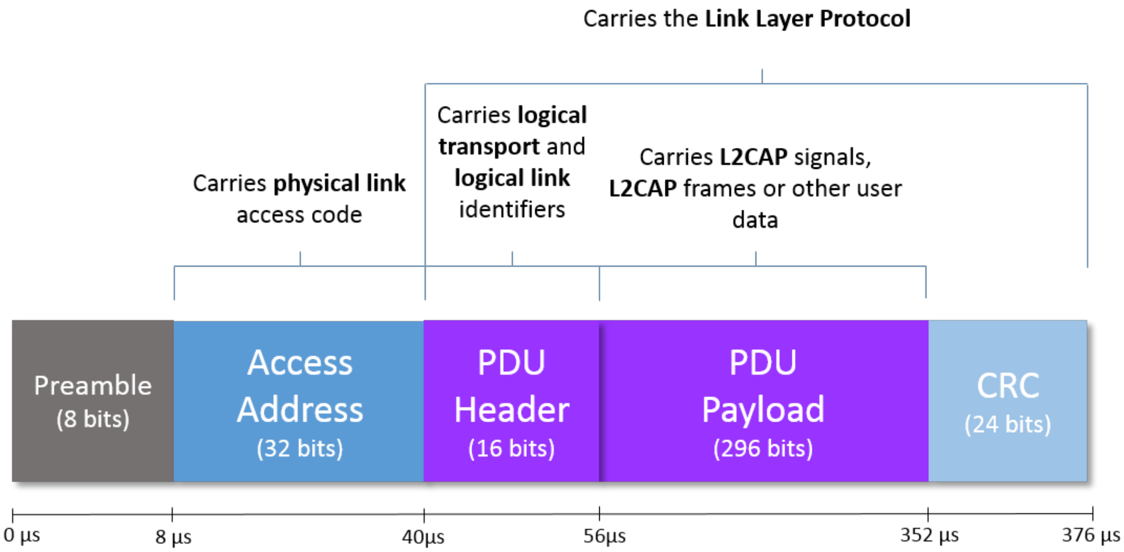


Figure 17 BT LE Packet Structure (1 Mbps)

Bluetooth Device Addressing (BD_ADDR)

The Bluetooth device address (BD_ADDR) is a unique 48-bit address sent in the access code. For BR/EDR, this address is assigned by the Bluetooth Registration authority and must be created in accordance with section 9.2 of the IEEE 802-2001 standard. The first 24 bits represent the OUI (Organization Unique Identifier). The BD_ADDR can assume any values except 64 contiguous lower address parts (LAPs) used for inquiry operations. The 63 reserved LAPs used for specific classes of devices are 0x9E8B00-0x9E8B3F. The last general inquiry purpose LAP is 0x9E8B33. The LAP consists of 24 bits, the upper address part (UAP) consists of 8 bits, and the non-significant address part consists of 16 bits. The LAP and UAP together make up the significant part of the address. The purpose of the Bluetooth address is for identification and authentication. However, the address is also used to set the frequency hopping scheme, to synchronize master and slave clocks, and to pair devices. The BR, EDR, and LE Bluetooth addresses all have 48 bits. The bit structure is shown in Figure 19.

company assigned						company id					
LAP						UAP		NAP			
0000	0001	0000	0000	0000	1100	0010	0111	1011	0011	0101	1001

LSB **MSB**

Figure 18. Bluetooth Address Format

Timing Scheme and Hopping Characteristics

The communication timing scheme between Bluetooth devices is determined by the transmission mode and the type of shared physical channel being used. As of Bluetooth 4.2 specification, there are three main transmission modes: Basic Rate, EDR, and Low Energy. Basic and Low Energy transmission transfer data at 1 Mb/s. EDR transmits data at either 2 Mb/s or 3 Mb/s, depending on the packet type being sent. To communicate with each other, two Bluetooth devices share the same access code and a physical channel tuned to a certain RF frequency which is determined by the pseudo-random RF channel hopping pattern. There are four physical channels that have different purposes and timing characteristics: basic, adapted, inquiry scan, and page scan. Each physical channel follows its own structure. To expand on this idea, the structure of the basic physical channel is described below.

The basic physical channel is set by three factors: the packet (slot) timing, the access code, and a pseudo-random RF channel hopping sequence. Also, the basic physical channel is divided into time slots, each 625 µs long. Time slot numbering ranges from 0 to 2^{27} -1. Both slave and master devices follow a time division duplex (TDD) scheme where they alternate time slots. The master device transmits on even time slots, while the slave device transmits on odd numbered time slots. Each packet can extend up to a maximum of five time slots. To have a synchronized piconet, the master and slave device clocks must be synchronized. All slave devices are synchronized to the master clock. The master clock is derived from the reference clock by incorporating a time base offset and a slave offset. For the master, the slave offset is zero, but the slave clocks will add a slave offset value greater than zero. Each device has its own native clock that it applies the offset values to align with the master clock. The clocks are synchronized regularly to ensure accurate timing. This is crucial because there is normally a 20 µs uncertainty window to allow for error in synchronization.

Frequency hopping is varying the frequency that devices are communicating on to reduce interference to the signal, or data, and increase security. The connection state, synchronization substate, and synchronization scan substate have a maximum hop rate of 1600 hops/s. The inquiry and page substates both have a maximum of 3200 hops/s. For basic rate and EDR, hopping sequences hop on all 79 RF channels. Hopping characteristics are determined by the Bluetooth clock and BD ADDR of the master device. All devices in a given piconet are time and hop synchronized to the physical channel.

The LE communication hops on a minimum of twenty frequencies but usually remains under the typical seventy-nine frequencies. The other key distinction for LE is that it uses forty channels that are each separated by 2 MHz. Three of the channels are for advertising events while the other thirty-seven are used as data channels. These forty channels incorporate frequency division multiple access (FDMA) and time division multiple access (TDMA) schemes. The algorithm to determine the hopping pattern is set by the initiating device (master) in the piconet.

There are five basic hop sequence types and one adapted hop sequence type. Each is structured with a varying period length or number of frequencies used.

Sequence name	Description
Page Hopping Sequence	32 wake-up frequencies equally spread across the 79 MHz band. Period length = 32
Page response hopping sequence	Directly correspond to current page hopping sequence where the master and slave use respective rules that result in the same sequence
Inquiry hopping sequence	See “Page Hopping Sequence” description
Inquire response hopping sequence	Covers 32 response frequencies that directly correspond to inquiry hopping sequence
Basic channel hopping sequence	Equally spread frequencies over the 79 MHz band with a very long period length and short time interval. It does not repeat sequences.
Adapted channel hopping sequence	Uses same channel structure as basic channel hopping sequence that may utilize less than 79 frequencies

Table 6. Hopping Sequences

Bluetooth Test Modes

BR/EDR Test Modes

The Bluetooth test mode is an operation mode that allows Bluetooth devices to accept certain commands related to testing while ignoring other non-test mode related commands. Control of the test mode is performed via Link Manager Protocol, LMP commands using a hardware or software interface. BR/EDR Bluetooth devices feature two different test modes: transmitter and loopback test mode. The test modes are primarily used for certification/compliance as well as production testing of the DUT's physical layer (radio and baseband).

In loopback test mode, the Bluetooth tester (master) device sends packets to the DUT (slave). The DUT must decode the packet and send the same payload and packet type back to the Bluetooth tester. The tester acquires the re-transmitted packet from the DUT and performs receiver measurements (e.g. BER, sensitivity, etc.) according to the Bluetooth specification.

In transmitter test mode, the tester (master) establishes a connection to the DUT (slave) to form a piconet with a certain timing scheme. The master/slave communication within the piconet is separated into TDD time slots. During each time slot, only a master or slave is allowed to transmit. During the master TX time slot, the tester sends POLL packets to the DUT. The DUT decodes the POLL packet and transmits a certain packet type containing a bit pattern of either constant ones (11), constant zeros (00), alternating 1010 (AA), alternating 1111 0000 (FF00) or a pseudorandom bit pattern (PRBS-9) based on the instructions contained in the received POLL packets from the tester.

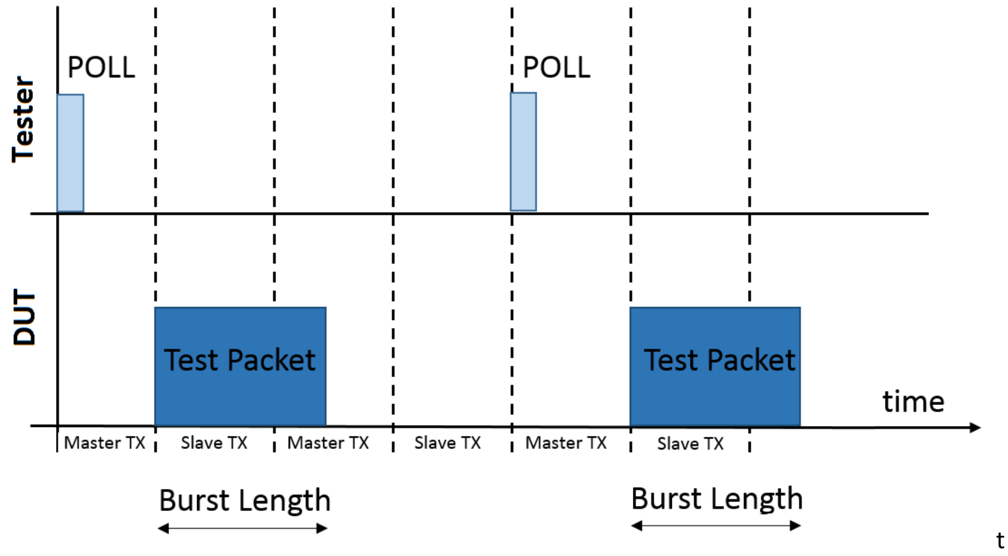


Figure 19. Transmitter Test Timing

Different bit patterns are used to stress different components of the DUT. This will be explained further in the transmitter measurements section. The transmission of test packets from the DUT happens during the slave TX time slot. The tester acquires the packets transmitted from the DUT and performs transmitter measurements such as Adjacent Channel Power, Modulation Accuracy, etc., according to the Bluetooth specification. The transmitter test mode can be configured for a single, user specified frequency or to follow a certain hopping routine.

Direct Test Mode

Direct Test Mode is available for low energy Bluetooth devices and is used to control the DUT and send results back to the test equipment.

In Direct Test Mode, the communication between the tester and the DUT can be established using one of the two alternate methods:

- Over Host Controller Interface (HCI)
- Through a 2-wire UART interface

When the DUT is being designed, either of the above can be implemented to test the low energy PHY layer. The following figure demonstrates the two alternatives for Direct Test Mode setup.

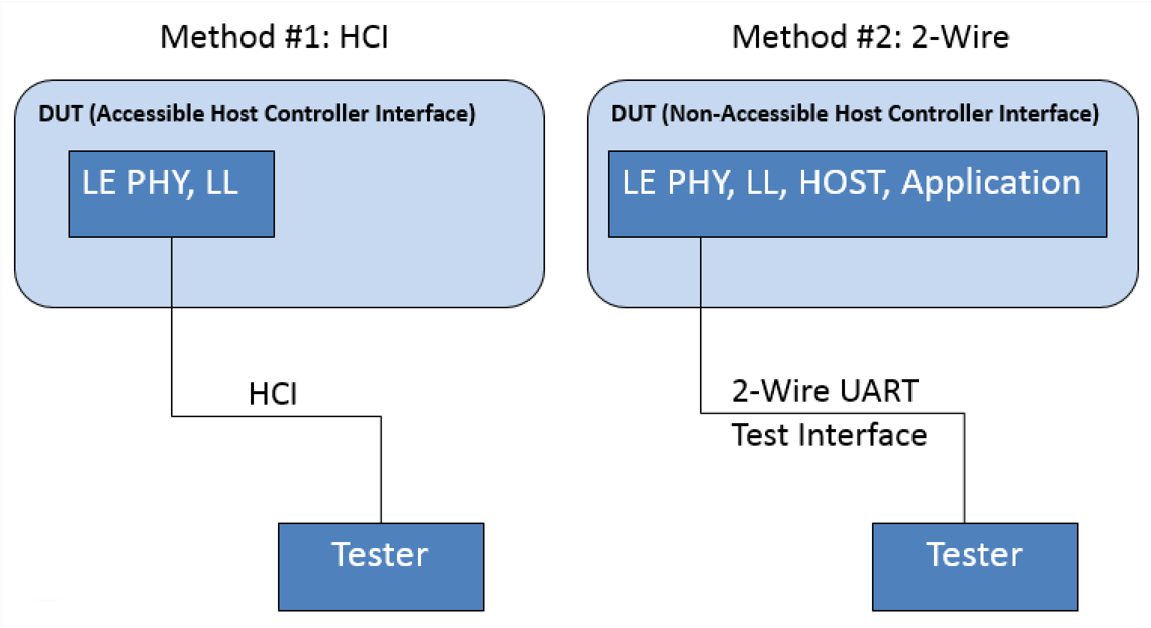


Figure 20. LE Direct Test Mode: Setup Alternatives

NI Bluetooth Toolkit supports LE direct test mode via HCI communication.

The LE test packet structure is shown in the figure below. It includes an 8-bit preamble, 32-bit sync word, 8-bit PDU header, and 8-bit PDU length, a payload that can vary between 296 bits and 2040 bits and a 24-bit CRC. LE test packets do not include a PDU address field.

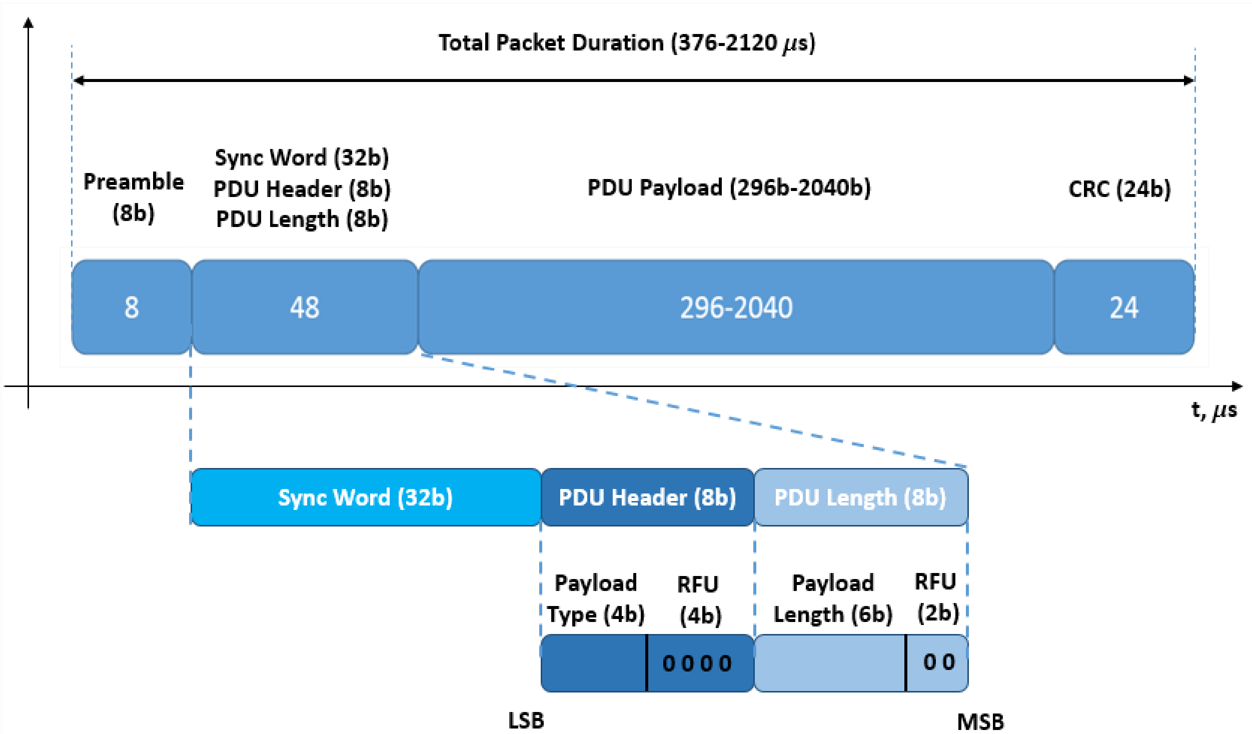


Figure 21. BTLE Direct Test Mode Packet

The payload of an LE test packet varies in size and its content is defined based on the four Payload Type bits contained in the PDU header. The following table describes the payloads that are generated for each payload type bit sequence.

Payload Type Bits, $b_3b_2b_1b_0$	Payload Description
0000	PRBS9 sequence "1111111100000111101…" random sequence of 2^9-1 bits
0001	Repeat "11110000" bit sequence
0010	Repeat "0101010" bit sequence
0011	PRBS15 random sequence of 2^{15}-1 bits
0101	Repeat "00000000" bit sequence
0110	Repeat "00001111" bit sequence
0111	Repeat "01010101" bit sequence
0100	Repeat "11111111" bit sequence

*All bits are shown in transmission order (LSB to MSB)

Table 7. BTLE Test Packet Payloads

Now, let’s consider the timing between LE test packets in LE direct test mode. The figure below illustrates the timing between the tester and the DUT/EUT and how it varies with packet length.

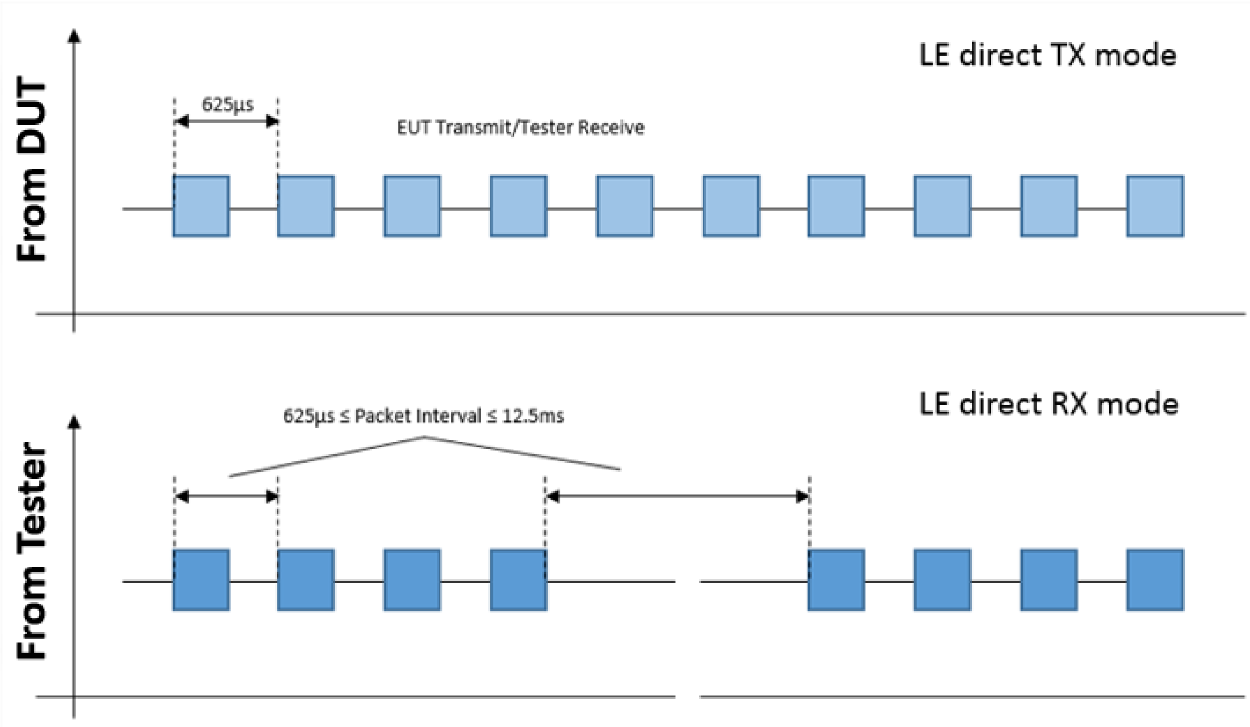


Figure 22. Direct Test Mode Packet Timing

LE Test Packet Length (µs)	Packet Interval (µs)
< 376	625
> 377 and < 1000	1250
> 1001 and < 1624	1875
> 1625 and < 2120	2500

Table 8. Direct Test Mode Packet Length and Interval

The NI Bluetooth Toolkit features a Direct Test Mode (DTM) Interactive Panel that can be used to connect to the LE DUT and run transmitter or receiver tests by sending the appropriate HCI commands via a serial interface. Figure 24 shows an LE transmitter test performed using the NI Bluetooth Toolkit DTM interactive panel. During this test, the interactive panel has established a serial connection to the DUT (TI CC2540 SimpleLink Bluetooth Smart Wireless MCU) and requested the DUT to transmit LE packets with ‘11110000’ sequence as the payload by sending an LE test packet with 0x01 (hex) or 0001 (binary) bits as the payload type in PDU header.

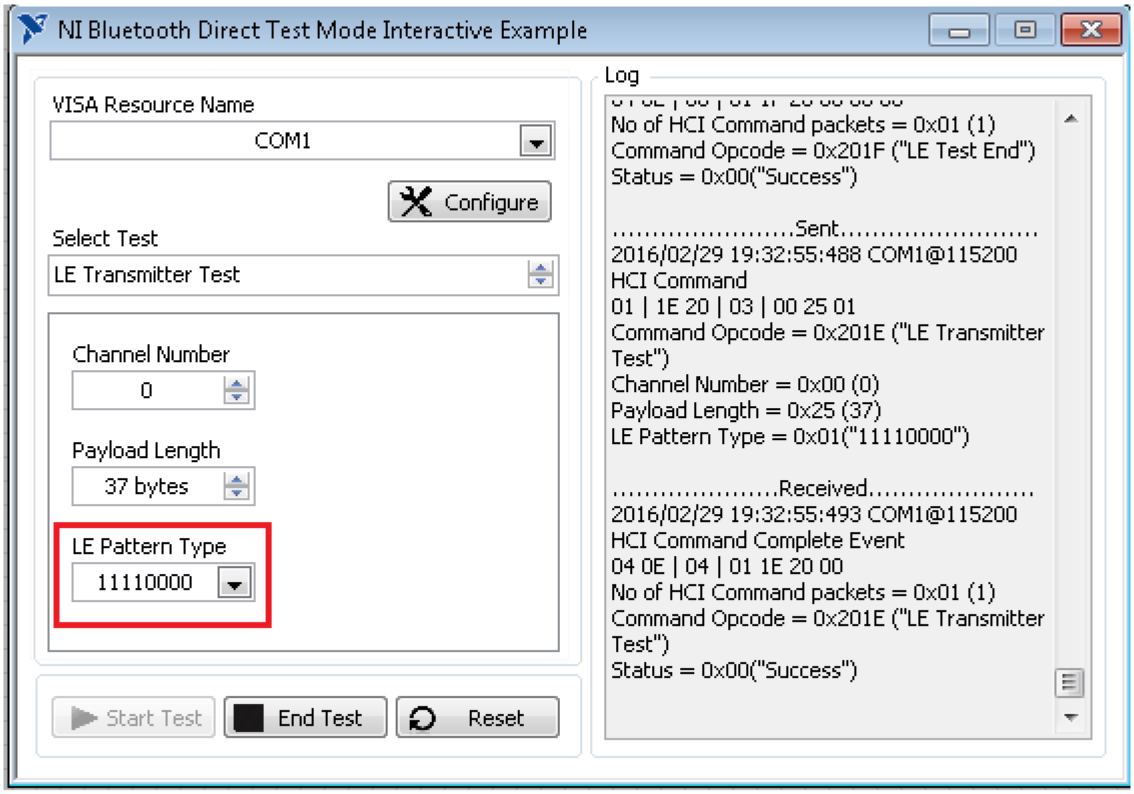


Figure 23. Generation of LE packets with 11110000 payload pattern using the Bluetooth DTM Interactive Panel

The packets transmitted by the DUT can be acquired and demodulated using the NI Bluetooth Analysis toolkit. Figure 25 shows the demodulated signal from the DUT. The first three periods of the LE '11110000' pattern are displayed. Note that the payload bits begin at bit 17.

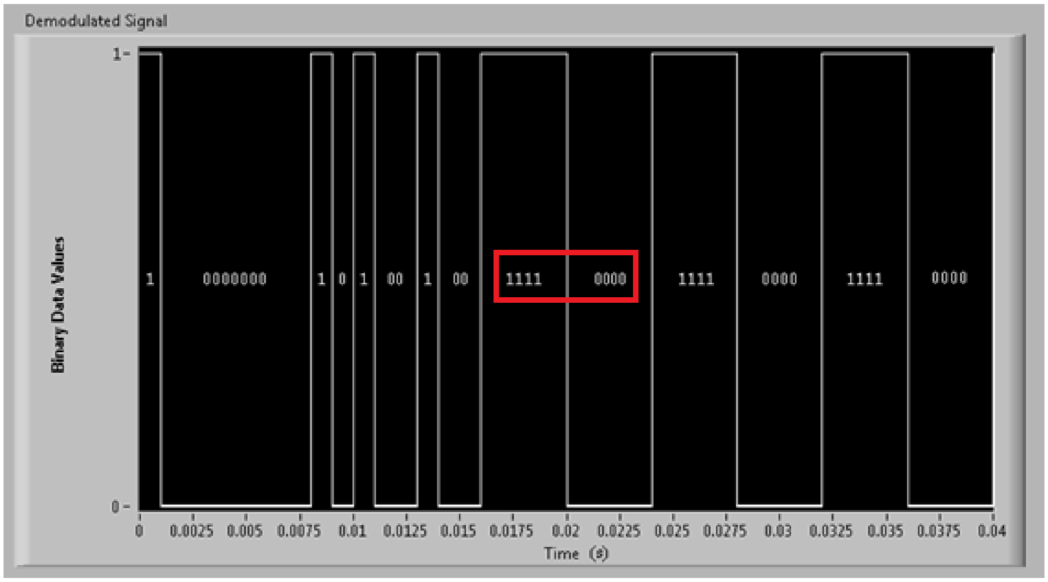


Figure 24. Demodulated LE packet with 11110000 payload pattern (NI Bluetooth Analysis Toolkit)

For more information on using Direct Test Mode in NI-Bluetooth Toolkit refer to the following video: *Controlling Bluetooth Low-Energy Devices with Direct Test Mode*.

2. NI's approach to Bluetooth Testing

There are two common methods of testing Bluetooth devices: over-the-air (OTA) link and direct, no-link test method. During the over-the-air link testing, a Bluetooth connection is established between a tester and a DUT. The tester places the DUT into a test mode and then conducts a series of tests and measurements, all while the tester actively maintains the link to the DUT. By contrast, during the direct test method, the tester never establishes an active Bluetooth connection with the DUT. Instead, the tester communicates with the DUT by sending it specific test commands using the Host Controller Interface (HCI) through a direct, wired connection.

NI has adopted a direct test method approach to test Bluetooth devices. This test method minimizes the overall test time per DUT since no test time is spent on creating and maintaining an active link between the test equipment and the Bluetooth DUT. The trade-off is that an external DUT control functionality needs to be provided and integrated with NI's test system. However, in a high-volume test environment, the reduction in test times significantly offsets any costs associated with the external DUT control. Furthermore, for testing Low Energy transmitters, NI Bluetooth Toolkit has built-in DUT control through Direct Test Mode feature in the toolkit.

Instrument Configuration for Bluetooth Measurements

Test and measurement of fully integrated devices generally require a combination of a vector signal generator (VSG) and a vector signal analyzer (VSA). The VSG is used to send a Bluetooth signal to a DUT's receiver, for sensitivity and BER testing, while the VSA is used to characterize a DUT's transmitter. NI offers an integrated VSG and VSA, known as a vector signal transceiver (VST) which is commonly used for Bluetooth device test.

When testing a fully assembled Bluetooth device, transmit and receive functionality of the device are generally combined into a single port. As a result, the test setup requires an RF switch or a combiner/splitter to connect the Bluetooth device to both the output of the VSG and the input of the VSA, as shown in Figure 25**.**

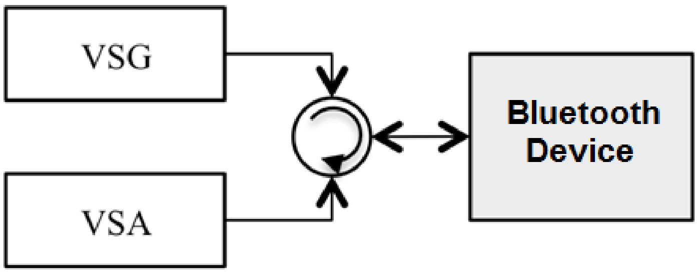


Figure 25. Typical test setup for a Bluetooth device

When selecting a signal analyzer for Bluetooth testing, keep in mind that the Bluetooth transmitter measurements include metrics for spectral leakage and modulation quality. As a result, the signal analyzer must have corresponding vector analysis capabilities in order to appropriately demodulate the signal.

3. *Transmitter Measurements*

Understanding the physical layer measurements and interpreting measurement results is critical for both the device manufacturing process and the design process. This section focuses on transmitter measurements, which describe the signal output from the Bluetooth device.

The Bluetooth transmitter measurements are generally designed to ensure interoperability with other cellular and wireless technologies. The FHSS methodology described above is deployed for coexistence with other wireless devices in the ISM band. Measurements such as minimum output power and spectrum measurements characterize the amount of unintended interference a Bluetooth transmitter might produce during transmission. In addition, the modulation quality of the transmitted signal is important because it quantifies the presence of signal impairments that might prevent a Bluetooth receiver from demodulating the transmissions at the specified BER.

Bluetooth transmitter measurements are defined by *Test Suite Structure (TSS) and Test Purposes (TP) Specification 1.2/2.0/2.0 + EDR/ 2.1/2.1 + EDR/3.0/3.0 + HS (RF.TS/3.0.H.1)* and *Bluetooth Low Energy RF PHY Test Specification (RF-PHY.TS.4.2.0)* and include requirements on transmit power, spectrum emissions, and modulation quality as summarized in Table 9.

Table 9 Bluetooth Transmitter Measurements

Measurement Category	**Measurement Description**	**Identifier**	**RF-PHY TS.3.0/4.2(LE) Section**
Power	Output power	TRM/CA/01/C	*5.1.3*
	Power density	TRM/CA/02/C	*5.1.4*
	Power control	TRM/CA/03/C	*5.1.5*
	Enhanced data rate relative transmit power	TRM/CA/10/C	*5.1.12*
	Enhanced power control	TRM/CA/14/C	*5.1.16*
	Output power at NOC	TRM-LE/CA/01/C	6.2.1
	Output power at EOC	TRM-LE/CA/02/C	6.2.2
Modulation/Signal Quality	Modulation characteristics	TRM/CA/07/C	*5.1.9*
	Initial carrier frequency tolerance	TRM/CA/08/C	*5.1.10*
	Carrier frequency drift	TRM/CA/09/C	*5.1.11*
	Enhanced data rate carrier frequency stability and modulation accuracy	TRM/CA/11/C	*5.1.13*
	Enhanced data rate differential phase encoding	TRM/CA/12/C	*5.1.14*
	Modulation characteristics	TRM-LE/CA/05/C	6.2.5
	Carrier frequency offset and drift at NOC	TRM-LE/CA/06/C	6.2.6
	Carrier frequency offset and drift at EOC	TRM-LE/CA/07/C	6.2.7
Spectrum	Tx output spectrum-frequency range	TRM/CA/04/C	*5.1.6*
	Tx output spectrum-20 dB bandwidth	TRM/CA/05/C	*5.1.7*
	Tx output spectrum-adjacent channel power	TRM/CA/06/C	*5.1.8*
	Enhanced data rate in-band spurious emission	TRM/CA/13/C	*5.1.15*
	In-band emissions at NOC	TRM-LE/CA/03/C	6.2.3
	In-band emissions at EOC	TRM-LE/CA/04/C	6.2.4

Note: Identifier naming convention is: (Test)/CA/NN/C, in which
TRM = Transmitter test

TRM –LE = Transmitter test (Low Energy)
CA = Capability test (defines the type of testing)
NN = Test purpose number
C = Conformance test performed on dedicated *Bluetooth* test system (defines the scope)

Table 10 provides a summary of major test settings required for various transmitter tests. Typically, transmitter tests are done in Loopback mode (except for TRM/CA/12/C), however, if Loopback mode is unavailable, the use of Transmitter mode is allowed. For more details, refer to RF-PHY TS.3.0/4.2 specifications.

Table 10 Transmitter test parameters

Bluetooth mode	**Measurement Description**	**Identifier**	***Packet Type***	***Payload data***	***Measurement settings***	***Frequency Hopping***
Basic Rate (BR) Test cases	Output power	TRM/CA/01/C	DH5	PRBS 9	3 MHz RBW 3 MHz VBW	On
	Power density	TRM/CA/02/C	DH5	PRBS 9	100 kHz RBW 100 kHz VBW	On
	Power control	TRM/CA/03/C	DH1	PRBS 9	3 MHz RBW 3 MHz VBW	Off
	Tx output spectrum-frequency range	TRM/CA/04/C	DH5 or DM5	PRBS 9	100 kHz RBW 300 kHz VBW	Off
	Tx output spectrum-20 dB bandwidth	TRM/CA/05/C	DH5 or DM5	PRBS 9	10 kHz RBW 30 kHz VBW	Off
	Tx output spectrum-adjacent channel power	TRM/CA/06/C	DH1	PRBS 9	100 kHz RBW 300 kHz VBW	Off
	Modulation characteristics	TRM/CA/07/C	DH5 or DM5	11110000 10101010	-	Off
	Initial carrier frequency tolerance	TRM/CA/08/C	DH1	PRBS 9	-	On
	Carrier frequency drift	TRM/CA/09/C	DH1 DH3 DH5	10101010	-	On

Bluetooth mode	**Measurement Description**	**Identifier**	*Packet Type*	*Payload data*	*Measurement settings*	*Frequency Hopping*
Enhanced Data Rate (EDR) test cases	Enhanced data rate relative transmit power	TRM/CA/10/C	2-DHx or 2-Evx 3-DHx or 3-Evx	PRBS 9	3 MHz RBW 3 MHz VBW	Off
	Enhanced data rate carrier frequency stability and modulation accuracy	TRM/CA/11/C	2-DH5 or 3-DH5	PRBS 9	-	Off
	Enhanced data rate differential phase encoding	TRM/CA/12/C	2-DH1 or 2-EV3 3-DH1 or 3-EV3	PRBS 9	-	Off
	Enhanced data rate in-band spurious emission	TRM/CA/13/C	2-DHx or 2-Evx 3-DHx or 3-Evx2	PRBS 9	100 kHz RBW 300 kHz VBW	Off
	Enhanced power control	TRM/CA/14/C	DH1	PRBS 9	3 MHz RBW 3 MHz RBW	Off
Low Energy (LE) test cases	Output power at NOC	TRM-LE/CA/01/C	LE	PRBS 9	3 MHz RBW 3 MHz RBW	Off
	Output power at EOC)	TRM-LE/CA/02/C	LE	PRBS 9	3 MHz RBW 3 MHz RBW	Off
	In-band emissions at NOC	TRM-LE/CA/03/C	LE	PRBS 9	100 kHz RBW 300 kHz RBW	Off

Bluetooth mode	Measurement Description	Identifier	*Packet Type*	*Payload data*	*Measurement settings*	*Frequency Hopping*
Low Energy (LE) test cases	In-band emissions at EOC	TRM-LE/CA/04/C	LE	PRBS 9	100 kHz RBW 300 kHz RBW	Off
	Modulation characteristics	TRM-LE/CA/05/C	LE	11110000 10101010	2 MHz (Demodulator filter BW)	Off
	Carrier frequency offset and drift at NOC	TRM-LE/CA/06/C	LE	10101010	2 MHz (Demodulator filter BW)	Off
	Carrier frequency offset and drift at EOC	TRM-LE/CA/07/C	LE	10101010	2 MHz (Demodulator filter BW)	Off

Power Tests

Bluetooth devices are divided into three power classes based on their highest output power and modulation mode. Therefore, measuring output power is essential to making sure the Bluetooth device of a certain power class behaves according to the specification limits. The following measurements will be covered in this section:

- Output power
- Power density
- Power control
- Enhanced data rate relative transmit power

Output Power

Test Specification

- TRM/CA/01/C (Output power)
- TRM-LE/CA/01/C (Output power at NOC)
- TRM-LE/CA/02/C (Output power at EOC)

What is the purpose of the test?

Bluetooth power measurements are generally designed to ensure that the transmitter is able to produce the appropriate range of power levels required for interoperability with other Bluetooth devices at the same time minimizing interference within the ISM band and achieving balanced power consumption. The output power test verifies the maximum peak and average RF-output power, in dBm or mW, of the DUT. For low energy rate, the output power test is conducted at normal operating conditions (NOC) as well as EOC (extreme operating conditions).

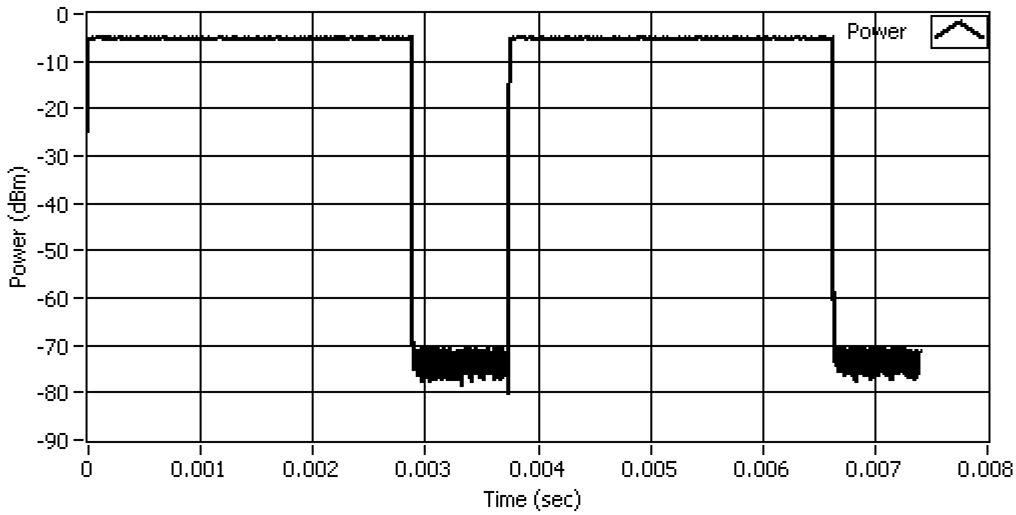
Minimum passing requirements:

Power Class	Power Range Requirement	
	Average Power	Peak Power
1	0 dBm < P_{AVG} < +20 dBm	P_{PK} < +23dBm
2	-6dBm <P_{AVG} < +4dBm	P_{PK} < +23dBm
3	P_{AVG} < 0dBm	P_{PK} < +23dBm
LE	-20dBm <= P_{AVG} <= +10dBm	P_{PK} <= P_{AVG}+3dB

Table 11. Power Test Requirements

How is the measurement performed?

The output power measurement is conducted in the time domain. Due to the bursted nature of the Bluetooth signal, a triggered measurement is setup based on the rising edge of the burst. The tester calculates the average power (P_{av}) over at least 20% to 80% of the burst and also records the highest power (P_{pk}) in the trace. The following figure illustrates the Power vs. Time plot for DH5 packet.



Measurement Interval=7.4ms, Reference Level=-5dBm, Bandwidth=3MHz, RBW Filter Type=Flat; Trigger Level=-25dBm.

Figure 26. Power vs. Time (DH5 packet)

Using the NI Bluetooth toolkit, measurements such as “Total Average Power” (P_{AVG}) and “Maximum Average power” (P_{PK}) can be easily performed. The following figure illustrates the output power measurement on DH5 packet with 339 bytes payload (PN9) at -5 dBm power output. The signal is transmitted on Channel 3 (2.405 GHz).

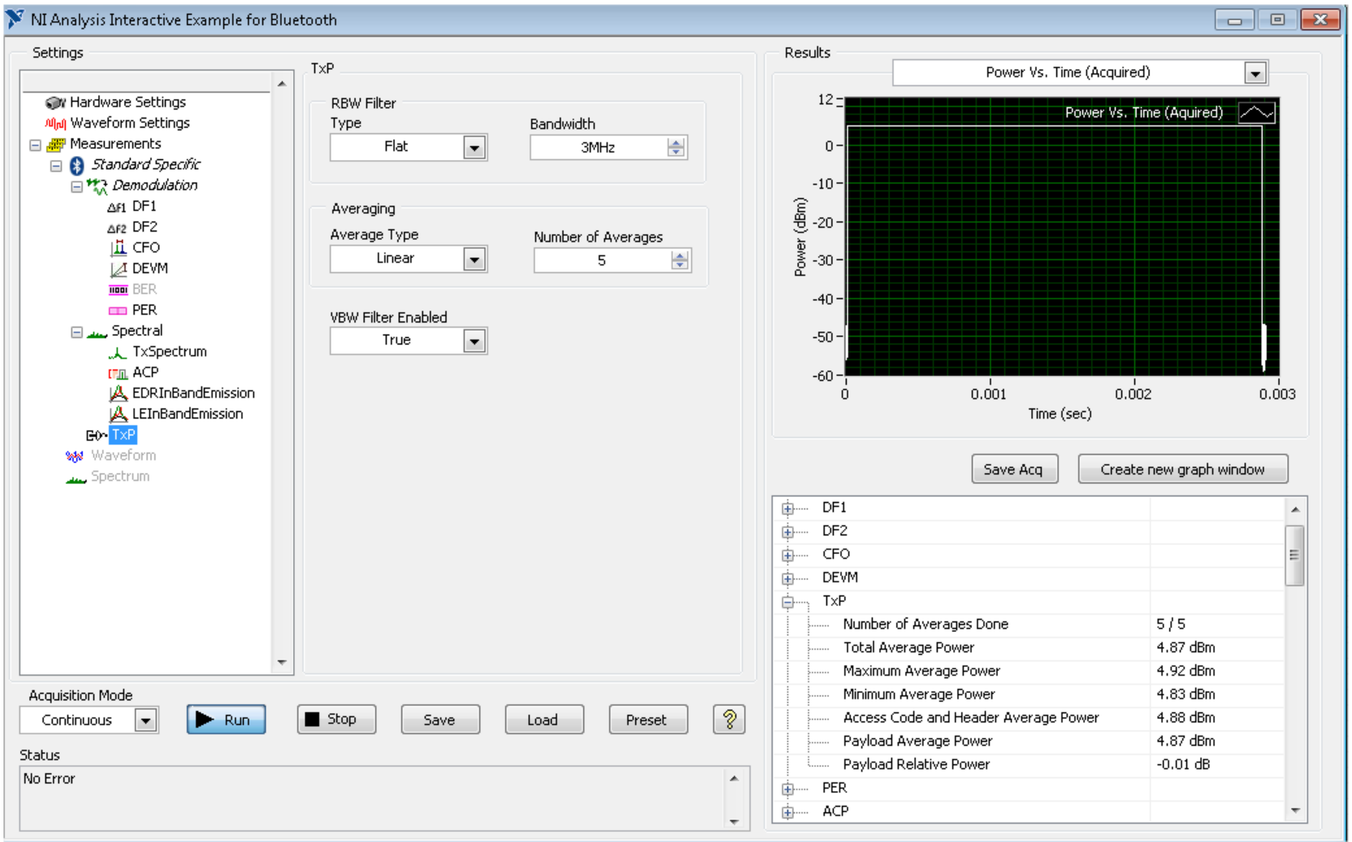


Figure 27. Output Power Measurement (DH5 packet)

In the figure above, TxP power measurements are displayed as well as a trace for one complete DH5 packet in time domain.

The output power test procedure for Bluetooth low energy devices is the very similar to the test procedure for BR/EDR Bluetooth devices. The following figure illustrates the output power measurement on LE packet with 37 bytes payload (PN9) at -5 dBm power output. The signal is transmitted on Channel 3 (2.408GHz).

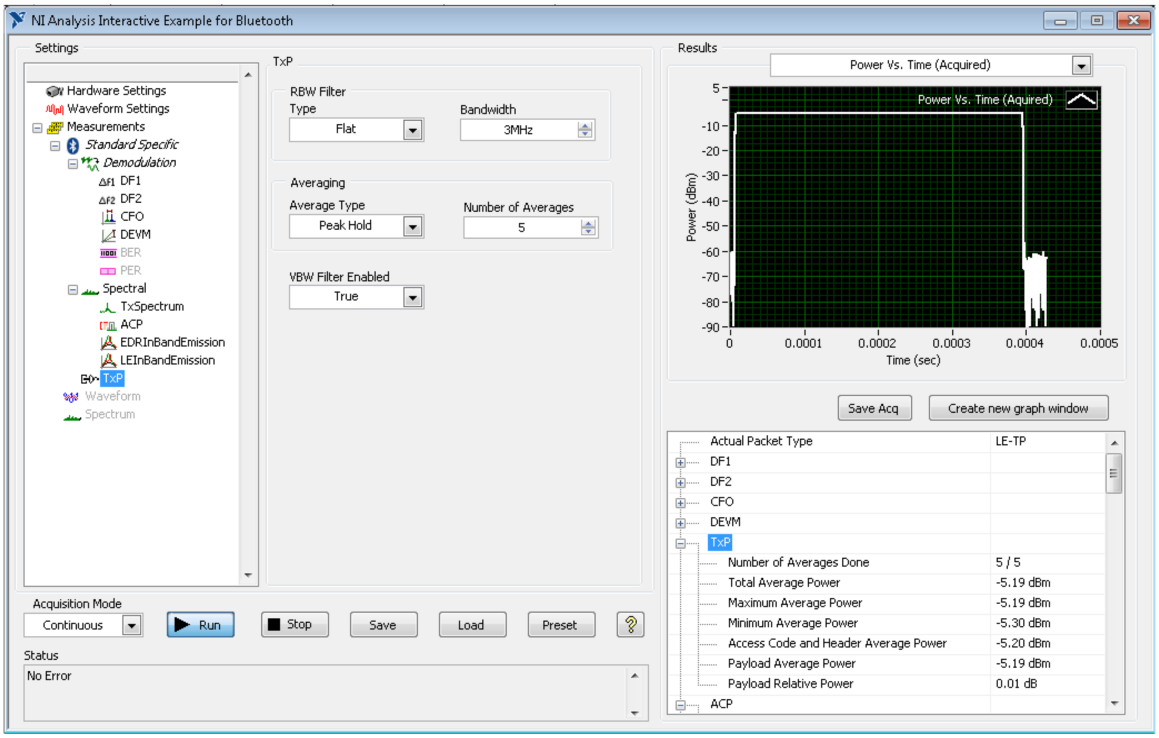


Figure 28. Output Power Measurement (LE packet)

Power density

<u>Test Specification</u>

- TRM/CA/02/C (Power density)

<u>What is the purpose of the test?</u>

The power density test verifies that the maximum transmitted RF-power density of the DUT does not exceed 100 mW (20 dBm) per 100 kHz. In addition, certain countries have additional regulations that put a limit on the maximum allowable power density transmitted by a device.

<u>Minimum passing requirements</u>:

All measured values must fulfill the following requirement:

Passing Requirement	Comments
Power Density < 100 mW (20dBm) per 100kHz EIRP	For any Power Class

Table 12. Passing requirements for the Power Density test

How is the measurement performed?

To determine the power density of the DUT, first, the frequency corresponding to the peak power value is determined across the entire Bluetooth operating band. The frequency hopping on the DUT is enabled. The tester is placed in the frequency mode, centered in the middle of the Bluetooth band, for example 2441MHz, and the span is set wide enough to acquire the entire Bluetooth band, for example 80MHz). The resolution bandwidth set to 100 kHz and the trace is set to Max Hold. Once the peak power frequency is determined, the tester is placed in the zero-span mode centered around the determined frequency. The sweep time is set to one minute and peak value in the trace is determined, corresponding to the power density per 100 kHz. The test is repeated under the extreme operating conditions (EOC) as well as for all country specific hopping modes.

Power control

Test Specification

- TRM/CA/03/C (Power control)

What is the purpose of the test?

Power control test verifies that power control step sizes and power levels are within the required range for a particular power class. During an active Bluetooth link, power control feature is used when one Bluetooth device wants to control or limit the TX power of another Bluetooth device to get the received signal characteristics within preferred levels.

Minimum passing requirements:

All measured values must fulfill the following requirement:

Passing Requirement	Comments
2 dB (min step size) ≤ step size ≤ 8 dB (max step size)	
P_{AV} < +4 dBm (at min power step)	For Any Power Class 1 Equipment

Table 13. Passing requirements for Power Control test

How is the measurement performed?

To conduct the power control test, an active connection has to be established between the DUT and the tester. Once the connection is established, the DUT starts off by transmitting DH1 packets at the maximum output power to the tester. The tester acquires the packets and measures the average power across 20% to 80% of the duration of a packet/burst. Then the tester issues an LMP command to decrease the output power by one power step. The average power is measured again and the process continues until the minimum possible output power step of the DUT is reached. This test is typically performed during the DUT development phase and requires the DUT to possess level control circuitry and RSSI functionality.

Enhanced data rate relative transmit power

Test Specification

- TRM/CA/10/C (Enhanced data rate relative transmit power)

What is the purpose of the test?

The Enhanced data rate relative transmit power test ensures that the difference in the average transmit power during frequency-modulated GFSK (PGFSK) and phase-modulated DPSK (PDPSK) portions of an EDR packet is within the standard-required range. Within the EDR packet, the Access Code & Header portions of the packet are modulated with GFSK and Synchronization Sequence, EDR payload portions of the packet are modulated with DPSK.

Minimum passing requirements:

All measured values must fulfill the following requirement:

	Passing Requirement
EDR	$(P_{GFSK} - 4\text{ dB}) < P_{DPSK} < (P_{GFSK} + 1\text{ dB})$

Table 14. Passing requirements for EDR Relative Transmit Power test

How is the measurement performed?

During this test, the DUT transmits, at maximum output power, longest supported π/4-DQPSK packet type (2-DHx or 2-EVx) with maximum length payload containing pseudorandom bit sequence (PRBS9). The measurement is conducted in time-domain (zero-span mode) with 3MHz RBW and sweep time long enough to accommodate one complete packet. For example, the 2-DH5 packet may occupy up to five time slots, therefore to cover one complete packet the sweep time would need to be 5x625us = 3.125ms. The trace type is set to average and ten traces are acquired to complete the measurement. The tester calculates average power PGFSK over 100% of the GFSK portion (Access Code & Header period) of the packet as well as the average power PDPSK over 100% of the DPSK portion of the packet (Synchronization sequence and EDR payload). The measurement is repeated at the middle and highest operating frequencies of the DUT, as well as for 8DPSK (3-DHx or 3-EVx) packets if supported by the DUT.

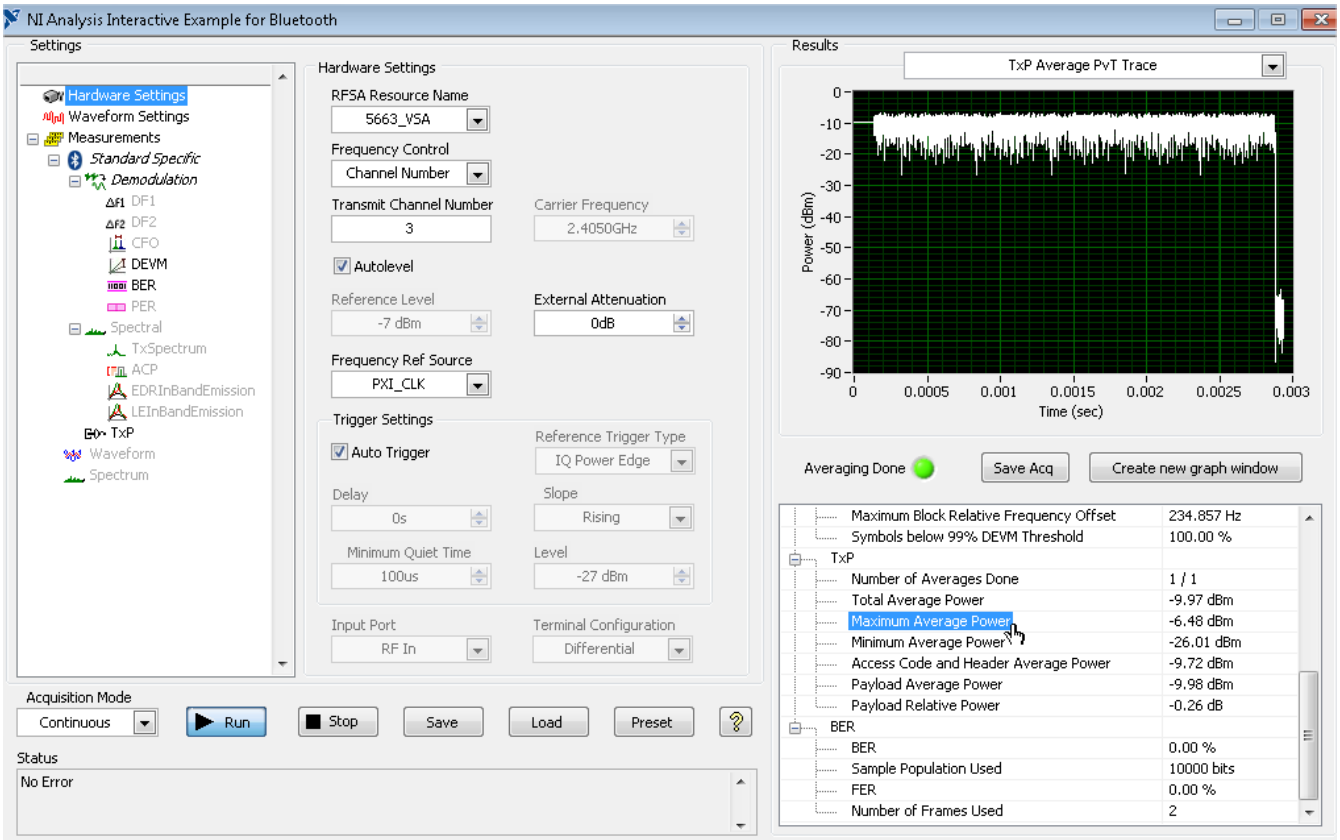


Figure 29 EDR relative transmit power measurement (NI Bluetooth Toolkit)

Modulation tests

Modulation measurements verify the performance of the modulation circuitry of the transmitter as well as the stability of its local oscillator. The following measurements will be covered in this section:

- Modulation characteristics
- Initial carrier frequency tolerance
- Carrier frequency drift
- Enhanced data rate carrier frequency stability and modulation accuracy
- Enhanced data rate differential phase encoding

Modulation Characteristics

Test Specification

- TRM/CA/07/C (Modulation characteristics)
- TRM-LE/CA/05/C (Modulation characteristics)

What is the purpose of the test?

In Bluetooth packets modulated using GFSK, a positive frequency deviation represents a binary one and a negative frequency deviation a binary zero. Refer to Figure 7 for more information on FSK modulation process. Modulation characteristics of a Bluetooth system verifies that the frequency deviations of the data bits transmitted in a GFSK packet are within appropriate limits. To accomplish that, two 8-bit sequences are transmitted with the following data patterns: 11110000 and 10101010. The frequency deviation corresponding to 11110000 pattern is called $\Delta f1$, and the frequency deviation corresponding to 10101010 pattern is called $\Delta f2$. Each of the bit patterns stresses different components of the system. For instance, the 11110000 checks the performance of the Gaussian filter of the Bluetooth transmitter whereas 10101010 gives a signal with symmetrical and equal time-weighted energy at each of the two frequencies, which tests the ability of the DUT to rapidly transition between them.

Bluetooth SIG specifies the required values of the frequency deviations for two sequences: the 11110000 bit pattern and 01010101 bit pattern. These values differ based on whether a basic rate or low energy packet is measured. The minimum passing requirements for frequency deviations are summarized below.

Minimum passing requirements:

All measured values must fulfill the requirements shown in Table 15.

	Passing Requirements
Basic Rate	• 140 kHz ≤ $\Delta f1_{avg}$ ≤ 175 kHz • $\Delta f2_{max}$ ≥ 115 kHz for at least 99.9% of all $\Delta f2_{max}$ • $\Delta f2_{avg}/\Delta f1_{avg} \geq 0.8$
Low Energy (LE)	• 140 kHz ≤ $\Delta f1_{avg}$ ≤ 175 kHz • At least 99.9% of $\Delta f2_{max}$ values over 10 test packets ≥ 185 kHz • $\Delta f2_{avg}/\Delta f1_{avg} \geq 0.8$

Table 15. Passing requirements for Modulation Characteristics test

How is the measurement performed?

To perform modulation characteristic test, the DUT initially transmits at the lowest operating frequency the longest supported DM, DH, or LE packet with full payload (1, 3 or 5 slot) with 11110000 bit pattern as payload. Maximum transmit power is used. The tester acquires the signal from the DUT and determines the zeroth bit position (p0) for each received packet to establish the timing reference for bits in the payload. Once the zeroth bit of the packet payload has been established, the tester calculates for each "00001111" 8-bit sequence in the received payload the average frequency over the frequency values of the 8 bits. Each bit is oversampled at least four times for basic rate packets and thirty-two times for low energy packets. The final frequency deviation for each bit is determined by taking an average value across these samples. For each second, third, sixth and seventh of the 8 bits the deviation from the average frequency within bit period is calculated and recorded as $\Delta f1_{max}$. The average of all the $\Delta f1_{max}$ deviation values is calculated and recorded as $\Delta f1_{AVG}$. In the next part of the test, a similar measurement procedure is performed while the DUT transmits a 01010101 bit pattern. However, in this case, for each bit maximum deviation from the average frequency is found and recorded as $\Delta f2_{max.}$ The average of all the $\Delta f2_{max}$ deviation values is calculated and recorded as $\Delta f2_{AVG}$. As a result, the maximum frequency deviation $\Delta f2_{max}$ and the average frequency deviation $\Delta f2_{AVG}$ are determined for 01010101 bit pattern. Once the four deviation values ($\Delta f1_{max}$, $\Delta f1_{AVG}$, $\Delta f2_{max}$, $\Delta f2_{AVG}$) have been obtained they are compared against the minimum passing requirements referenced in the specification. Bluetooth specification requires the measurement to be performed over a period of at least 10 packets. In addition to lowest operating frequency the modulation characteristic test should be conducted at mid operating frequency and highest operating frequency of the DUT.

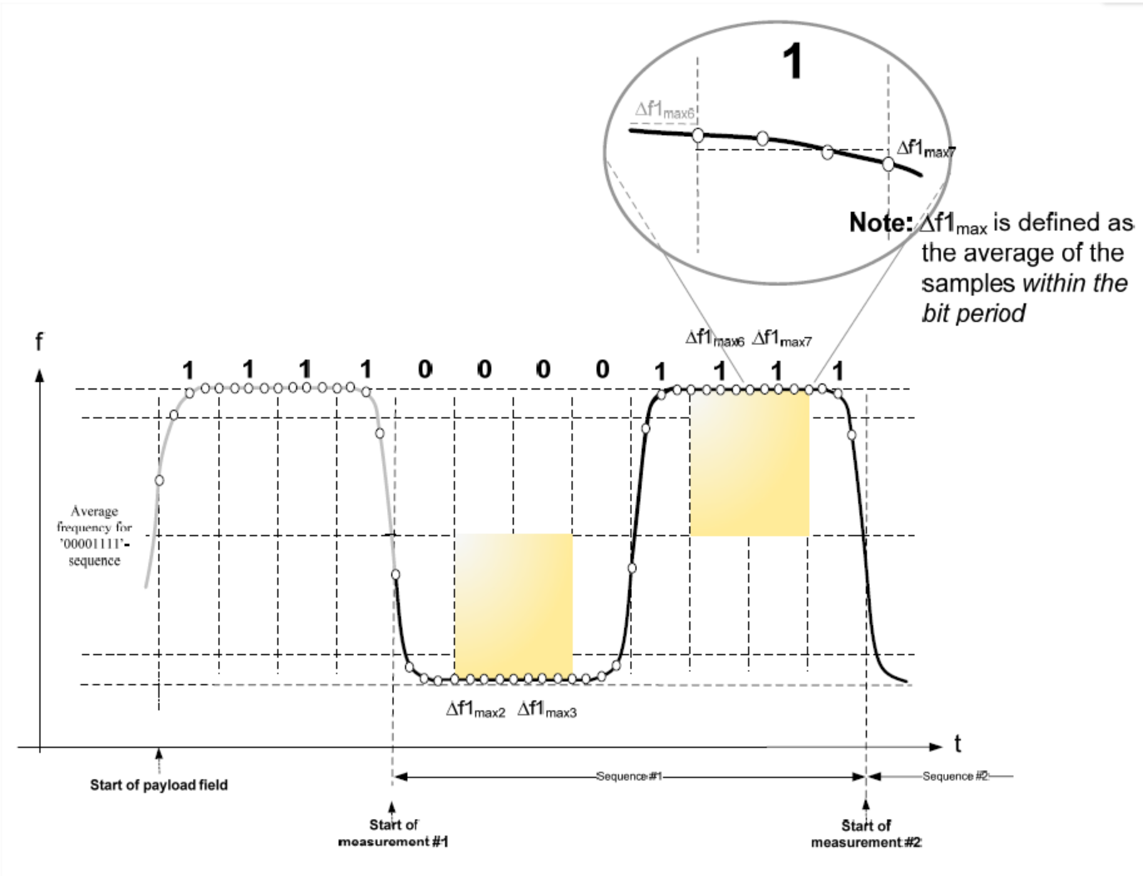


Figure 30. Frequency deviation measurement principle for 11110000-payload sequence [6]

All the standard required modulation characteristics measurements can be easily performed with the NI Bluetooth Analysis toolkit. The following figure demonstrates a standard-compliant modulation characteristics measurement on a Bluetooth low energy signal.

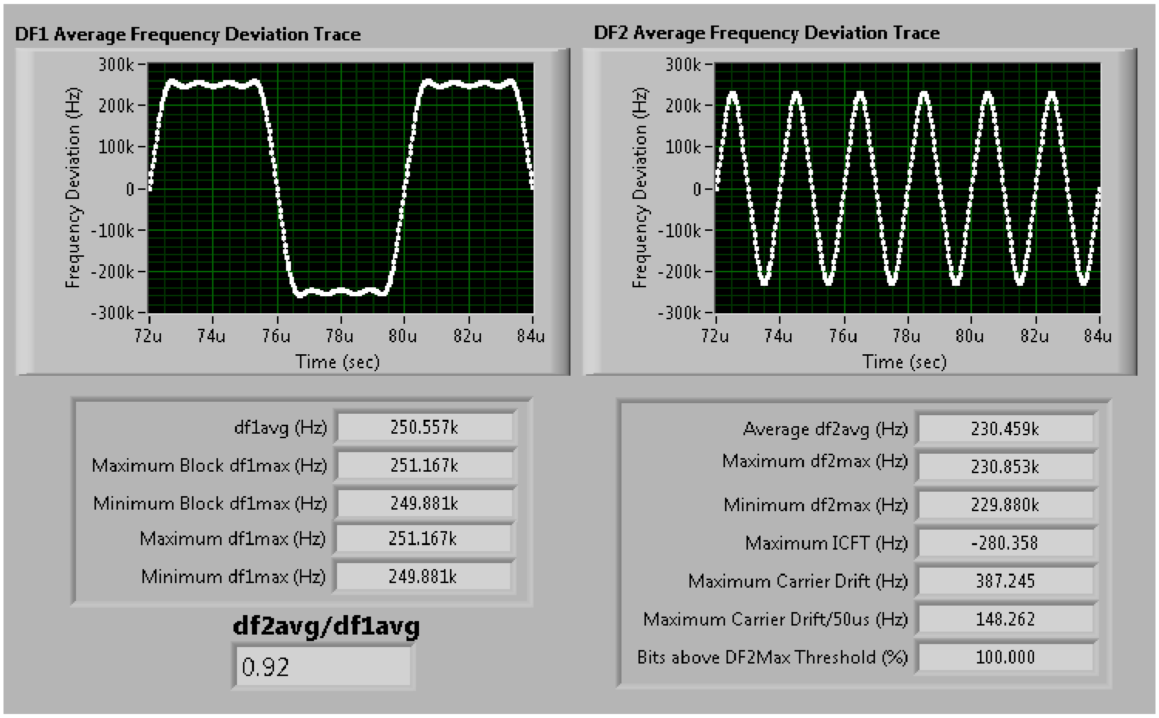


Figure 31. Modulation Characteristic Measurement on Low Energy Bluetooth signal (LabVIEW)

In Figure 32, the frequency deviation traces are displayed for one and a half bit periods (12 bits) of the 11110000 and 10101010 bit patterns respectively. In addition, all the standard-required measurements ($\Delta f1_{max}$, $\Delta f1_{AVG}$, $\Delta f2_{max}$, $\Delta f2_{AVG}$) are provided so that the pass/fail decision can be made. To obtain a sequential analysis of both bit patterns, the following NI Bluetooth Analysis property has to be enabled: Demodulation:Advanced:Pattern Check Enabled Property.

Initial Carrier Frequency Tolerance (ICFT)

Test Specification

- TRM/CA/08/C (Initial Carrier Frequency Tolerance)
- TRM-LE/CA/06/C (Carrier frequency offset and drift at NOC)

What is the purpose of the test?

The purpose of the Initial Carrier Frequency Tolerance test, which is also sometimes referred to as frequency offset test, is to measure the accuracy of the carrier frequency of the transmitter. The results of the test can reveal any accuracy issues with the transmitter's crystal oscillator.

Minimum passing requirements:

All measured values must fulfill the following requirement:

Passing Requirement
f_{TX} - 75 kHz ≤ f_0 ≤ f_{TX} + 75 kHz

Table 16. Passing requirements for Initial Carrier Frequency Tolerance test

How is the measurement performed?

To perform the carrier frequency tolerance test, the DUT initially transmits DH1 packets with PBRS9 payload at the lowest operating frequency and maximum output power. In the case of a low energy transmitter, low energy packets are transmitted with maximum payload containing repeating 1010101 bit pattern. The tester acquires the signal from the DUT and performs the measurement on the first four or eight preamble bits based on whether the basic rate or low energy packet has been acquired. In the basic rate case, after determining the zeroth bit position (*p0*) of the preamble, the tester integrates the frequency from the center of the first preamble bit to the center of the first bit following the fourth preamble bit. The result of this integration is the DUT's carrier frequency and is named f_0. For low energy packets, the measurement is performed on the first eight bits of the preamble instead of four. Figure 33 illustrates this principle.

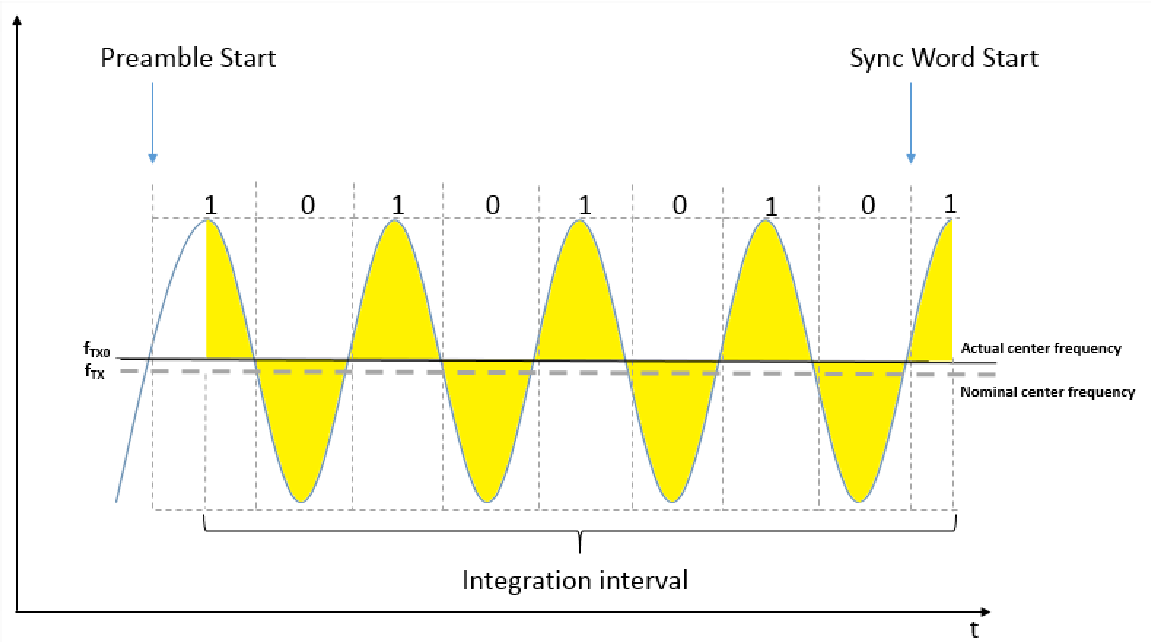


Figure 32. Initial frequency offset (f0) measurement principle (Low Energy Packet)

Once the DUT's carrier frequency, f_0 is measured, it's compared against the minimum passing requirements referenced in the specification. In addition, the measurement is performed over a period of at least 10 packets and the DUT's carrier tolerance is tested at mid and highest operating frequencies. Finally, the test specification mandates this test to be performed with both hopping turned on and off. When the hopping is on, the frequency settling characteristic of the transmitter can have an effect on the results. Figure 34 demonstrates the ICFT measurement using the NI Bluetooth Analysis Toolkit.

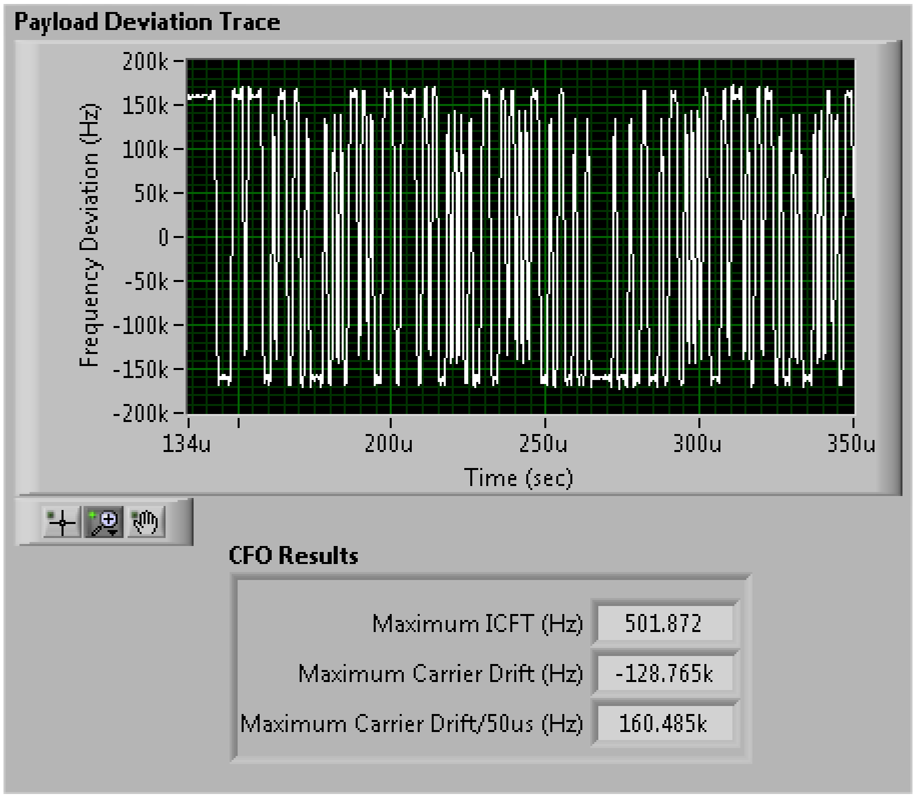


Figure 33. ICFT measurement on a DH1 packet with full payload (216 bits) at 2.405GHz (10 averages)

Maximum ICFT result provided by the toolkit represents the difference between the set carrier frequency and the measured carrier frequency of the DUT.

Carrier Frequency Drift

Test Specification

- TRM/CA/09/C (Carrier Frequency Drift)
- TRM-LE/CA/06/C (Carrier frequency offset and drift at NOC)
- TRM-LE/CA/07/C (Carrier frequency offset and drift at EOC)

What is the purpose of the test?

The purpose of the Carrier frequency drift test is to verify the transmitter center frequency drift within a packet.

Minimum passing requirements:

The center frequency of the transmitter is not allowed to drift more than the following limits:

Basic Rate Packets:

Packet Type	BR Passing Requirement	Comments
One slot Packet	$f_0 \pm 25$ kHz	The maximum drift rate is 20 kHz / 50 us, anywhere in a packet. f_0: average frequency of the 4 preamble bits. f_K: average frequency of any 10-bits in the payload field.
Three slot packet	$f_0 \pm 40$ kHz	
Five slot packet	$f_0 \pm 40$ kHz	
All packets	$f_{k+5} - f_k \leq 20$ kHz, $k = 0 \ldots max$	

Table 17. Passing requirement for BR Carrier Frequency Drift test

Low Energy Packets:

LE Passing Requirement	Comments
• $f_{TX} - 150 \text{ kHz} \leq f_n \leq f_{TX} + 150$ kHz, where $n = 0,1,2 \ldots k$ • $\lvert f_0 - f_n \rvert \leq 50$ kHz, where n=2,3,4…k • $\lvert f_1 - f_0 \rvert \leq 23$ kHz & $\lvert f_n - f_{n-5} \rvert \leq 20$ kHz, where n=6,7,8…k	The maximum drift rate is 20kHz / 50us, anywhere in a packet. f_K is the last frequency before CRC field.

Table 18. Passing requirements for LE Carrier Frequency Drift test

How is the measurement performed?

To perform the carrier frequency test, the DUT initially transmits packets with 10101010 payload at the lowest operating frequency and maximum output power. For BT/EDR transmitters all supported packets (DH1/3/5) with the longest supported payload is used. For LE transmitters, LE packets with longest supported payload are used. The tester acquires the signal from the DUT and performs the measurement on the first four or eight preamble bits based on whether the basic rate or low energy packet has been acquired. In the basic rate/EDR case, after determining the zeroth bit position (p0) of the preamble, the tester integrates the frequency from the center of the first preamble bit to the center of the first bit following the fourth preamble bit. The result of this integration is the DUT's initial carrier frequency and is named f_0. For low energy packets, the measurement is performed on the first eight bits of the preamble instead of four. The following figure illustrates this principle for Low Energy packets.

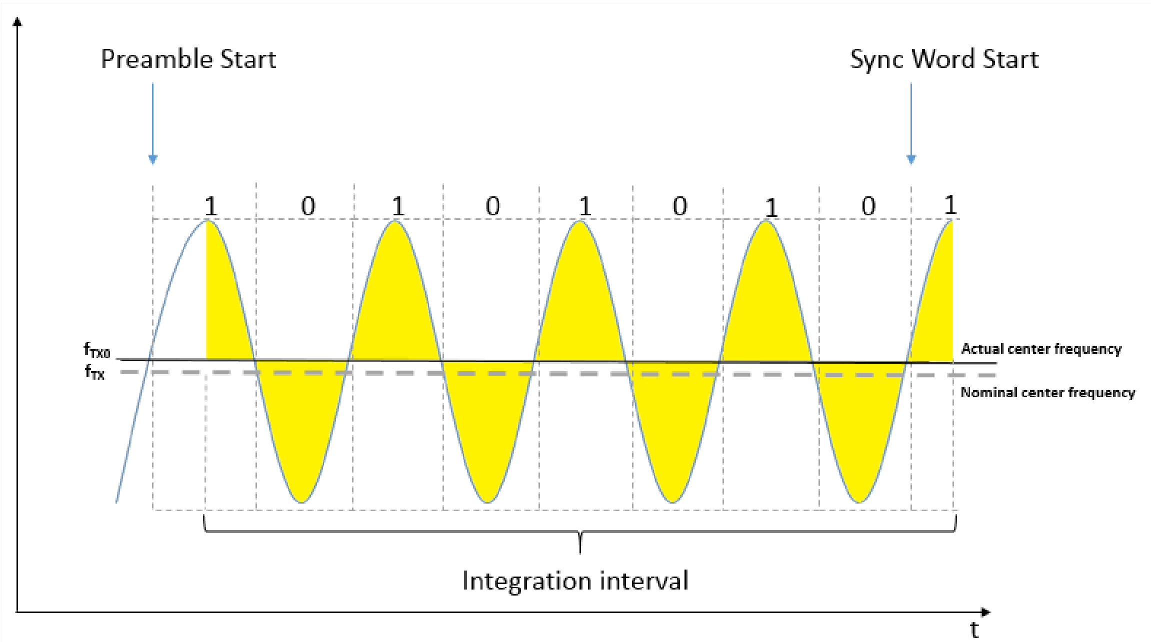


Figure 34. Initial frequency offset (f0) measurement principle (Low Energy Packet)

Once the DUT's initial carrier frequency, f_0 in the preamble is measured, the tester determines the frequency drift throughout the payload potion of the packet. The tester integrates the frequency deviations in 10-bit intervals starting at the beginning of the second bit within the payload body. Refer to figure below.

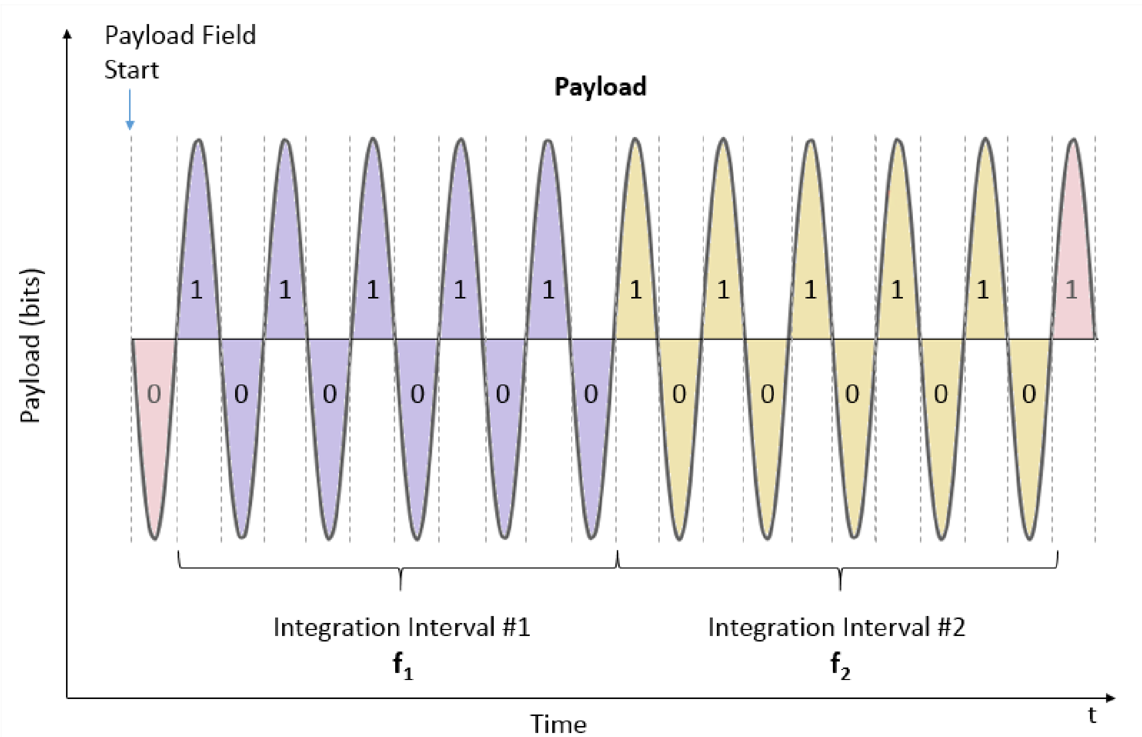


Figure 35. Frequency drift measurement principle

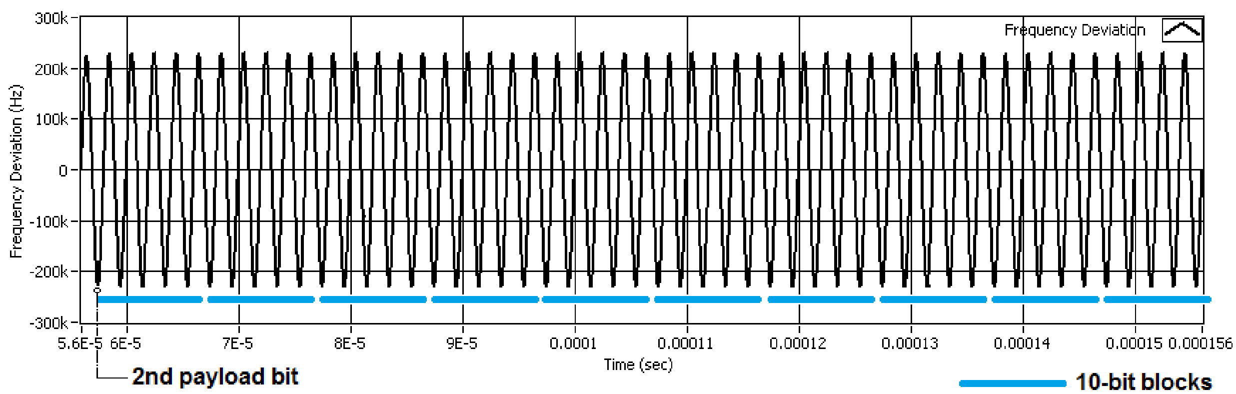


Figure 36 CFO Payload Deviation Trace (100us of the 37-byte LE payload containing 10101010 pattern)

The measurement is repeated until the end of the payload duration. Each time the integration on the ten payload bits is performed the result is recorded as f_n, where n is an integer from 1 to k. f_k represents the last integral sum before the start of the CRC field in the packet. Refer to the figure below.

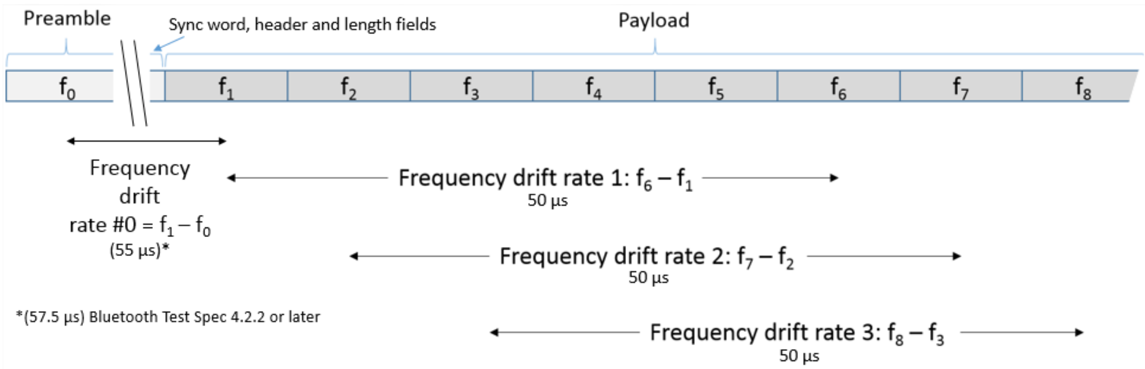
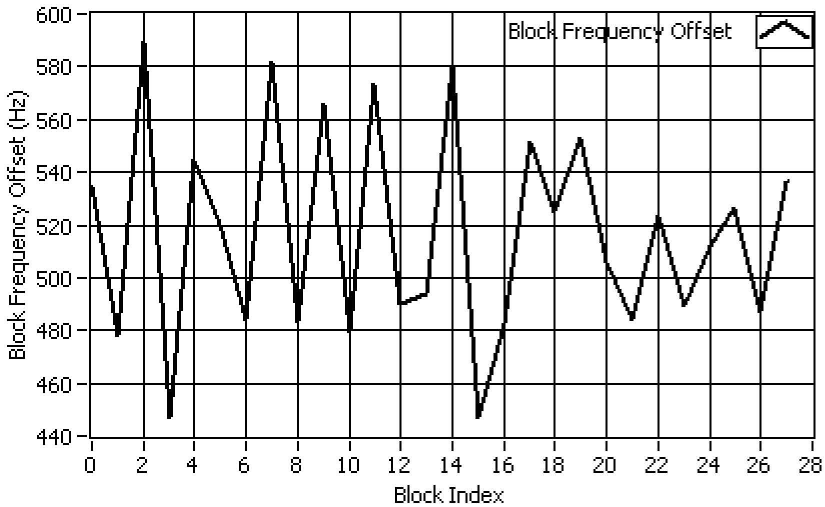


Figure 37. Frequency drift rate measurement principle

In addition, the measurement is performed over a period of at least 10 packets and the DUT's carrier drift is tested at mid and highest operating frequencies. Finally, the test specification mandates this test to be performed at normal (NOC) and extreme operating conditions (EOC) with packet whitening turned off. The frequency drift measurement results are compared against the passing requirement from the Bluetooth specification which mandates the maximum drift rate to be 20 kHz x 50 us, anywhere in the packet. The maximum drift rate applies to the difference between any two 10-bit blocks separated by 50 µs within the payload field of the returned packets. |fk + 5 – fk| ≤ 20 kHz Hz, k=0 … max. The following figure shows the Block Frequency (f_n) Offset trace for an LE packet with 37-byte payload containing the 10101010 bit pattern. This measurement was performed using NI Bluetooth Analysis Toolkit.



Actual Packet Type	LE-TP
DF1	
DF2	
CFO	
Number of Averages Done	10 / 10
Maximum ICFT	-506.503 Hz
Maximum Carrier Drift	589.136 Hz
Maximum Carrier Drift/50us	198.513 Hz
Maximum Payload Block frequency Offset	-506.503 Hz
Maximum Carrier Drift/55us	462.184 Hz

Figure 38. Carrier Frequency Offset (CFO) Trace and Measurement Results (LE packet, 37-byte payload containing 10101010 pattern)

Enhanced data rate carrier frequency stability and modulation accuracy

<u>Test Specification</u>

- TRM/CA/11/C (Enhanced data rate carrier frequency stability and modulation accuracy)

What is the purpose of the test?

The purpose of the EDR carrier frequency stability test is to verify that the drift of the transmitter center frequency, within the EDR portion of the packet, meets the standard-required limits. Similarly, the EDR modulation accuracy test verifies that the modulation errors, within the EDR portion of the packet, is below a certain, standard-required threshold based on the modulation scheme (pi/4-DQPSK or 8-DPSK) being used.

Minimum passing requirements:

All measured values must fulfill the following conditions:

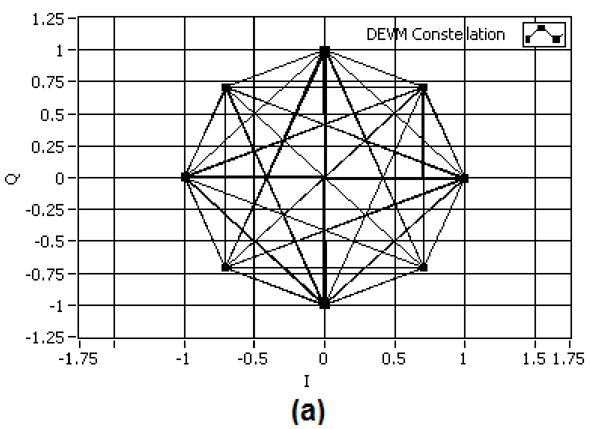
Measurement	Limits	Notes
Carrier Frequency Stability	$-75kHz \le \omega_i \le +75kHz$	for all packets
	$-75kHz \le (\omega_i+\omega_o) \le +75kHz$	for all blocks
	$-10kHz \le \omega_o \le +10kHz$	for all blocks
RMS DEVM	RMS DEVM ≤ 20%	for all π/4-DQPSK blocks
	RMS DEVM ≤ 13%	for all 8DPSK blocks
Peak DEVM	DEVM ≤ 35%	for all π/4-DQPSK symbols
	DEVM ≤ 25%	for all 8DPSK symbols
99% DEVM	DEVM ≤ 30%	for 99% of π/4-DQPSK symbols
	DEVM ≤ 20%	for 99% of 8DPSK symbols

Table 19. DEVM minimum passing requirements

How is the measurement performed?

To perform EDR frequency stability and modulation test, the DUT initially transmits at the lowest operating frequency the longest supported π/4-DQPSK packet type (2-DH1, 2-DH3, 2-DH5, 2-EV3, or 2-EV5) with PRBS9 pseudo-random as payload. Maximum transmit power is used. The tester acquires the signal from the DUT and calculates the initial center frequency error based on the frequency deviations of bits in the packet header. The average frequency deviation of the packet header bits that represent a transmitted "1" is denoted as $\Delta\omega_1$ and the average frequency deviation of the packet header bits that represent a transmitted "0" is denoted as $\Delta\omega_2$. Once the average frequency deviations have been measured, the tester calculates the initial frequency error as follows:
$\omega_i = (\Delta\omega_1 + \Delta\omega_2)/2$

Next, the tester uses the initial frequency error, ωi result to compensate for the frequency error in EDR portion of the packet. In addition, the tester applies a square-root raised cosine measurement filter with a roll-off factor, α of 0.4 and a 3 dB bandwidth of ±500 kHz to the EDR portion of the packet. The output of the measurement filter is then partitioned into 50 us, non-overlapping blocks starting at the first synchronization symbol in the packet and finishing at the final payload CRC symbol. For each 50 us block, the tester calculates the sampling phase ε_o and frequency error ω_o for the RMS differential error vector magnitude (DEVM) for the block. These results are then used to calculate DEVM for each symbol in the block. This procedure is repeated for the further packets transmitted by the DUT until a total 200 blocks have been measured. The test repeated at mid and highest operating frequencies. Finally, if the DUT supports 8-DPSK modulation, the whole test procedure described above is repeated using the longest supported 8-DPSK packet type (3-DH1, 3-DH3, 3-DH5, 3-EV3, or 3-EV5). The following figure shows the DEVM Constellation for the 3-EV5 packet as well as its associated DEVM Block Frequency Error, DEVM Block RMS Magnitude Error, and DEVM Payload Symbol DEVM traces. This measurement was performed using NI Bluetooth Analysis Toolkit.



Actual Packet Type	3-EV5
DEVM	
Number of Averages Done	10 / 10
Mean Block RMS DEVM	0.23 %
Maximum Block RMS DEVM	0.27 %
Mean Symbol Peak DEVM	0.21 %
Maximum Symbol Peak DEVM	0.67 %
99% DEVM	0.50 %
Mean Block RMS Magnitude Error	0.13 %
Maximum Block RMS Magnitude Error	0.15 %
Mean Block RMS Phase Error	0.14 deg
Maximum Block RMS Phase Error	0.26 deg
Mean Packet Initial Frequency Offset	216.385 Hz
Maximum Packet Initial Frequency Offset	288.307 Hz
Mean Block Absolute Frequency Offset	2.211 Hz
Maximum Block Absolute Frequency Offset	27.614 Hz
Mean Block Relative Frequency Offset	-214.174 Hz
Maximum Block Relative Frequency Offset	-307.338 Hz
Symbols below 99% DEVM Threshold	100.00 %

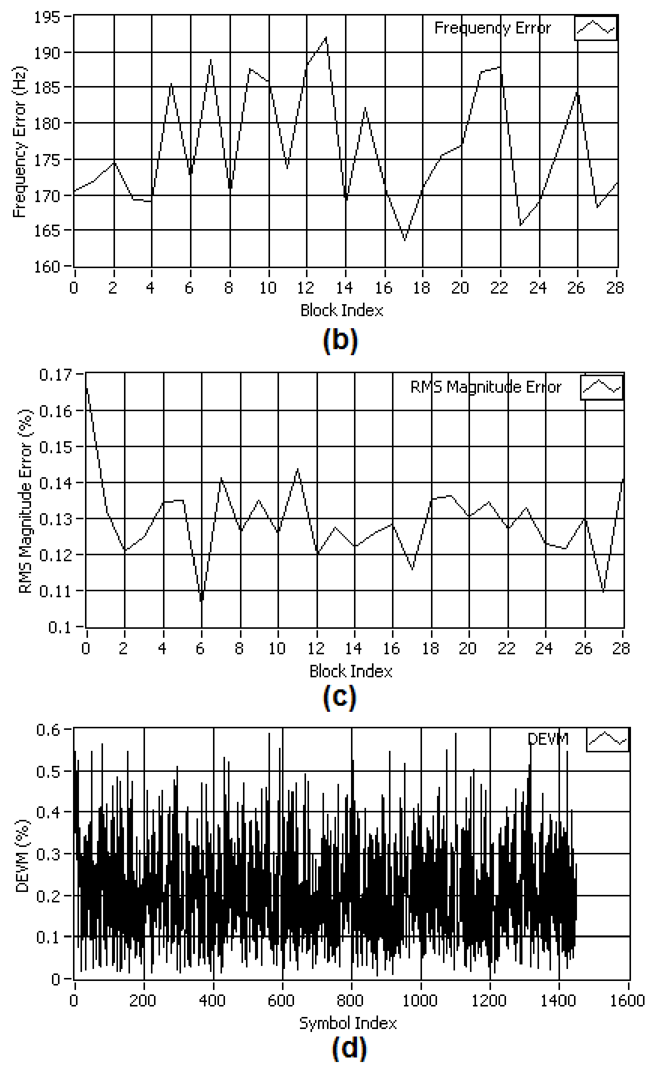


Figure 39. (a) DEVM Constellation for 3-EV5 packet (with 540-byte payload), (b) DEVM Block Frequency Error, (c) DEVM Block RMS Magnitude Error, (d) DEVM Payload Symbol DEVM Trace

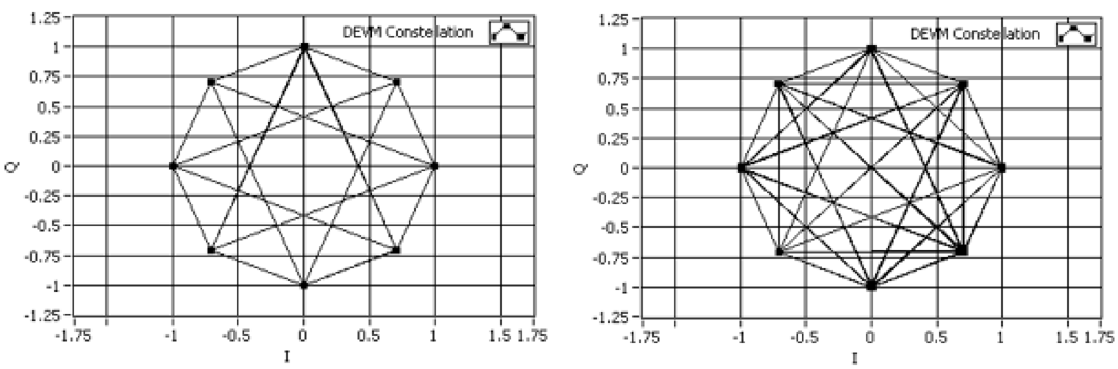
Enhanced data rate differential phase encoding

Test Specification

- TRM/CA/12/C (Enhanced data rate differential phase encoding)

What is the purpose of the test?

The purpose of this test is to verify that the differential PSK modulator correctly differential phase encodes the binary data stream onto the correct set of phase angles on the constellation diagram. Refer to Figure 41 below for pi/4-DQPSK and 8-DPSK modulations.



π/4-DQPSK Mapping	
Bit Sequence	**Phase Shift**
00	π/4
01	3π/4
11	-3π/4
10	-π/4

8DPSK Mapping	
Bit Sequence	**Phase Shift**
000	0
001	π/4
011	π/2
010	3π/4
110	π
111	-3π/4
101	-π/2
100	-π/4

Figure 40. Bits to Constellation Symbols Mapping

Minimum passing requirements:

Passing Requirement
Zero errors detected in 99% of packets

Table 20. Passing requirement for EDR Differential Phase Encoding test

How is the measurement performed?

To perform EDR differential phase encoding test, the DUT initially transmits at the lowest operating frequency the longest supported 2-DH1 or 2-EV3 packets with PRBS9 pseudo-random as payload. Maximum transmit power is used. The tester acquires the signal from the DUT and demodulates 100 packets and compares each packet payload with the expected PRBS9 data. For the purpose of this test, the PRBS9 pseudo random generator is initialized with a seed of all ones at the beginning of each test packet. Finally, if the DUT supports 8-DPSK modulation, the test procedure above is repeated using the longest supported 3-DH1 or 3-EV5 packets. The expected outcome of this test is that 99% of the packets will have no detected errors.

Spectrum Measurements

Spectral measurements provide several key insights to the performance of Bluetooth transmitters. Unlike modulation accuracy measurements, which are primarily used to ensure that a compatible receiver can demodulate the transmitted signal successfully, frequency domain measurements are intended to certify that the signal will not interfere with others. Many frequency domain measurements do not require the phase content of the captured signal. Thus you can use a spectrum analyzer for these measurements if a VSA is unavailable. To provide compliance with test specification, Bluetooth toolkit offers both FFT-based and Sweep based measurement methods. The following measurements will be covered in this section:

- Tx output spectrum-frequency range
- Tx output spectrum-20 dB bandwidth
- Tx output spectrum-adjacent channel power
- Enhanced data rate in-band spurious emission
- In-band emissions at NOC
- In-band emissions at EOC

Tx output spectrum-frequency range

Test Specification

- TRM/CA/04/C (Tx output spectrum-frequency range)

What is the purpose of the test?

The purpose of the frequency range test is to verify that transmitter emissions inside the Bluetooth operating frequency range (2.4GHz to 2.4835 GHz) are within the standard-required limits.

Minimum passing requirements:

Passing Requirement
2.4 GHz ≤ f_L, f_H ≤ 2.4835 GHz

Table 21. Passing requirement for TX Output Spectrum – Frequency Range test

How is the measurement performed?

To perform spectrum-range frequency test, the DUT initially transmits at the lowest operating frequency the longest supported DM or DH packet (1,3 or 5 slot) with full payload containing PRBS9 pseudo-random sequence. Maximum transmit power is used. The tester acquires the signal from the DUT and finds the lowest frequency below the operating frequency at which spectral power density drops below the level of –80 dBm/Hz EIRP (-30 dBm if measured with 100 kHz RBW, $Power_{dBm} = PSD_{dBm/Hz} + 10 * \log(BW_{Hz})$). The measured frequency is denoted as f_L. Next, the DUT transmits at the highest operating frequency the longest supported DM or DH packet with full payload. The tester acquires the signal from the DUT and finds the highest frequency above the operating frequency at which spectral power density drops below the level of –80 dBm/Hz EIRP. The measured frequency is denoted as f_H. The above procedure is repeated for all country specific operating frequency ranges supported by the DUT as well as at extreme test conditions (EOC). Figure 42 illustrates the frequency range measurement using the 5-slot DM packet with maximum payload.

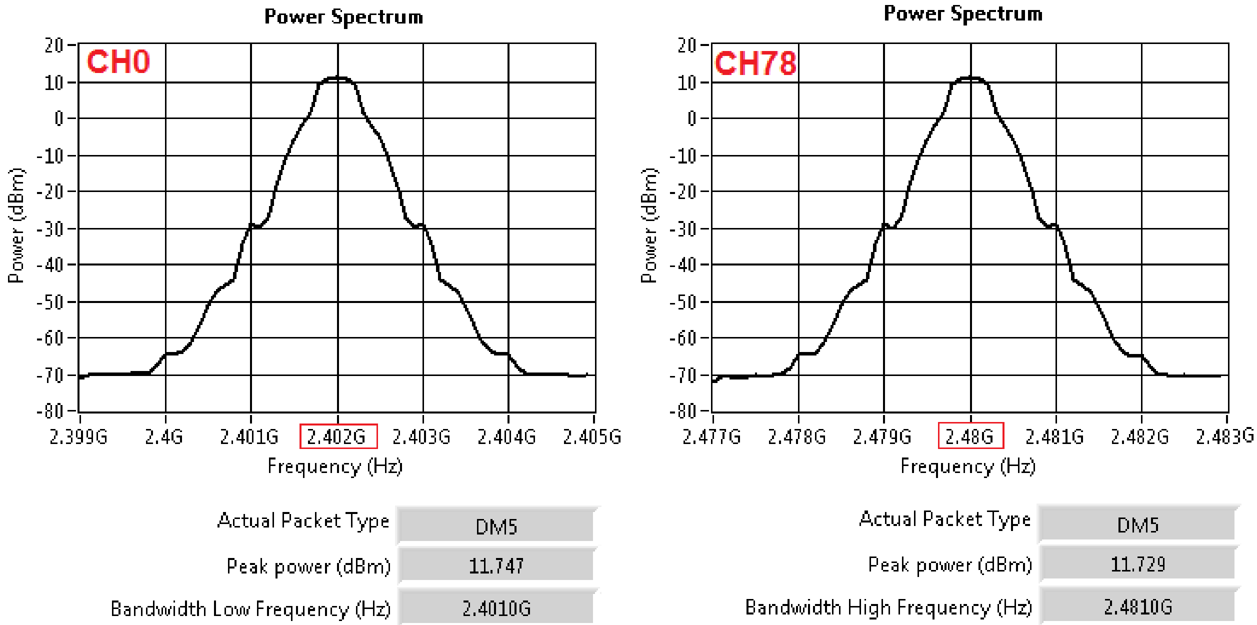


Figure 41. Frequency Range Measurement

Tx output spectrum-20 dB bandwidth

Test Specification

- TRM/CA/05/C (Tx output spectrum-20 dB bandwidth)

What is the purpose of the test?

The purpose of the 20 dB Bandwidth test is to verify that the frequency range, outside of which the DUT's transmit power drops 20 dB below the peak power in the transmit channel, is within the required limits.

Minimum passing requirements:

The transmit spectrum shall fulfill the following mask:

Passing Requirements
f=|fH-fL|=1.0 MHz, if highest power value measured ≥ 0 dBm
f=|fH-fL|=1.5 MHz, if highest power value measured < 0 dBm

Table 22. Passing requirements for TX Output Spectrum – 20 dB Bandwidth

How is the measurement performed?

To perform 20 dB bandwidth test, the DUT initially transmits at the lowest operating frequency the longest supported DM or DH packet (1,3 or 5 slot) with full payload containing PRBS9 pseudo-random sequence. Maximum transmit power is used. The tester acquires the signal from the DUT and finds the peak power in the transmit channel. Next, the tester determines the lowest frequency below the operating frequency at which transmit power drops 20dB below the peak power in the channel. The measured frequency is denoted as f_L. Next, the tester finds the highest frequency above the operating frequency at which transmit power drops 20 dB below the peak power in the channel. The measured frequency is denoted as f_H. The difference between the measured frequencies $\Delta f := |fH - fL|$ is the 20 dB bandwidth. The above procedure is repeated at mid and highest operating frequencies as well as at extreme test conditions (EOC). The following figure illustrates the 20 dB bandwidth measurement using the 5-slot DH packet with maximum payload.

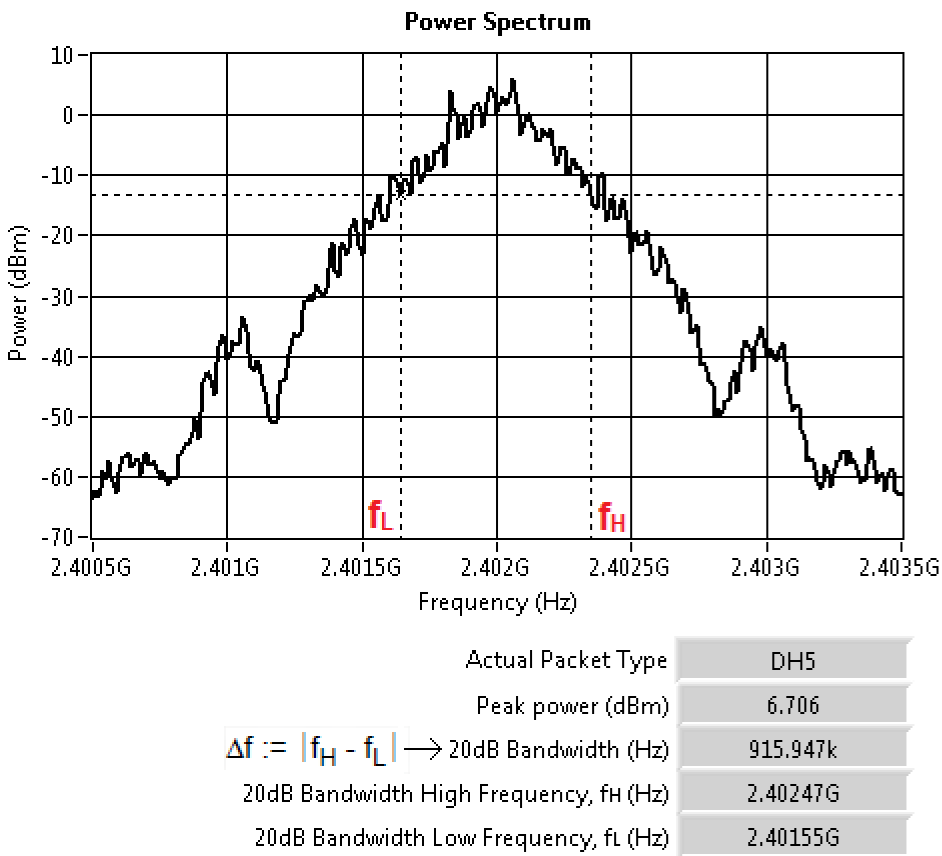


Figure 42. 20 dB Measurement on 5-slot DH packet

Tx output spectrum-adjacent channel power

Test Specification

- TRM/CA/06/C (Tx output spectrum-adjacent channel power)

What is the purpose of the test?

The purpose of the Adjacent Channel Power (ACP) test is to verify that the channel power in the channels adjacent to the main channel is within limits while the DUT is actively transmitting a Bluetooth signal in the main channel.

Minimum passing requirements:

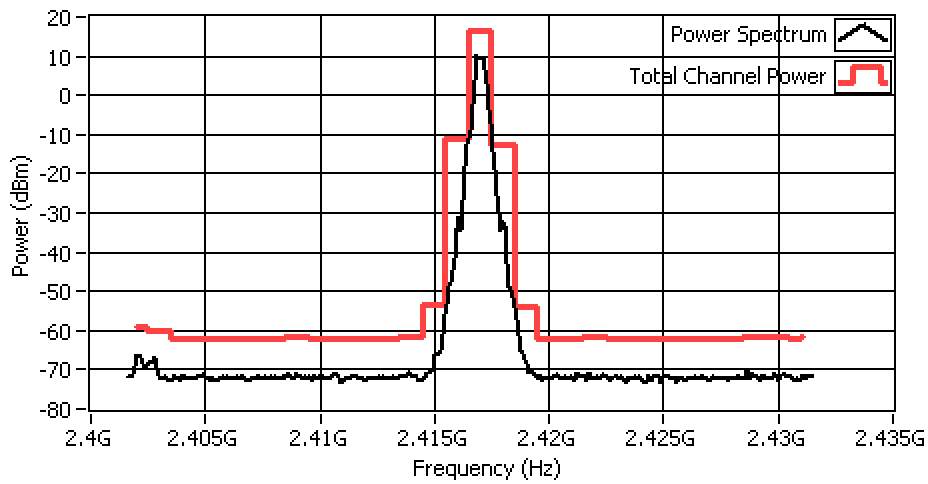
The DUT is transmitting on channel *M* and the adjacent channel power measurement is performed on channel number *N*.

Passing Requirements
$P_{TX}(f) \leq -20$ dBm, $\|M\text{-}N\|=2$
$P_{TX}(f) \leq -40$ dBm, $\|M\text{-}N\| \geq 3$

Table 23. Passing Requirements for TX Output Spectrum – Adjacent Channel Power test

How is the measurement performed?

To perform ACP test, the DUT initially transmits DH1 packets with PRBS9 as payload at f_{TX} = f(*M*)=f(3) (M=3), where *M* is the transmit frequency index. Maximum transmit power is used. The measurement frequency index is denoted by *N* and is initially set to zero (*N*=0). The tester acquires the signal from the DUT using the zero span mode, RBW = 100 kHz at center frequency equal to f(*N*)-450 kHz.The maximum power P_{TXn} of the trace is determined. The tester repeats the above measurement ten times, increasing the center frequency by 100 kHz until the center frequency of f(*N*) + 450 kHz is reached. Once the ten measurements have been performed, the total power in the adjacent channel is calculated by summing results of individual measurements as follows: P_{TX} (f) = Σ(P_{TXi}), *i* = 1….10. Next, the measurement center frequency is increased by 1 MHz(*N* = *N*+1) and the above procedure is repeated until the highest operating frequency is reached (f(*N*)is above the maximum TX frequency). The above procedure is also repeated at mid operating frequency and the frequency f(M_{max} – 3) where f(M_{max}) corresponds to the highest operating frequency. The following figure illustrates ACP measurement using the DH1 packet transmitted at channel 15 (*M* = 15).



ACP	
Measurement Status	Pass
Measurement Start Channel	0
Reference Total Channel Power	16.36 dBm
Upper Total Channel Power	-12.69 dBm
Lower Total Channel Power	-11.15 dBm
Total Channel Powers	
Channel [0]	-59.12 dBm
Channel [1]	-59.89 dBm
Channel [2]	-61.71 dBm
Channel [3]	-61.85 dBm
Channel [4]	-61.89 dBm
Channel [5]	-62.01 dBm
Channel [6]	-62.00 dBm
Channel [7]	-61.85 dBm
Channel [8]	-61.94 dBm
Channel [9]	-61.76 dBm
Channel [10]	-62.00 dBm
Channel [11]	-61.98 dBm
Channel [12]	-61.73 dBm
...	...

Figure 43 ACP measurement on DH1 packet at 2.417GHz (CH=15)

In-band spurious emission

Test Specification

- TRM/CA/13/C (Enhanced data rate in-band spurious emission)
- TRM-LE/CA/03/C (In-band emissions at NOC)
- TRM-LE/CA/04/C (In-band emissions at EOC)

What is the purpose of the test?

The purpose of the In-Band Spurious Emission test is to verify that the level of unwanted signals from the transmitter, within the operating frequency range of the device, doesn't exceed the specified limits. This test is performed for EDR and Low Energy transmitters. For example, for EDR transmitter, there should be no emissions exceeding 26 dB below the maximum transmitted power beyond 500 kHz range away from the carrier.

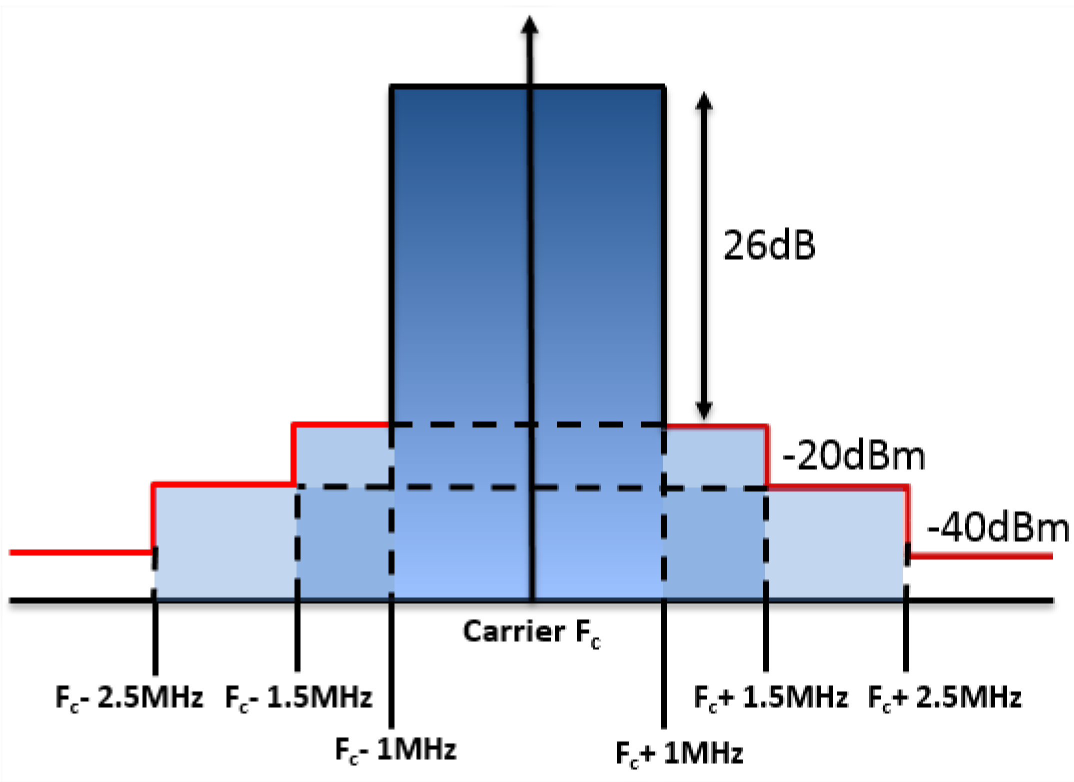


Figure 44. EDR Transmitter Spectral Mask

Minimum passing requirements:

All measured values must fulfill the following requirements:

	Passing Requirements
Basic Rate/EDR	• $P_{TX\text{-}26dB}(f) \leq P_{TXref}$ -26 dB for |M-N| = 1 • $P_{TX}(f) \leq$ -20 dBm for |M-N| = 2 • $P_{TX}(f) \leq$ -40 dBm for |M-N| ≥ 3
Low Energy	• $P_{TX} \leq$ -20 dBm for (f_{TX} ± 2 MHz) • $P_{TX} \leq$ -30 dBm for (f_{TX} ± [3+n] MHz); where n=0,1,2…

Table 24. Passing requirements for In-Band Spurious Emission test

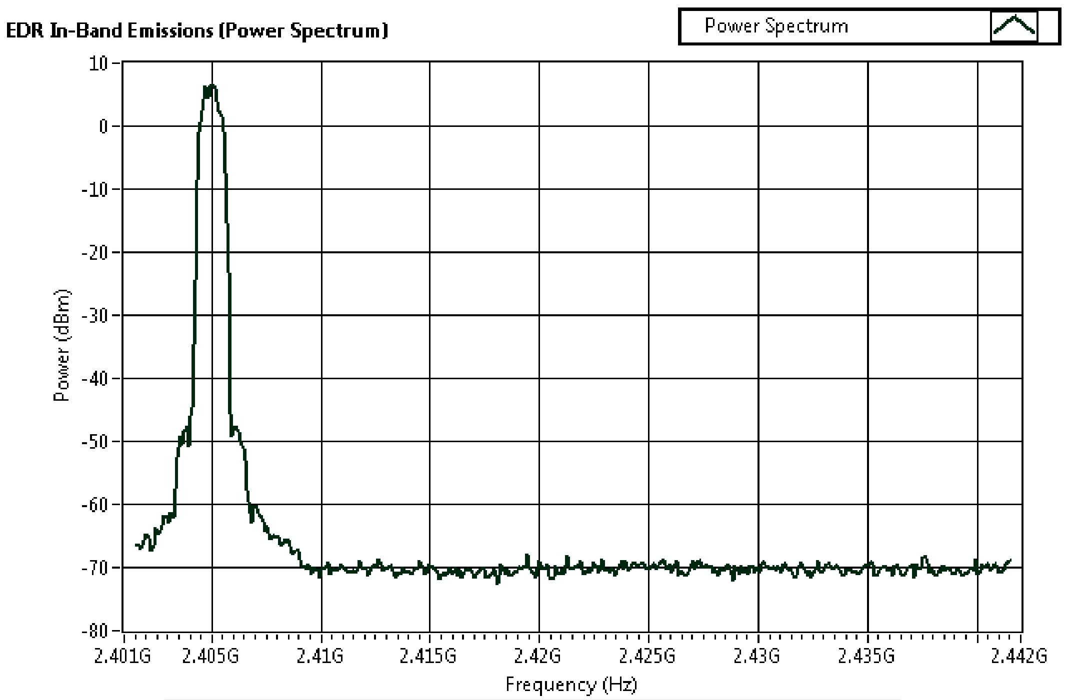
How is the measurement performed?

To perform EDR In-Band Spurious Emission test, the DUT initially transmits the longest supported π/4-DQPSK packet type (2-DH1, 2-DH3, 2-DH5, 2-EV3, or 2-EV5) with PRBS9 pseudo-random as payload at $f_{TX} = f(M)=f(3)$ (M=3), where M is the *transmit* frequency index. For example, M = 3 corresponds to third Bluetooth EDR channel with center frequency of 2.405 GHz. Maximum transmit power is used. The *measurement frequency index/channel* is denoted by N and is initially set to zero (N=0). As the test progresses N is incremented by one until the whole regulatory range is covered. The tester acquires the signal from the DUT using the gated zero span mode, RBW = 100kHz, VBW = 300 kHz at center frequency equal to f(N)-450 kHz. Only the DPSK portion of the packet as well as the preceding guard interval and power down ramp at the end of the packet are acquired by the tester. During the measurement, as the f(N) is increased while the transmit frequency, f(M) is kept constant, the emission levels at different regions within the operating range are calculated based on the following four scenarios:

1. If $|M-N|>1$, the tester acquires the signal from the DUT at f(N) – 450 kHz and determines the maximum power P_{TXn} of the trace. The tester repeats the above measurement ten times, increasing the center frequency by 100 kHz until the center frequency of f(N) + 450 kHz is reached. Once the ten measurements have been performed, the total power in the analyzed frequency band is calculated by summing results of individual measurements as follows: $P_{TX}(f) = \Sigma(P_{TXi})$, where i = 1....10.
2. If (M-N) = +1 (lower channel), the tester acquires the signal from the DUT at f(N)-450 kHz and determines the maximum power P_{TXn} of the trace. The tester repeats the above measurement five times, increasing the center frequency by 100 kHz until the center frequency of f(N) – 50 kHz is reached. Once the five measurements have been performed, the average power in the analyzed frequency band is calculated as follows: $P_{TX\text{-}26dB}(f) = \Sigma(P_{TXi})/5$, where i = 1....5.

3. If (M-N)=0 (reference channel), the tester acquires the signal from the DUT at f(N)-450kHz and determines the maximum power P_{TXn} of the trace. The tester repeats the above measurement ten times, increasing the center frequency by 100kHz until the center frequency of f(N)+450kHz is reached. Once the ten measurements have been performed, the maximum power in the analyzed frequency band is as follows: P_{TXref} (f) = max(P_{TXi}), where i = 1....10.
4. If (M-N) = -1 (upper channel), the tester acquires the signal from the DUT at f(N) + 50 kHz and determines the maximum power P_{TXn} of the trace. The tester repeats the above measurement five times, increasing the center frequency by 100kHz until the center frequency of f(N) + 450 kHz is reached. Once the five measurements have been performed, the average power in the analyzed band is calculated as follows: $P_{TX-26dB}$ (f) = Σ(P_{TXi})/5, where *i* = 1....5.

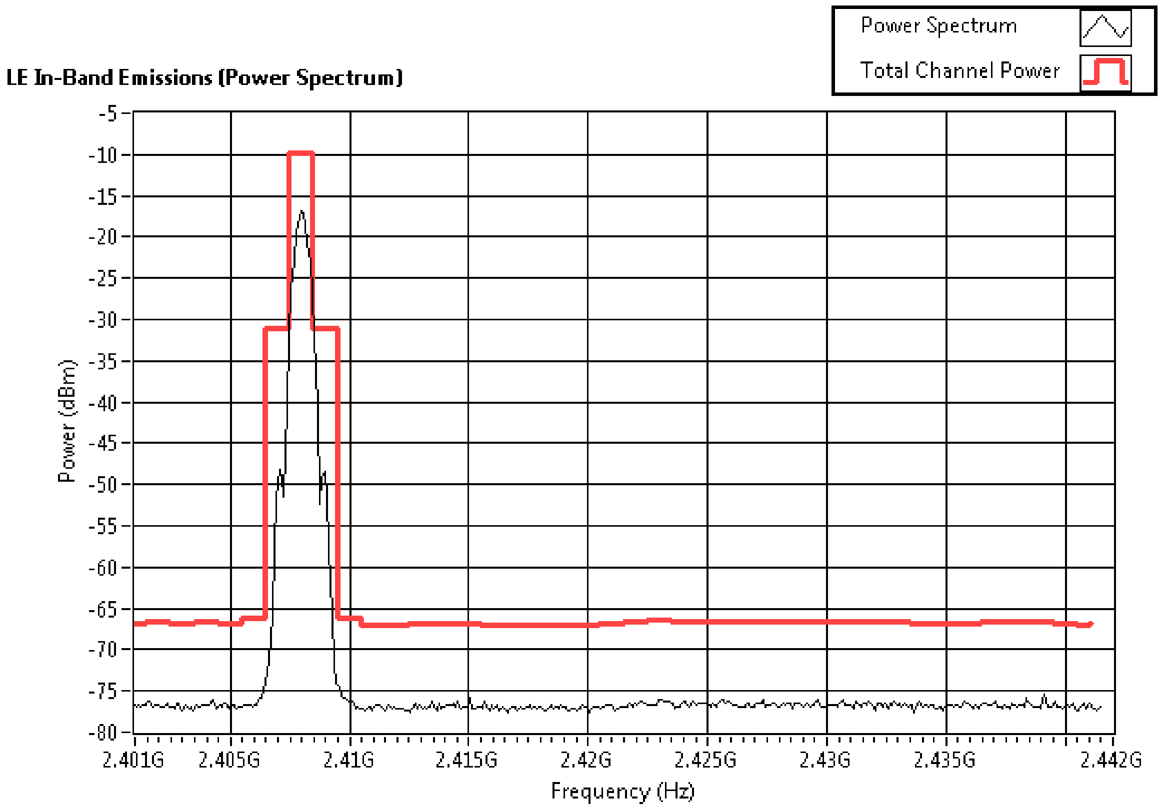
The above procedure is repeated until the highest operating frequency is reached (f(*N*)is above the maximum TX frequency). Finally, the whole procedure is repeated at mid operating frequency and the frequency f(M_{max} – 3) where f(M_{max}) corresponds to the highest operating frequency. The following figure illustrates EDR In-Band Emissions measurement using the 3-EV3 packet transmitted at 10 dBm on channel 3 (*M*=3) or 2.405 GHz.



EDRInBandEmission	
Measurement Status	Pass
Measurement Start Channel	0
Reference Channel Power	6.65 dBm
Upper Channel Power	-48.64 dBm
Lower Channel Power	-49.26 dBm
Guard Position	138.13u sec
Channel Powers	
Channel [0]	-55.83 dBm
Channel [1]	-49.29 dBm
Channel [2]	-49.26 dBm
Channel [3]	6.65 dBm
Channel [4]	-48.64 dBm
Channel [5]	-49.21 dBm
Channel [6]	-55.65 dBm
Channel [7]	-58.96 dBm
Channel [8]	-62.05 dBm
Channel [9]	-61.19 dBm
Channel [10]	-61.62 dBm
Channel [11]	-61.77 dBm
Channel [12]	-62.12 dBm

Figure 45. EDR In-band Emissions (40 channels shown)

To perform Low Energy In-Band Spurious Emission test, a similar approach is used as for EDR in-band spurious emissions test. The DUT transmits LE test packets with maximum payload size and PRBS9 as the payload. The tester acquires the signal from the DUT using 1 MHz frequency span and RBW = 100 kHz, VBW = 300 kHz. The acquisition center frequency is set to 2401 MHz + *N* MHz, with *N* initially set to zero. As the test progresses, *N* is incremented by 1 MHz until the whole regulatory range is covered. At each *N* increment the tester determines the maximum power, $P_{TX\_N,i}$ at the following ten frequencies: 2401 MHz + N MHz – 450 kHz + I * 100 kHz, where *I* = 0..9. Once those values have been determined the total channel power for the analyzed band is calculated and recorded: : $P_{TX} = \Sigma(P_{TX\_N,i})$. The above process is repeated until center frequency of 2481 MHz is reached. Finally, the whole procedure is repeated at mid and high operating frequencies. The following figure illustrates Low Energy In-Band Emissions measurement using the LE packet transmitted at 0dBm at 2.408GHz.



LEInBandEmission	
Measurement Status	Pass
Measurement Start Channel	-1
Reference Total Channel Power	-3.66 dBm
Upper Total Channel Power	-67.01 dBm
Lower Total Channel Power	-67.08 dBm
Total Channel Powers	
Channel [-1]	-79.84 dBm
Channel [0]	-79.33 dBm
Channel [1]	-79.25 dBm
Channel [2]	-78.50 dBm
Channel [3]	-77.06 dBm
Channel [4]	-67.08 dBm
Channel [5]	-25.24 dBm
Channel [6]	-3.66 dBm
Channel [7]	-24.99 dBm
Channel [8]	-67.17 dBm
Channel [9]	-76.91 dBm

Figure 46 LE In band Emissions Measurement

4. *Receiver Measurements*

The Bluetooth receiver measurements are designed to ensure that a receiver is able to consistently demodulate over-the-air transmissions with minimal error. As a result, receiver performance must be measured over a range of conditions, including conditions where the transmitted signal has a high power, conditions where the signal has a lower power level, and in the presence of both out-of-band and in-band interferes. The Bit Error Rate is the primary metric used to assess the performance of the receiver across the range of conditions. BER is determined by comparing the received payload data to the payload data that has been originally transmitted. The BER is calculated by taking ratio of the received erroneous bits to the total number of received bits in the payload data. The receiver measurements specified by Bluetooth specification are summarized in the table below.

Bluetooth mode	**Measurement Description**	**Identifier**	**RF-PHY TS.3.0/4.0(LE) Section**
Basic Rate (BR) Test cases	Sensitivity – single-slot packets	RCV/CA/01/C	*5.1.17*
	Sensitivity - multi-slot packets	RCV/CA/02/C	*5.1.18*
	C/I performance	RCV/CA/03/C	*5.1.19*
	Blocking performance	RCV/CA/04/C	*5.1.20*
	Inter-modulation performance	RCV/CA/05/C	*5.1.21*
	Maximum input level	RCV/CA/06/C	*5.1.22*
*Enhanced Data Rate (*EDR) test cases	Enhanced data rate sensitivity	RCV/CA/07/C	*5.1.23*
	Enhanced data rate BER floor sensitivity	RCV/CA/08/C	*5.1.24*
	Enhanced data rate C/I performance	TP/RCV/CA/09/C	*5.1.25*
	Enhanced data rate maximum input level	RCV/CA/10/C	*5.1.26*
Low Energy (LE) test cases	Receiver sensitivity at NOC	RCV-LE/CA/01/C	6.3.1
	Receiver sensitivity at EOC	RCV-LE/CA/02/C	6.3.2
	C/I and receiver selectivity performance	RCV-LE/CA/03/C	6.3.3
	Blocking performance	RCV-LE/CA/04/C	6.3.4
	Intermodulation performance	RCV-LE/CA/05/C	6.3.5
	Maximum input signal level	RCV-LE/CA/06/C	6.3.6
	PER Report Integrity	RCV-LE/CA/07/C	6.3.7

Note: Identifier naming convention is: (Test)/CA/NN/C, in which
TRC = Transceiver test
RCV = Receiver test
CA = Capability test (defines the type of testing)
NN = Test purpose number
C = Conformance test performed on dedicated *Bluetooth* test system (defines the scope)

Table 25 Receiver Measurements

The receiver tests are usually performed with frequency hopping turned off and PRBS 9 is used as the payload, however the packet type being used will vary based on the test being performed. Table 26 provides a summary of major test settings required for various receiver tests. Most of the receiver test are done in Loopback mode and the tester is required to be able to correctly identify and demodulate the return packets from the DUT. For more details, refer to RF-PHY TS.3.0/4.0 specifications. Although currently NI Bluetooth toolkit does not directly support loopback mode, the majority of the receiver tests can be still performed if the DUT control is available and the DUT is able to report BER data through a serial interface. The Loopback is primarily needed for testing Bluetooth Basic Rate and EDR devices. When testing Bluetooth Low Energy devices, NI Bluetooth Toolkit features Direct Test Mode that allows sending HCI commands to the DUT and obtaining measurements from the DUT such as RX PER which is the primary metric for Bluetooth receiver tests.

Bluetooth mode	**Measurement Description**	**Identifier**	***Packet Type***	***Payload data***	***BER measurement***	***Frequency Hopping***	***Whitening***
Basic Rate (BR) Test cases	Sensitivity – single-slot packets	RCV/CA/01/C	DH1	PRBS 9	< 0.1%	Off On (optional)	Off
	Sensitivity - multi-slot packets	RCV/CA/02/C	DH5	PRBS 9	< 0.1%	Off On (optional)	Off
	C/I performance	RCV/CA/03/C	Longest supported	PRBS 9	< 0.1%	Off	Off
	Blocking performance	RCV/CA/04/C	DH1	PRBS 9	< 0.1%	Off	Off
	Inter-modulation performance	RCV/CA/05/C	DH1	PRBS 9	< 0.1%	Off	Off
	Maximum input level	RCV/CA/06/C	DH1	PRBS 9	< 0.1%	Off	Off
*Enhanced Data Rate (*EDR) test cases	Enhanced data rate sensitivity	RCV/CA/07/C	2-DHx or 2–Evx 3-DHx or 3–Evx	PRBS9	< 7x10^–5 or < 10^–4	Off	On
	Enhanced data rate BER floor sensitivity	RCV/CA/08/C	2-DHx or 2–Evx 3–DHx	PRBS9	< 7x10^–6 or < 10^–5	Off	On
	Enhanced data rate C/I performance	TP/RCV/CA/09/C	2-DHx or 2–Evx	PRBS9	< 10–3 less than 5	Off	On

Bluetooth mode	**Measurement Description**	**Identifier**	***Packet Type***	***Payload data***	***BER measurement***	***Frequency Hopping***	***Whitening***
			3–DHx		times within 2 Mhz from the wanted signal		
	Enhanced data rate maximum input level	RCV/CA/10/C	2-DHx or 2–Evx 3–DHx	PRBS9	< 10^-3	Off	On
Low Energy (LE) test cases	Receiver sensitivity at NOC	RCV-LE/CA/01/C	LE	PRBS9	< 0.1%*	Off	Off
	Receiver sensitivity at EOC	RCV-LE/CA/02/C	LE	PRBS9	< 0.1%*	Off	Off
	C/I and receiver selectivity performance	RCV-LE/CA/03/C	LE	PRBS9 PRBS15	< 0.1%*	Off	Off
	Blocking performance	RCV-LE/CA/04/C	LE	PRBS9	< 0.1%*	Off	Off
	Intermodulation performance	RCV-LE/CA/05/C	LE	PRBS9	< 0.1%*	Off	Off
	Maximum input signal level	RCV-LE/CA/06/C	LE	PRBS9	< 0.1%*	Off	Off
	PER Report Integrity	RCV-LE/CA/07/C	LE	PRBS9	< 0.1%*	Off	Off

*- For Bluetooth Low Energy the BER limit will vary based on the payload length (<0.1% is for payload length of 37 bytes).. Refer to Table 50 in the Appendix for more details.

Table 26. Bluetooth RF.TS.4.0 Receiver Measurements

The following receiver tests will be covered in this section:

- Sensitivity
- C/I and receiver selectivity performance
- Blocking performance
- Intermodulation performance
- Maximum input signal level
- EDR - BER Floor Performance

Sensitivity

Test Specification

- RCV/CA/01/C (Sensitivity – single-slot packets)
- RCV/CA/02/C (Sensitivity - multi-slot packets)
- RCV/CA/07/C (Enhanced data rate sensitivity)
- RCV-LE/CA/01/C (Receiver sensitivity at NOC)
- RCV-LE/CA/02/C (Receiver sensitivity at EOC)

What is the purpose of the test?

The purpose of the receiver sensitivity test is to verify that the sensitivity of the DUT meets the required limit of-70 dBm or less, while being stimulated by non-ideal signals representing realistic traffic conditions. The receiver sensitivity level is one of the key parameters that affects the maximum range of a radio link.

Minimum passing requirements:

	Passing Requirements
Basic Rate	BER ≤ 0.1%, after minimum of 1,600,000 payload bits
Enhanced Data Rate	BER ≤ 0.007%, after minimum of 1,600,000 bits or BER≤ 0.01% after 16,000,000 bits
LE	PER ≤ 30.8%*, minimum of 1500 packets

*- For Bluetooth Low Energy the BER/PER limit will vary based on the payload length (BER<0.1% or PER≤30.8% is for payload length of 37 bytes). Refer to Table 50 in the Appendix for more details.

Table 27. Passing requirements for Sensitivity test

How is the measurement performed?

To perform the sensitivity test, the tester initially transmits the packets to the DUT at the transmit power such that the input power at the DUT interface is -70 dBm. The DUT receives the packets, extracts the payload data and re-transmits the recovered payload data in the same packet type as it received. The tester acquires the re-transmitted packets from the DUT and performs the BER measurement. Although the sensitivity test procedure remains the same, the actual sensitivity test parameters used during the test will vary based on the data rate and the duration of the test packets.

Basic Rate (single-slot packets): To perform the sensitivity test for basic rate single-slot packets, the tester and the DUT are initially set to the lowest operating frequency and the tester transmits “dirty”, single-slot DH1 packets with maximum payload (PRBS9) size to the DUT. The “dirty” packets contain various impairments as summarized in Table 28.

Dirty Transmitter Parameters for Basic Rate Packets

Set of Parameters	Carrier Frequency Offset	Modulation Index	Symbol Timing Error
1	75 kHz	0.28	-20 ppm
2	14 kHz	0.3	-20 ppm
3	-2 kHz	0.29	+20 ppm
4	1 kHz	0.32	+20 ppm
5	39 kHz	0.33	+20 ppm
6	0 kHz	0.34	-20 ppm
7	-42 kHz	0.29	-20 ppm
8	74 kHz	0.31	-20 ppm
9	-19 kHz	0.28	-20 ppm
10	-75 kHz	0.35	+20 ppm

Table 28 Dirty Transmitter Parameters for Basic Rate Packets

The tester transmits the first 20 ms using the first impairment set, the next 20 ms using the second impairment set and so on. Once the 10th impairment set is transmitted the sequence is repeated starting from the first impairment set. In addition to the carrier frequency offset and symbol timing error, a carrier-frequency drift over time is added to the input signal. This is implemented by adding a sine wave with deviation of ±25kHz and modulation frequency of 1.6kHz to the impaired packets. The sine wave is synchronized with the packets such that every other packet starts at either 0° or 180° of the synchronized sine wave. Refer to the Figure 47 for more information on frequency drift emulation principle for Basic Rate packets:

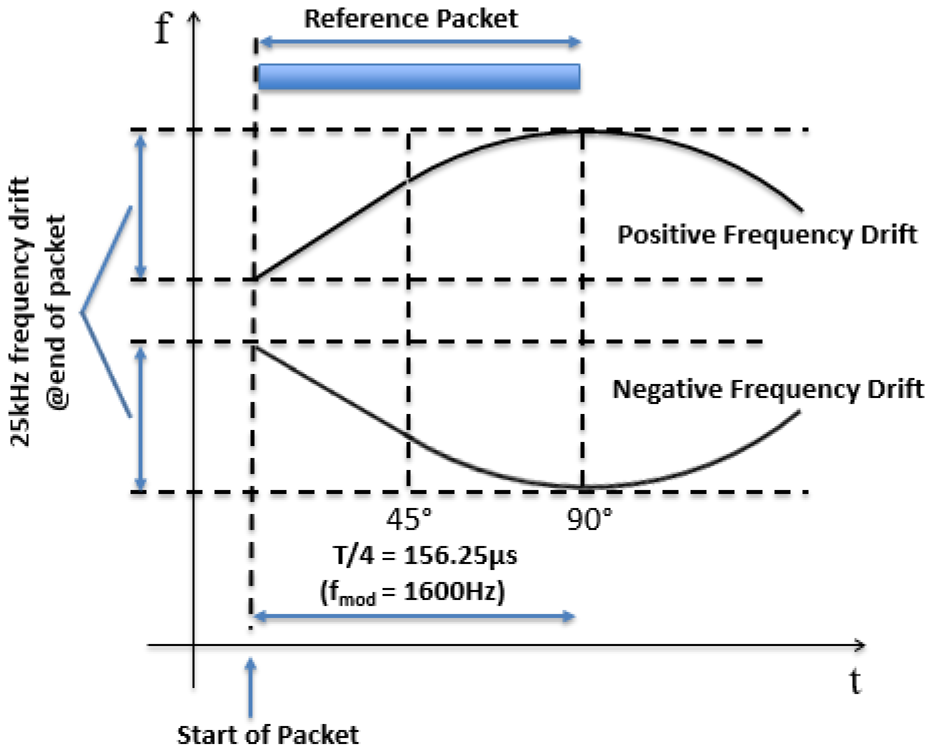


Figure 47 Dirty Transmitter Frequency Drift Emulation Principle (BR, single slot)

The above test procedure is also repeated at mid and highest operating frequencies, as well as extreme test conditions (EOC).

Basic Rate (multi-slot packets): The sensitivity test procedure for multi-slot packets is the same as for the single-slot packets. However, for the multi-slot case the tester continuously sends “dirty” DH5 or DH3 packets (in case the 5-slot packets are non-supported by the DUT) with PRBS9 as the payload. The “dirty” packets contain various impairments as summarized in Table 28. Finally, to realize the carrier frequency drift, additional, packet-synchronized sine wave is added to the signal with a deviation of ±40kHz and modulating frequency of 300Hz for 5-slot packets (DH5) and 500Hz for 3-slot packets (DH3). The test procedure is also repeated at mid and highest operating frequencies, as well as extreme test conditions (EOC).

Enhanced Data Rate (EDR): The sensitivity test procedure for EDR packets is the same as for basic rate packets. However, for EDR case, the tester continuously sends “dirty” pi/4-DQPSK packets with the longest supported packet type (2-DHx or 2-EVx) and with maximum size payload containing PRBS9 sequence. The “dirty” packets contain various impairments as summarized in Table 30.

Dirty Transmitter Parameters for Enhanced Data Rate Packets		
Set of Parameters	**Carrier Frequency Offset**	**Symbol Timing Error**
1	0 kHz	0 ppm
2	+65 kHz	+20 ppm
3	-65 kHz	-20 ppm

Table 29. Dirty Transmitter Parameters for Enhanced Data Rate Packets

The tester transmits the first 20 packets using the first impairment set, the next 20 packets using the second impairment set and so on. Once the 3rd impairment set is transmitted the sequence is repeated starting from the first impairment set. In addition to the carrier frequency offset and symbol timing error, a carrier-frequency drift over time is added to the input signal as well. This is implemented by adding a sine wave with deviation of ±10kHz and modulation frequency of 10 kHz to the impaired packets. The sine wave is synchronized with the packets such that every other packet starts at either 0° or 180° of the synchronized sine wave. Refer to the Figure 48 for more information on frequency drift emulation principle for EDR packets.

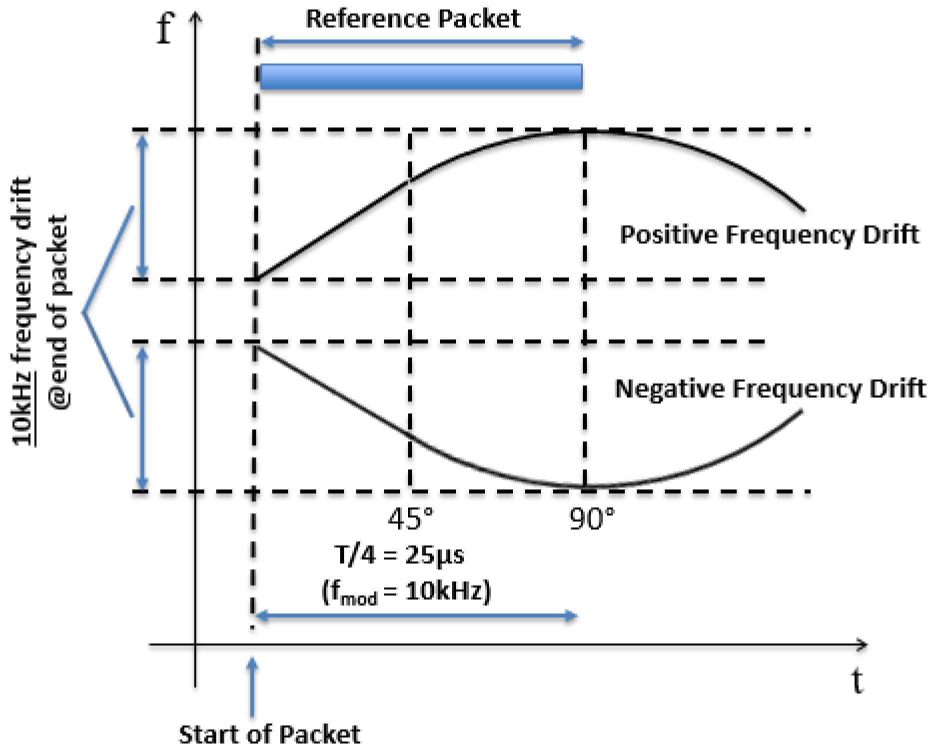


Figure 48 Transmitter Frequency Drift Emulation Principle (EDR)

The test procedure is also repeated at mid and highest operating frequencies, as well as extreme test conditions (EOC). Finally, if the DUT supports 8-DPSK packets the above test procedure is repeated with longest supported 8-DPSK packets (3-DHx or 3-EVx) with maximum size payload containing PRBS9 sequence.

Low energy: For low energy the sensitivity test is very similar to sensitivity test for BR/EDR devices. The tester continuously sends “dirty” LE packets with maximum size payload containing PRBS9 sequence. The “dirty” packets contain various impairments as summarized in Table 32.

Dirty Transmitter Parameters for Low Energy Packets

Set of Parameters	Carrier Frequency Offset	Modulation Index	Symbol Timing Error
1	100 kHz	0.45	-50 ppm
2	19 kHz	0.48	-50 ppm
3	-3 kHz	0.46	+50 ppm
4	1 kHz	0.52	+50 ppm
5	52 kHz	0.53	+50 ppm
6	0 kHz	0.54	-50 ppm
7	-56 kHz	0.47	-50 ppm
8	97 kHz	0.5	-50 ppm
9	-25 kHz	0.45	-50 ppm
10	-100 kHz	0.55	+50 ppm

Table 30 Dirty Transmitter Parameters for Low Energy Packets

The tester transmits the first 50 packets using the first impairment set, the next 50 packets using the second impairment set and so on. Once the 10th impairment set is transmitted the sequence is repeated starting from the first impairment set. In addition to the carrier frequency offset and symbol timing error, a carrier-frequency drift over time is added to the input signal as well. This is implemented by adding a sine wave with deviation of ±50kHz and modulation frequency of 625Hz* to the impaired packets. The sine wave is synchronized with the packets such that every other packet starts at either 0° or 180° of the synchronized sine wave. Refer to the Figure 49 for more information on frequency drift emulation principle for LE packets.

* - Corrected as 1250 Hz in Bluetooth Low Energy test specification 4.2.3

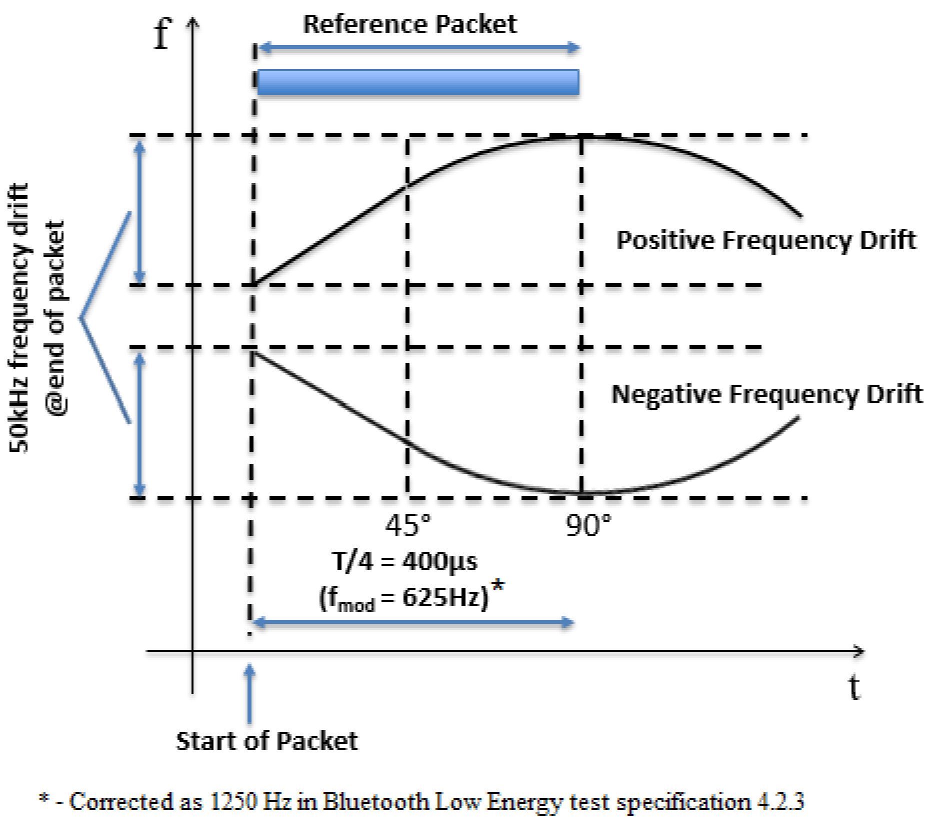


Figure 49 Dirty Transmitter Frequency Drift Emulation Principle (LE)

The low energy sensitivity test needs to be performed only at normal test conditions (NOC).

EDR BER Floor Performance

Test Specification

- RCV/CA/08/C (Enhanced data rate BER floor sensitivity)

What is the purpose of the test?

The purpose of the test it to verify the ability of the receiver to meet the minimum required BER at -60 dBm (10 dB above the reference sensitivity level).

Minimum passing requirements:

Passing Requirement
• BER ≤ 7×10^{-6} after 8,000,000 bits, or • BER ≤ 10^{-5} after 160,000,000 bits

Table 31. Passing requirements for EDR BER Floor Performance test

How is the measurement performed?

To perform the EDR BER floor performance test, the tester initially transmits the pi/4-DQPSK packets to the DUT at lowest operating frequency and transmit power such that the input power at the DUT interface is -60 dBm (measured over the DPSK modulated version of the packet). The longest supported packet type is used (2-DHx or 2-EVx) with maximum payload containing PRBS9. The DUT receives the packets, extracts the payload data and re-transmits the recovered payload data in the same packet type as it received. The tester acquires the re-transmitted packets from the DUT and performs the BER measurement after 8,000,000 bits have been received. The measurement is compared with the threshold 7*10^-6. If the measured BER is less than the threshold, the tester repeats the above test procedure at mid and highest operating frequencies. If the BER is greater than the threshold the measurement is continued until 160 000 000 payload bits have been received. The tester then repeats the above test procedure at mid and highest operating frequencies. Finally, if the 8-DPSK packets are supported by the DUT the above test procedure is repeated with the longest supported 8-DPSK packet type (3-DHx or 3-EVx) with maximum size payload containing PRBS9. The EDR BER floor performance test is only performed under normal operating conditions.

Maximum Input Signal Level

Test Specification

- RCV/CA/06/C (Maximum input level)
- RCV/CA/10/C (Enhanced data rate maximum input level)
- RCV-LE/CA/06/C (Maximum input signal level)

What is the purpose of the test?

The purpose of the maximum input signal level test is to verify the receiver's ability to demodulate a signal at high input power level.

Minimum Passing Requirements:

	Passing Requirements
Basic Rate	BER ≤ 0.1%, minimum of 1,600,000 payload bits
Enhanced Data Rate	BER ≤ 0.01%, minimum of 1,600,000 payload bits
LE	PER ≤ 30.8%*, minimum of 1500 packets

*- For Bluetooth Low Energy the BER/PER limit will vary based on the payload length (BER<0.1% or PER≤30.8% is for payload length of 37 bytes). Refer to Table 50 in the Appendix for more details.

Table 32. Passing requirements for Maximum Input Signal Level test

How is the measurement performed?

To set up this test, the tester is directly connected to the DUT and hopping is turned off.

For Basic Rate, the DUT is set to test mode loop back and the tester sends DH1 packets with a PRBS9 payload. The power level of the tester is set so that the DUT sees -20 dBm at the input.

For Enhanced Data Rate, the DUT is set to test mode loop back and hopping is turned off. The tester will continuously send π/4-DPSK packets with a PRBS9 payload. The packets should be the longest supported packet type, either 2-DHx or 2-EVx. If the DUT supports 8-DPSK, the tests will be repeated with 8-DPSK packets with the longest supported packet type, either 3-DHx or 3-EVx.

For both Basic Rate and Enhanced Data Rate, the DUT receives the packets, extracts the payload data and re-transmits the recovered payload data in the same packet type as it received. The tester acquires the re-transmitted packets from the DUT and performs the BER measurement.

For LE frequency hopping is turned off and the DUT is set to direct RX mode. The tester transmits packets with the maximum length PRBS9 payload. The DUT returns the number of packets which pass CRC so that the tester can calculate the PER. The power level of the tester is set so that the DUT sees -10 dBm at the input port.

The tests are performed at the low, mid and high frequencies for BR, EDR and LE.

Intermodulation

Test Specification

- RCV/CA/05/C (Inter-modulation performance)
- RCV-LE/CA/05/C (Intermodulation performance)

What is the purpose of this test?

The purpose of the receiver intermodulation test is to verify that the receiver can demodulate a Bluetooth signal among unwanted signals nearby in frequency.

Minimum Passing Requirements

	Passing Requirements
Basic Rate	BER ≤ 0.1%
LE	PER < 30.8%*, minimum of 1500 packets

*- For Bluetooth Low Energy the BER/PER limit will vary based on the payload length (BER<0.1% is for payload length of 37 bytes). Refer to Table 50 in the Appendix for more details.

Table 33. Passing requirements for Intermodulation test

How is the measurement performed?

To set up the test, the DUT is connected to the tester via cable and the DUT is set to receive at the lowest frequency. The DUT is sent 3 test signals simultaneously. The 3 test signals include a wanted test signal which is a modulated carrier with a PRBS9 payload transmitted at frequency f_{rx}, and two interference signals. The first interference signal should be a single tone, un-modulated sine wave transmitted at frequency f_1. The second interference signal should be a continuous PRBS15 modulated carrier at frequency f_2. The relationships between the signals should be the following:

$$f_{rx} = 2 * f_1 - f_2 \text{ and } |f_2 - f_1| = n * 1 \text{ MHz}, \text{ where n = 3,4, or 5}$$

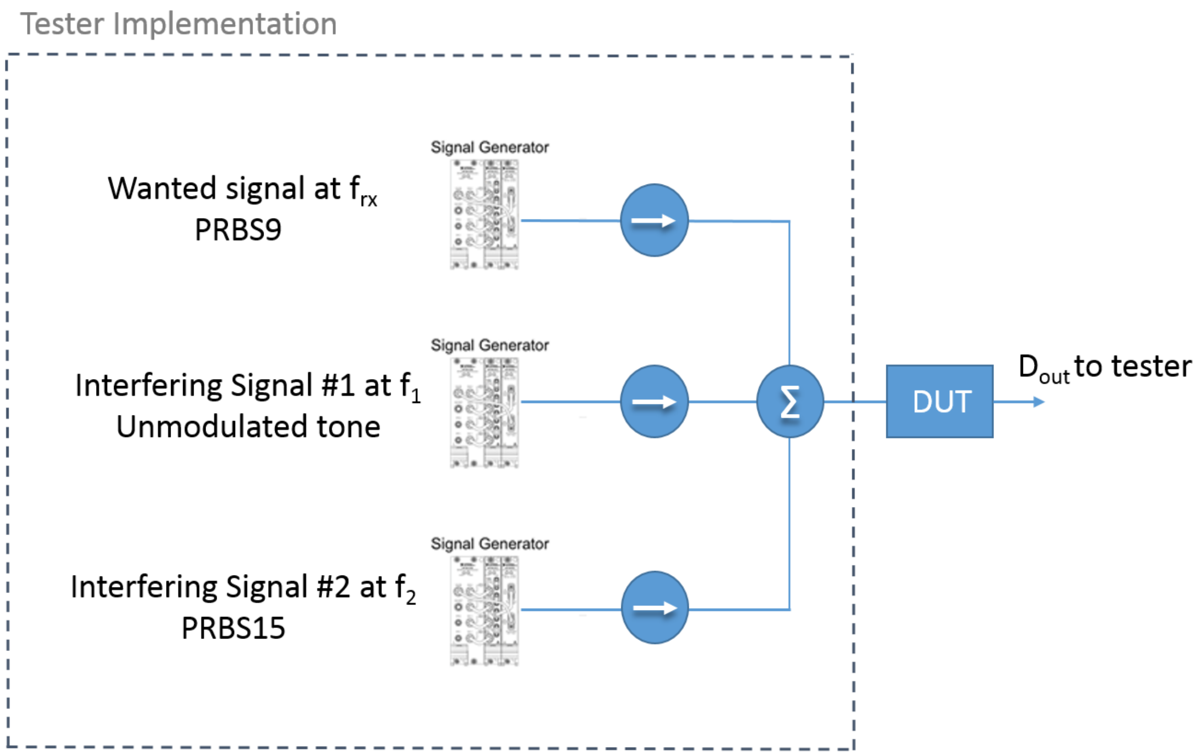


Figure 50. Hardware diagram for intermodulation test

The tester transmits the 3 combined signals to the DUT. For both Basic Rate and Enhanced Data Rate, the DUT receives the packets, extracts the payload data and re-transmits the recovered payload data in the same packet type as it is received. The tester acquires the re-transmitted packets from the DUT and performs the BER measurement. For LE, frequency hopping is turned off and the DUT is set to direct RX mode. The tester transmits packets with the maximum length PRBS9 payload. The DUT returns the number of packets which pass CRC so that the tester can calculate the PER.

The test is performed with the interference signals both above and below the receiving frequency for each value of *n*. The test is repeated with the receive frequency set to the mid and highest operating frequency.

The output power level of the signal generators is set to account for the path loss such that the input to the DUT sees a particular power level. The two interference signals should be -50 dBm for LE and -39 dBm for Basic Rate and Enhanced Data Rate. The wanted Bluetooth signal should be -64 dBm for LE, Basic Rate and Enhanced Data Rate.

Carrier-to-Interference, C/I

Test Specification

- RCV/CA/03/C (BR C/I performance)
- RCV/CA/09/C (Enhanced data rate C/I performance)
- RCV-LE/CA/03/C (C/I and receiver selectivity performance)

What is the purpose of this test?

The C/I performance test quantifies the receiver's ability to measure the desired signal with adjacent and co-channel interfering signals. Similar to blocking performance, carrier-to-interference (C/I) is important because the wanted signal will often not be the only signal transmitting in the given frequency range.

Minimum Passing Requirements:

	Passing Requirements
Basic Rate	BER ≤ 0.1%
Enhanced Data Rate	BER ≤ 0.1%
LE	PER < 30.8%*, minimum of 1500 packets

*- For Bluetooth Low Energy the BER/PER limit will vary based on the payload length (BER<0.1% is for payload length of 37 bytes). Refer to Table 50 in the Appendix for more details.

Table 34 Passing requirements for C/I test

How is the measurement performed?

Basic Rate:

The interference performance of a DUT is tested by coupling a signal of interest with an interfering signal and measuring the bit error rate (BER). Two vector signal generators are used to generate the wanted signal and the interfering signal. These signals are combined and sent to the DUT. A schematic of the hardware setup is shown in Figure 49.

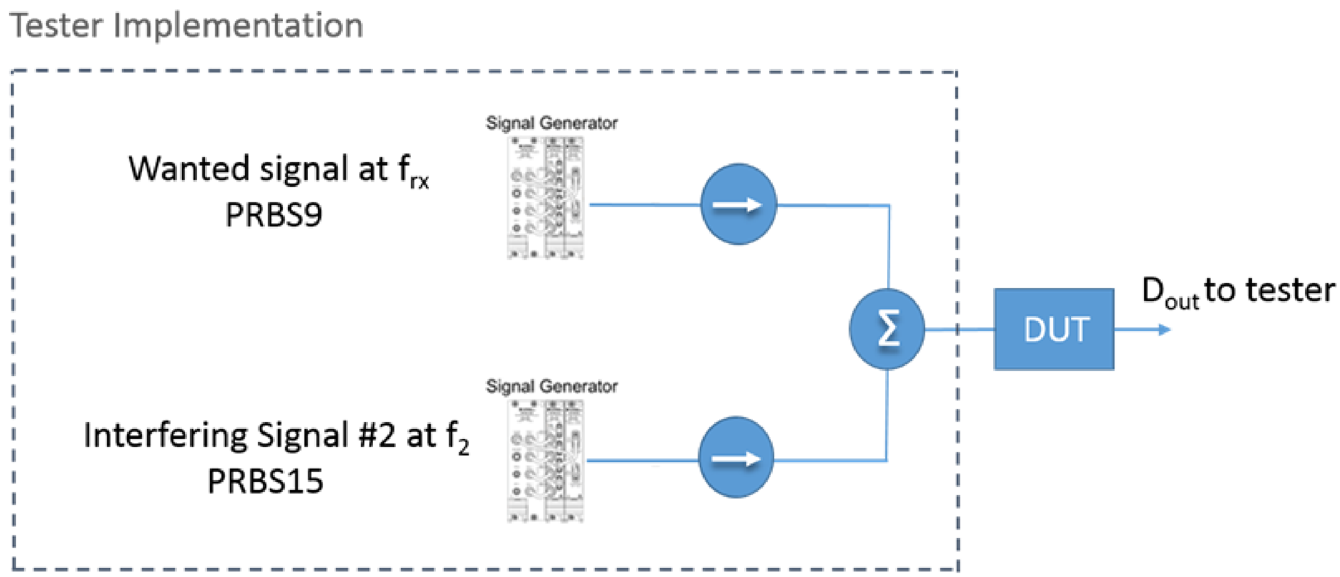


Figure 51. Hardware diagram for C\I test

The DUT is tested by placing interfering signals at a known set of frequencies and amplitudes and measuring the wanted signal's bit error rate (BER). This test is performed in loopback mode. Figure 49 illustrates the general relationship between power and frequency of the wanted signal and several interfering signals.

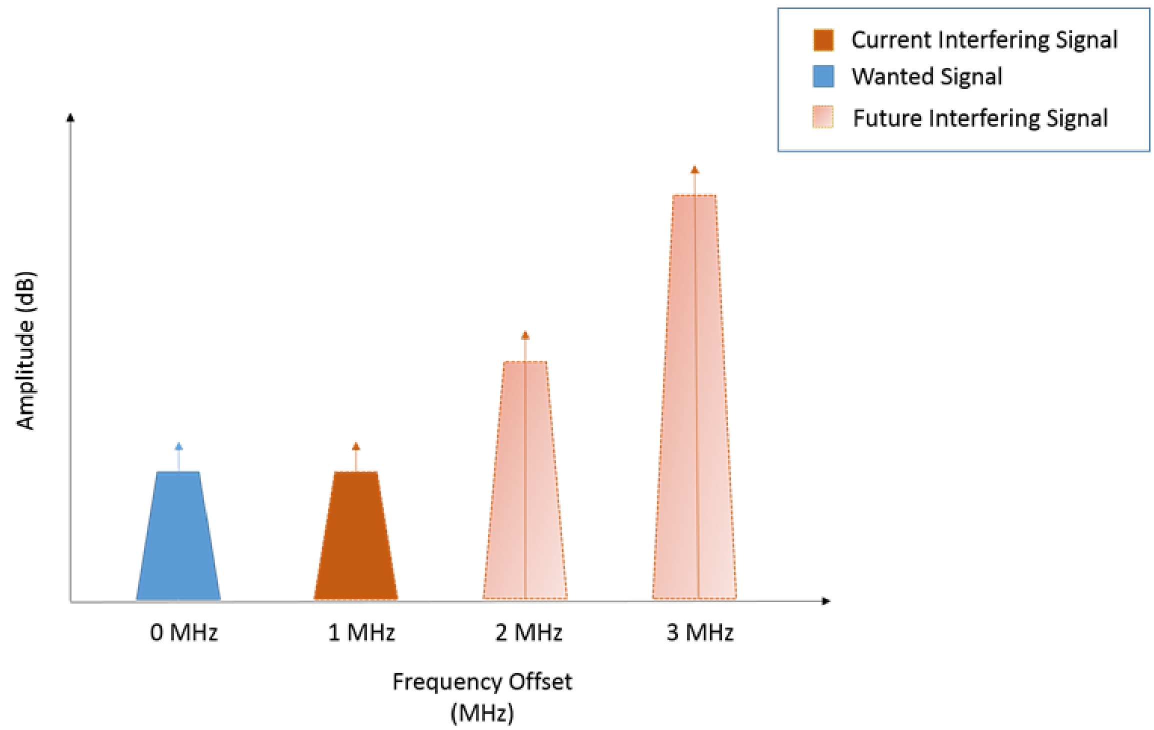


Figure 52. Relationship of Interfering Signal to Wanted Signal (Image is not to scale)

The C/I test will only have one interfering signal generated at a time. Figure 52 depicts interfering signals at 1 MHz, 2 MHz, and 3 MHz offsets from the wanted signal. It does not show the other possible interfering signals for this test. For additional information, refer to the Bluetooth RF–PHY.TS 3.0/4.0 Test Specification.

During the C/I test, the center frequency for the wanted signal changes from the low frequency to the middle operating frequency, and finishes at the highest operating frequency. The interfering signals are generated through the list of 79 interfering signal frequencies (2402 – 2480 MHz). The wanted signal structure, and interfering signal structure are defined in Table 38.

Modulation	GFSK
Modulation Index	$0.32 \pm 1\%$
BT	$0.5 \pm 1\%$

Bit Rate	$1\frac{\text{Mb}}{s} \pm 1\,ppm$
Modulation Sequence for Wanted Signal	PRBS9
Modulation Sequence for Interfering Signal	PRBS15
Frequency Accuracy	$\pm 1\,ppm$

Table 35. Basic Rate Signal Characteristics

The interfering signal frequencies and signal-to-interference ratios are defined in Table 39:

Interference Frequency	Ratio (dB)
Co-Channel Interference, $C/I_{co\text{-}channel}$	11
1 MHz Interference – C/I_{1MHz}	0
2 MHz Interference – C/I_{2MHz}	-30
$\geq$ 3 MHz Interference – $C/I_{\geq 3MHz}$	-40
Image Frequency Interference - C/I_{image}	-9
1 MHz Interference to Image Frequency - $C/I_{1MHz \pm image}$	-20

Table 36 Basic Rate Interfering Signal Characteristics

While performing the co-channel, 1 MHz, and 2 MHz interference frequency tests, the wanted signal must be kept at 10 dB over (-60 dBm) the reference sensitivity level (-70 dBm). While conducting other portions of the test, the wanted signal must be kept 3 dB (-67 dBm) over the reference sensitivity level. Also, consider that frequencies outside the 2400 – 2483.5 MHz band should follow the out-of-band blocking specifications, section 4.1.3 of the Bluetooth 4.2 Specification [7]. Both the interfering signal and wanted signal should be GFSK-modulated.

Note that a maximum of five spurious responses are allowed at RF channels $\geq$ 2 MHz from the wanted signal. The C/I ratio should be equal to -17 dB for these spurs.

EDR:

The C/I test for EDR is similar to the Basic Rate C/I test, but it does have several differences. The interfering signal should be modulated the same as the wanted signal for co-channel interference. All other channels will follow the same format as the Basic Rate (GFSK) modulated interference signal, shown in Table 37. Refer to Table 40 for interference frequencies and amplitudes for the DQPSK-modulated signal of interest:

Interference Frequency	$\frac{\pi}{4}$ – DQPSK Ratio (dB)	8DPSK Ratio (dB)
Co-Channel Interference, $C/I_{co\text{-}channel}$	13	21
1 MHz Interference – C/I_{1MHz}	0	5
2 MHz Interference – C/I_{2MHz}	-30	-25
$\geq$ 3 MHz Interference – $C/I_{\geq 3MHz}$	-40	-33
Image Frequency Interference - C/I_{image}	-7	0
1 MHz Interference to Image Frequency - $C/I_{1MHz \pm image}$	-20	-13

Table 37. EDR Interfering Signal Characteristics

The signal structure for the wanted and interfering signals are summarized in Table 41.

Modulation	$\frac{\pi}{4}$ – DQPSK	8DPSK
Symbol Rate	$1\frac{\mathrm{MS}}{s} \pm 1\,ppm$	$1\frac{\mathrm{MS}}{s} \pm 1\,ppm$
Frequency Accuracy	$\leq \pm 1\,ppm$	$\leq \pm 1\,ppm$
Modulation for Wanted Signal	PRBS9	PRBS9
Modulation for Interfering Signal	PRBS15	PRBS15
RMS Differential EVM	$< 5\%$	$< 5\%$

Average Power[1]	± 1 dB	± 1 dB

1 Average Power over GFSK and DPSK modulated portions of the packet

Table 38. EDR Signal Characteristics

Similar to Basic Rate, five spurious responses are allowed within ≥ 2 MHz. The C/I ratio must be-15 dB for $\frac{\pi}{4}-$ DQPSK and -10 dB for 8-DPSK.

Low Energy:

The LE C/I test procedure is similar to BR and EDR, however, it has its differences as well. First, the wanted signal will always be 3 dB over the reference sensitivity level (-70 dBm). Also, the measurement resolution, or step size, should be 1 MHz for the interfering signals. The interfering frequencies will be as follows: 2400 MHz + *N*·MHz where *N* = 1,2,3…83. The signal characteristics for the wanted and interfering signal are summarized in Table 42.

Modulation	GFSK
Modulation Index	$0.5 \pm 1\%$
BT	$0.5 \pm 1\%$
Bit Rate	$1\frac{\text{Mb}}{s} \pm 1\,ppm$
Modulation Sequence for Wanted Signal	PRBS9
Modulation Sequence for Interfering Signal	PRBS15
Frequency Accuracy	$\pm 1\,ppm$

Table 39. LE Signal Characteristics for C/I test

The only difference between these characteristics and BR is that the modulation index has increased. Also, note the interference frequencies and amplitudes in Table 42.

Interference Frequency	Ratio (dB)
Co-Channel Interference, $C/I_{co\text{-}channel}$	21
1 MHz Interference – C/I_{1MHz}	15

2 MHz Interference – C/I$_{2MHz}$	-17
≥ 3 MHz Interference – C/I$_{3MHz}$	-27
Image Frequency Interference - C/I$_{image}$	-9
1 MHz Interference to Image Frequency - C/I$_{1MHz \pm image}$	-15

Table 40. LE Interfering Signal Characteristics

Five spurs are also allowed for the LE C/I test, as long as they are ≥ 2 MHz from the wanted signal, excluding the image and ± 1 MHz of the image frequency. The C/I ratio is -17 dB for these spurs.

Blocking Performance

Test Specification

- RCV/CA/04/C (Blocking performance)
- RCV-LE/CA/04/C (Blocking performance)

What is the purpose of this test?

The purpose of the blocking test is to measure the DUT's performance in the presence of other out-of-band interfering signals. This is useful because devices will have to operate with other out-of-band signals in real traffic conditions.

Minimum passing requirements:

	Passing Requirements
Basic Rate	BER ≤ 0.1%
LE	PER < 30.8%*, minimum of 1500 packets

*- For Bluetooth Low Energy the BER/PER limit will vary based on the payload length (BER<0.1% is for payload length of 37 bytes). Refer to Table 50 in the Appendix for more details.

Table 41. Passing requirements for Blocking test

How is the measurement performed?

Basic Rate: The out-of-band blocking test is performed by generating the signal of interest and then combining it with the interfering signal that is out-of-band, as shown in Figure 51.

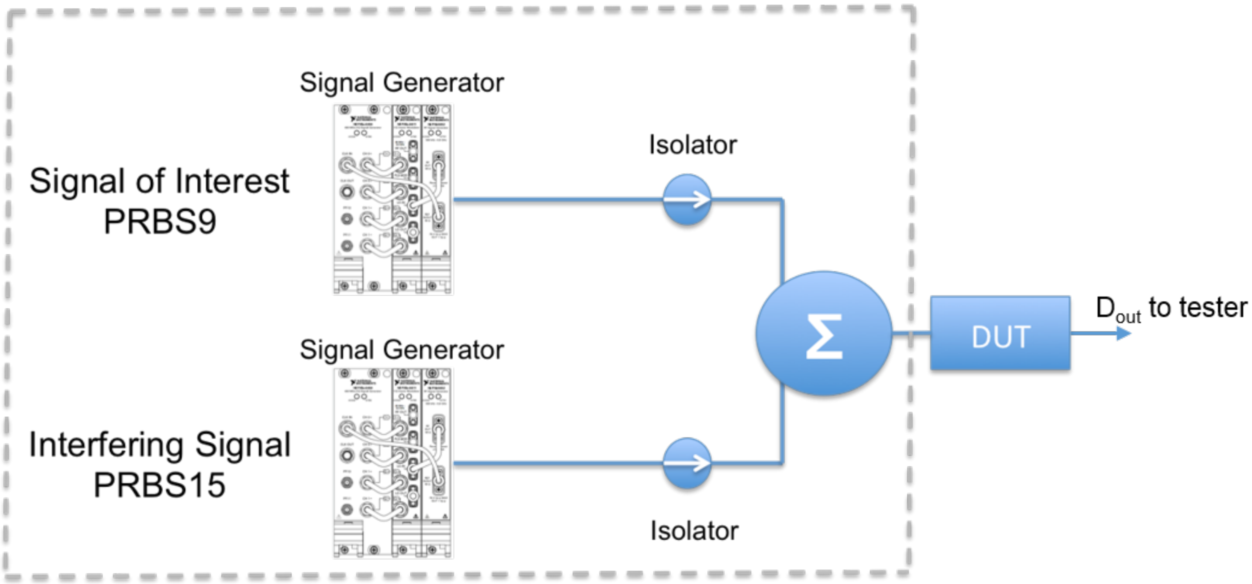


Figure 53. Blocking Hardware Diagram and Signal Flow

The wanted signal (DH1 packets with PRBS9 payload) is generated at 3 dB over the reference sensitivity level at the middle frequency (f_{RX} = 2460 MHz).The interfering signal is generated as a continuous wave, with its frequency changing from 30 MHz to 12.75 GHz in 1 MHz steps. The power of level of the interfering signal varies with frequency and is summarized in Table 45.

Frequency	Power
30 – 2000 MHz	-10 dBm
2000 – 2400 MHz	-27 dBm
2500 – 3000 MHz	-27 dBm
3000 MHz– 12.75 GHz	-10 dBm

Table 42. EDR and Basic Rate Blocking Interfering Signal Characteristics

The interfering signals can have 24 spurious exceptions at integer multiples of 1 MHz. Nineteen of these exceptions must have a lower interference level of at least -50 dBm. This allows for five of the spurs to have an amplitude below -50 dBm.

<u>Low Energy:</u> The out-of-band blocking test for LE measurements has a similar test procedure to the BR and EDR blocking tests, but the specification requirements vary. The BER of $\leq 0.1\%$ (or PER better than 30.8% for a minimum of 1500 packets) is still the same passing requirement. The wanted signal is also generated at the middle operating frequency and has the following characteristics:

Modulation	GFSK
Modulation Index	$0.5 \pm 1\%$
BT	$0.5 \pm 1\%$
Bit Rate	$1\frac{\text{Mb}}{s} \pm 1\,ppm$
Modulation Sequence for Wanted Signal	PRBS9
Modulation Sequence for Interfering Signal	PRBS15
Frequency Accuracy	$\pm 1\,ppm$

Table 43. Wanted Signal Characteristics for LE Blocking test

The interfering signal is generated as a continuous, un-modulated wave, with its frequency ($f_{blocker}$) changing from 30 MHz to 12.75 GHz according to the following equation: $f_{blocker\_n+1} = f_{blocker\_n}$ + measurement frequency resolution (n = 0,1,2…). The power of level and the measurement frequency resolution of the interfering signal varies with frequency and is summarized in Table 47.

Frequency	Wanted Signal Power at the DUT port	Blocking Signal Power at the DUT port	Measurement Frequency Resolution
30 – 2000 MHz	-67 dBm	-30 dBm	10 MHz
2000 – 2399 MHz	-67 dBm	-35 dBm	3 MHz
2484 – 2997 MHz	-67 dBm	-35 dBm	3 MHz
3000 MHz– 12.75 GHz	-67 dBm	-30 dBm	25 MHz

Table 44. Low Energy Out-of-Band Blocking Performance and measurement parameters

A total of 10 exceptions, 1 MHz integer multiple spurs, are allowed. Seven of these spurs must be at least -50 dBm. A maximum of three can have a lower power level.

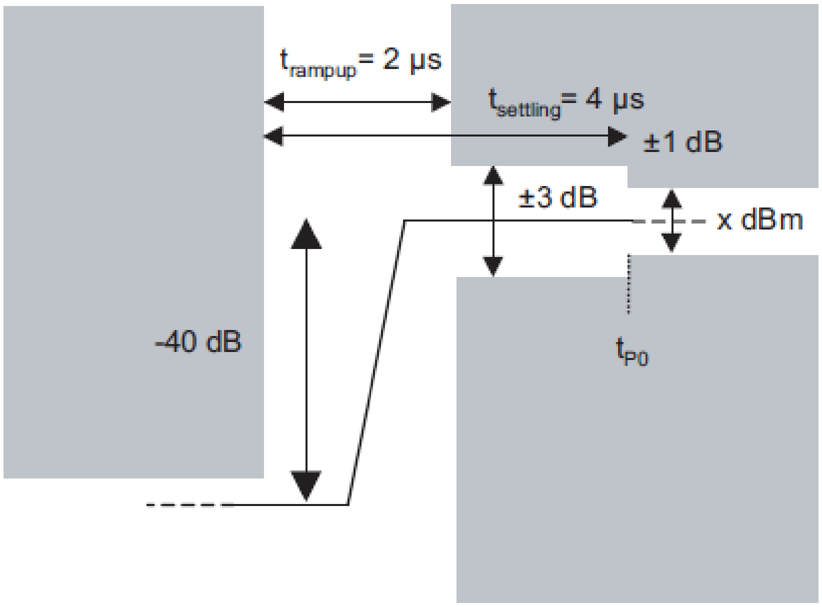
5. Appendix A: Bluetooth Test Spec (Additional Information)

A basic rate and enhanced data rate Bluetooth modulated signal used as “wanted signal” and “interfering signal” shall have the following characteristics:

Modulation	GFSK
Modulation Index	$0.32 \pm 1\%$
BT	$0.5 \pm 1\%$
Bit Rate	$1\,\frac{\mathrm{Mb}}{s} \pm 1\,ppm$
Modulation Sequence for Wanted Signal	PRBS9
Modulation Sequence for Interfering Signal	PRBS15
Access Code	Free Selectable
Frequency Accuracy	$\pm 1\,ppm$

Table 45. Reference Signal Definition (BR/EDR)

The reference signal shall also meet the following ramp up requirements:



t_{rampup} - time taken for signal generator output power to increase from below -40 dB to with +/- 3 dB of the final output power x dBm.
$t_{settling}$ - time taken for signal generator output power to reach to within better than +/- 1 dB of the final output power x dBm.
t_{P0} - time at which the first bit of the preamble begins.

Figure 54. Ramp-up profile of signal generator used in Bluetooth RF testing (BR/EDR)

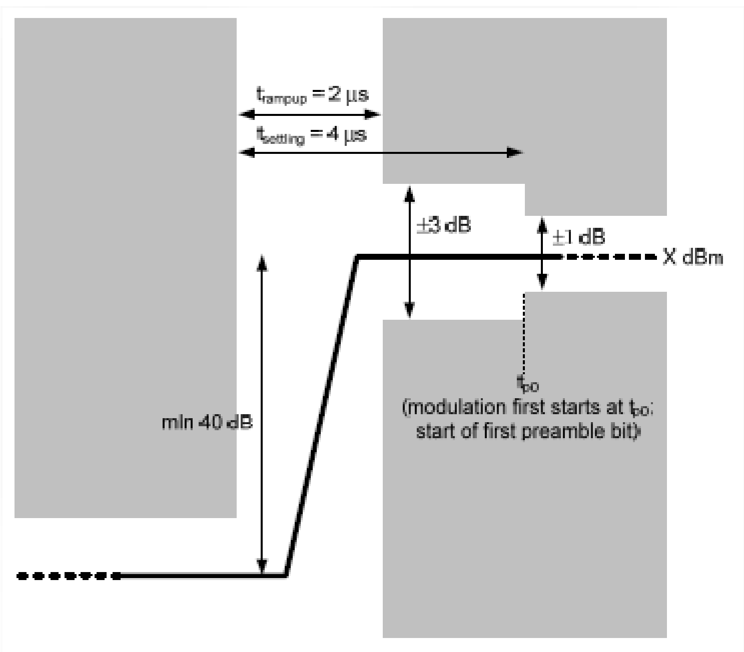
A Low Energy Bluetooth modulated signal used as "wanted signal" and "interfering signal" shall have the following characteristics:

Modulation	GFSK
Modulation Index	$0.5 \pm 1\%$
BT	$0.5 \pm 1\%$
Bit Rate	$1\frac{\text{Mb}}{s} \pm 1\,ppm$

Modulation Sequence for Wanted Signal	PRBS9
Modulation Sequence for Interfering Signal	PRBS15
Access Code	Free Selectable
Frequency Accuracy	Better than $\pm 1\ ppm$

Table 46. Reference Signal Definition (BR/EDR)

The low energy reference signal shall also meet the following ramp up requirements:



t_{rampup} - time taken for signal generator output power to increase from below -40 dB to with +/- 3 dB of the final output power x dBm.
$t_{settling}$ - time from signal generator output is 40 dB below the final output power (x dBm) to the time when the output power has reached a level within ±1dB of the final output power.
t_{P0} - time at which the first bit of the preamble begins.

Figure 55. Ramp-up profile of signal generator used in Bluetooth RF testing (LE)

Maximum Supported Payload Length in Receiver (bytes)	BER (%)
37	0.1
≥38 and ≤63	0.064
≥64 and ≤127	0.034
≥128 and ≤255	0.017

Table 47. Low Energy: Receiver Sensitivity - BER Limit

Normal Operating Conditions (NOC)

Normal Temperature and Air Humidity (BR/EDR)

The normal temperature and humidity conditions for tests shall be within the following ranges:
• temperature: +15 °C to +35 °C
• relative humidity: 20 % to 75 % [2]

For additional information refer to Bluetooth Test Specification v1.2/2.0/2.0 + EDR/2.1/2.1 + EDR/3.0/3.0 + HS (), RF.TS/3.0.H.1 ed. Bluetooth SIG, 2009.

Normal Temperature and Air Humidity (LE)

"The normal operating temperature shall be declared by the equipment manufacturer as a PIXIT value. The NOC test temperature shall be within ±10°C of this value[2].

Operating air humidity range shall be declared by the product manufacturer as maximum and minimum values (PIXIT). The air humidity level for the NOC tests shall be within the declared range". [6]

For additional information refer to *Bluetooth Low Energy RF PHY Test Specification*, RF–PHY.TS/4.0.0 ed. Bluetooth SIG, 2009.

[2]Test temperature shall not exceed EOC values.

Extreme Operating Conditions (EOC)

Extreme Temperature and Air Humidity (BR/EDR)

“The extreme temperature range is defined as the largest temperature range given by the combination of

- The minimum temperature range 0 °C to +35 °C
- The product operating temperature range declared by the manufacturer”. [2]

For additional information refer to Bluetooth Test Specification v1.2/2.0/2.0 + EDR/2.1/2.1 + EDR/3.0/3.0 + HS (), RF.TS/3.0.H.1 ed. Bluetooth SIG, 2009.

Extreme Temperature and Air Humidity (LE)

“The extreme temperature limits are defined as the minimum and maximum temperatures of the operating temperature range as declared in the PIXIT information by the EUT manufacturer.

For the extreme operating condition, the air humidity shall be at a level within the operating air humidity range declared by the EUT manufacturer (see Section 7.4.1)”. [6]

For additional information refer to Bluetooth Low Energy RF PHY Test Specification, RF–PHY.TS/4.0.0 ed. Bluetooth SIG, 2009.

6. *Appendix B. NI solutions for Bluetooth Test*

Modular PXI Platform for Bluetooth Test using NI RF Instruments and the Bluetooth Measurement Suite

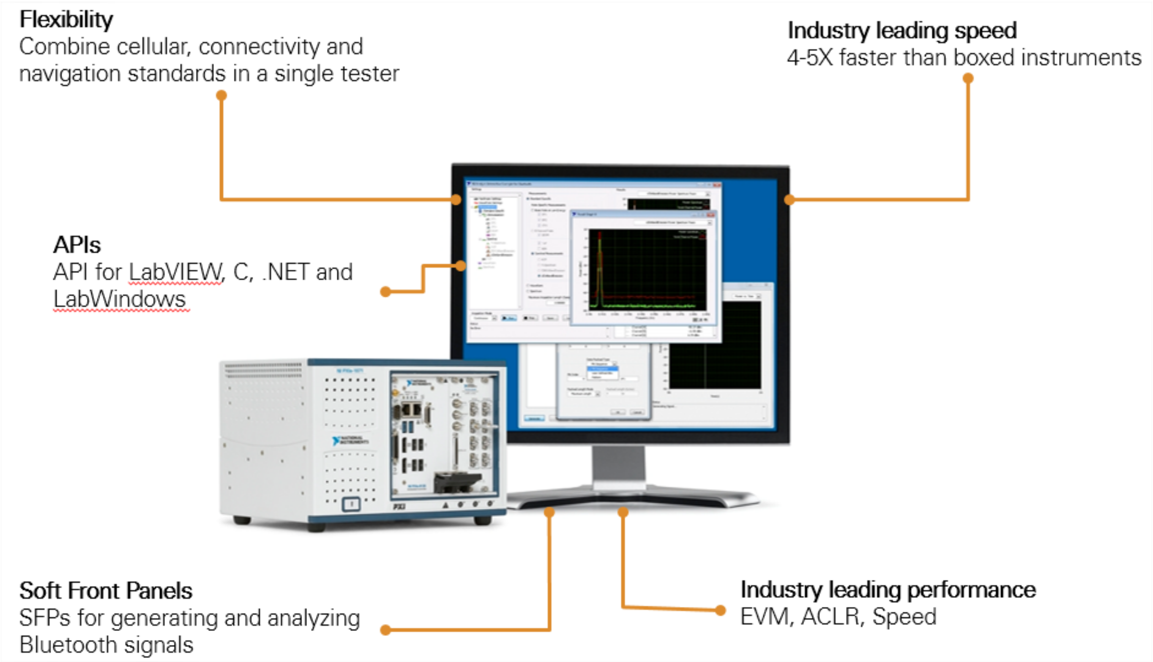


Figure 56. NI VST test solution

The NI Bluetooth Measurement Suite gives you a software-defined approach to Bluetooth testing, so that you can start taking faster Bluetooth measurements with PXI, the most cost-effective, flexible, and capable platform for wireless device test. It keeps you up with the latest Bluetooth standard developments becomes with free upgrades of the Bluetooth Measurement Suite. You also gain greater confidence in your Bluetooth design's performance and increase test coverage with a flexible toolkit that offers fine control of the generated Bluetooth waveforms and generates accurate measurement results.

Using the Vector Signal Trasceiver (VST) or separate vector signal generators (VSGs) and vector signal analyzers (VSAs), the NI Bluetooth Measurement Suite enables you to:

- Generate and analyze Bluetooth: 1.x, 2.x+EDR, 3.x+HS, 4.2, LE, and 5.0 LE (2 Mbps data rate)
- Characterize the performance of your Bluetooth design with powerful soft front panels
- Automate Bluetooth measurements with a comprehensive API for LabVIEW, Visual Studio, and others

Supported measurements:

- Output power Tx output spectrum
- Frequency range
- Tx output spectrum—20 dB
- Tx output spectrum—adjacent channel power
- Modulation characteristic
- Initial carrier frequency tolerance
- Carrier frequency drift
- EDR relative transmit power
- EDR carrier frequency stability and modulation accuracy
- EDR differential phase encoding
- EDR in-band spurious emissions
- LE Long Range
- LE 2Mb/s
- LE Extended Payload

Application and Technology

Soft Front Panels

You can use soft front panels (SFPs) to generate and analyze Bluetooth signals and gain fine control of the Bluetooth packets you generate. You can define custom payloads and signal impairments such as noise, IQ imbalance, skew, and DC offset. These SFPs include spectral and modulation measurements. Furthermore, they allow you to save waveforms and measurements for later analysis, remembering the hardware and measurement configurations, so that you can load them into the SFP at a later time or load the same settings into the programmable API.

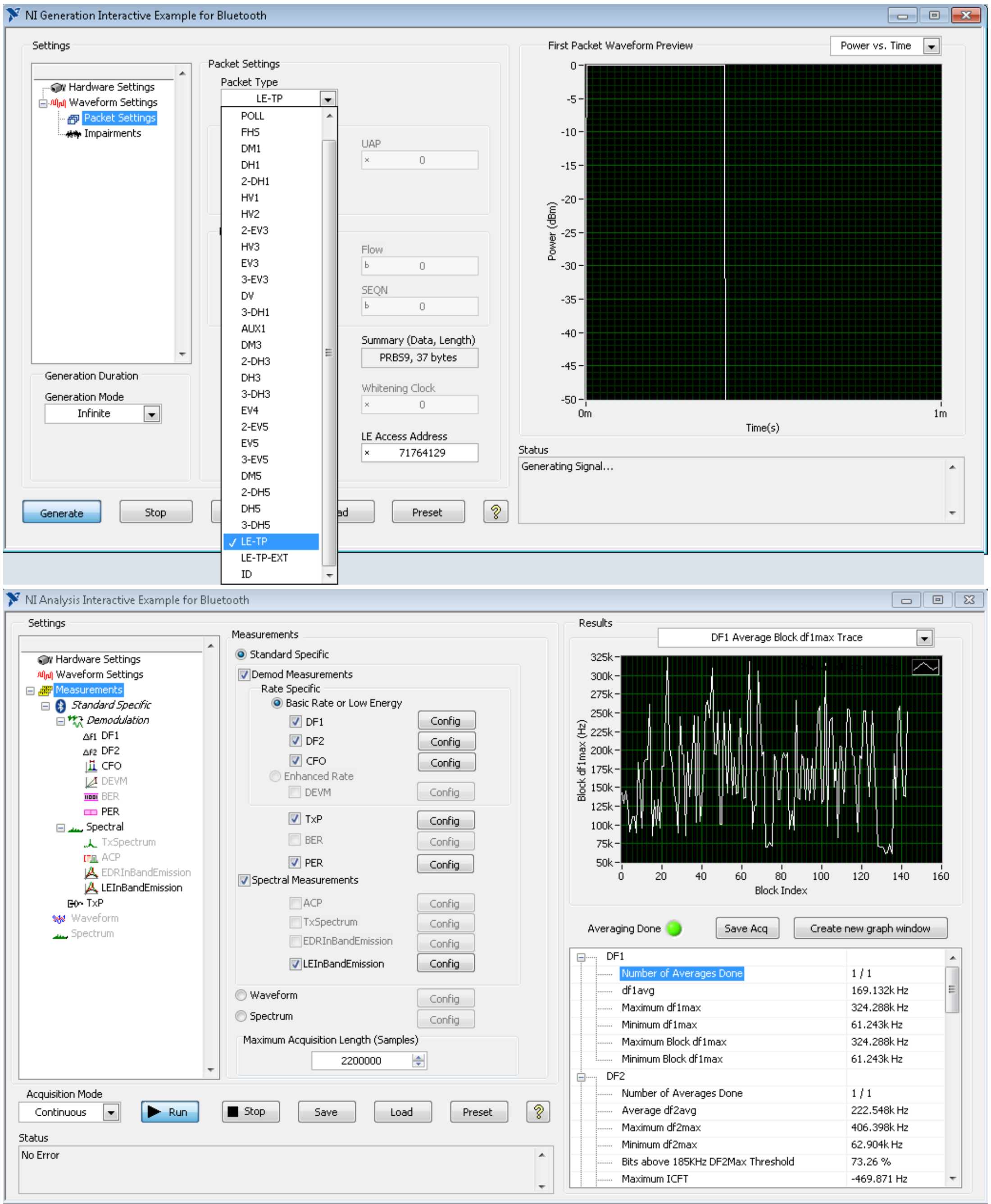


Figure 57 Soft Front Panels for the Generation and Acquisition of Bluetooth Signals

NI Bluetooth API

The NI Bluetooth Measurement Suite includes an API for LabVIEW, LabWindows/CVI, and C, with which you can create custom code for all kinds of test scenarios or custom settings. Support for .NET C# and VB is also available. The API gives you fine control over the Bluetooth packets and it includes a comprehensive library of example code to get you started quickly on all the different Bluetooth measurements for the various types of packets, including Bluetooth Low Energy.

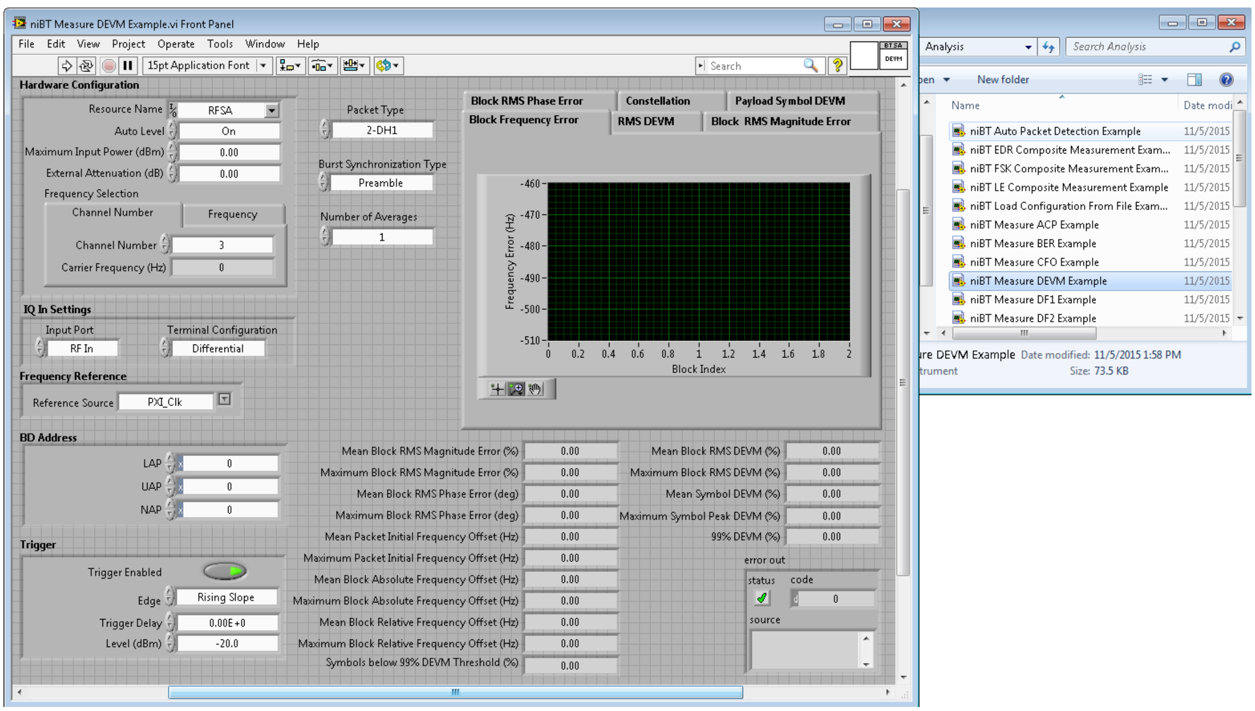


Figure 58 LabVIEW examples for fast customized development

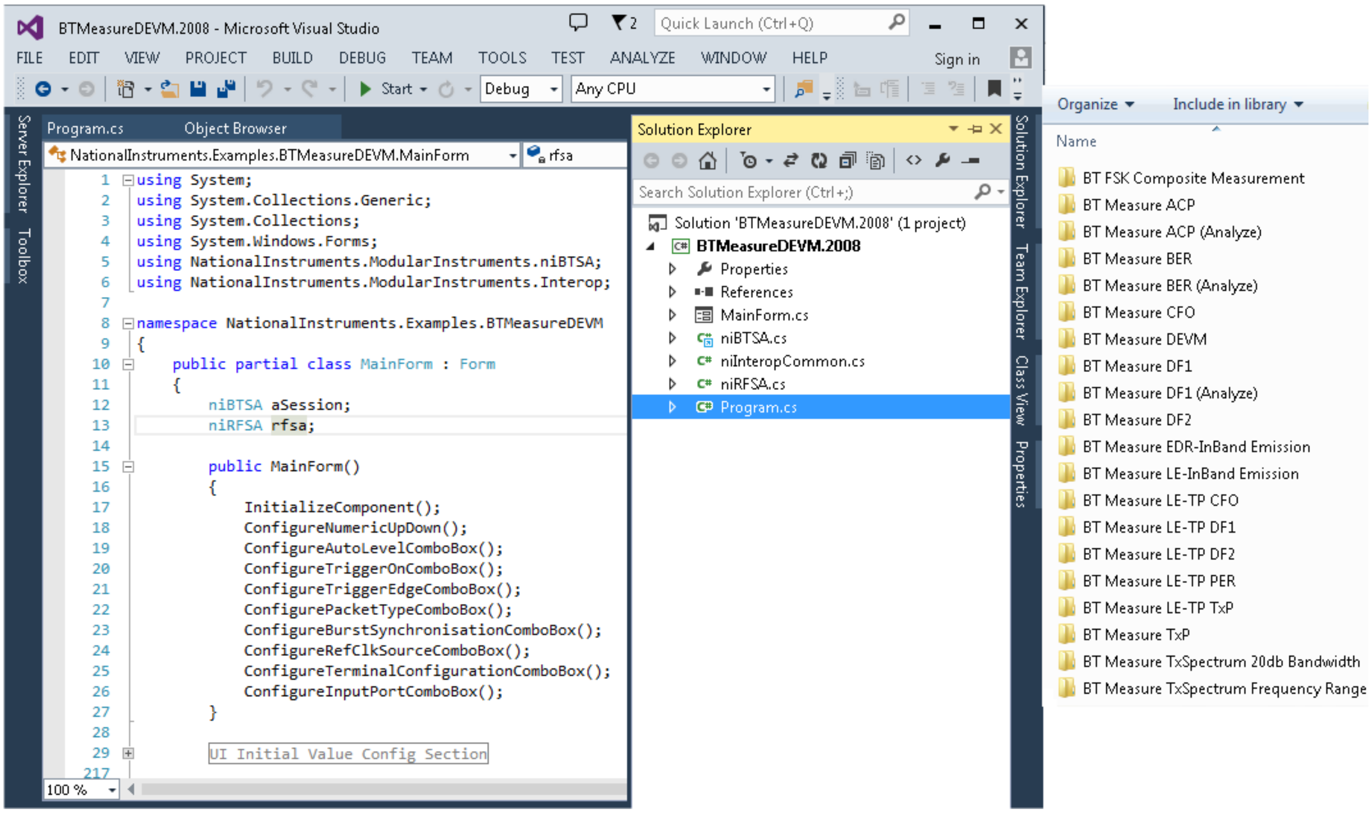


Figure 59 .NET C# examples for fast customized development

Bluetooth Low-Energy and Direct Test Mode

The Bluetooth standard now defines specific Bluetooth Low-Energy (BLE) RF PHY Test Cases and a new Direct Test Mode (DTM) for DUT control, to make sure that Bluetooth Low-Energy devices from all manufacturers operate properly. This standardization also verifies that a basic level of system performance is guaranteed for all BLE products. DTM and a combination of a more relaxed RF PHY spec, fewer PHY test cases and optimized test case implementations contribute to much shorter BLE RF PHY test times.

The NI Bluetooth Measurement Suite supports these BLE measurements and the new packet types associated with them, such as:

- LE Packet
- LE Extended payload packet (255 bytes)

- LE-Enhanced (1 and 2 Mbps)
- LE-Long range (125 and 500 kbps)

Additionally, it comes with a Direct Test Mode Interactive Example to help you control and test BLE DUTs easily.

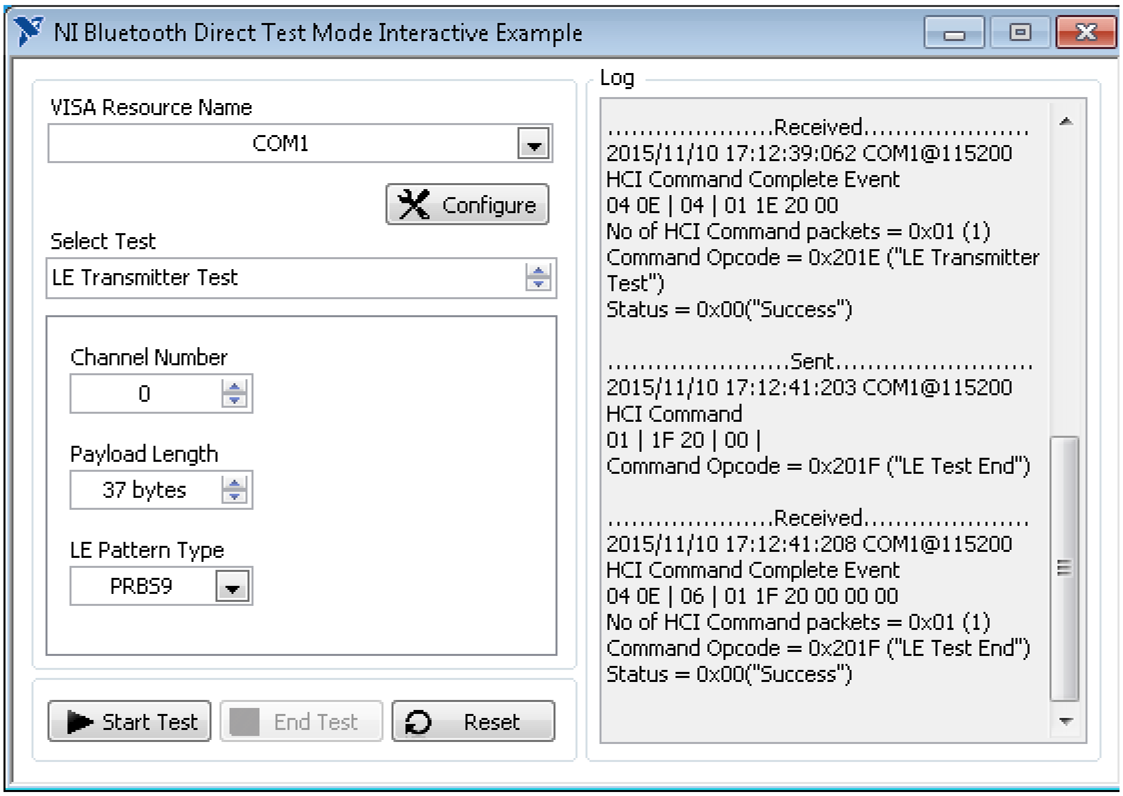


Figure 60 Direct Test Mode Interactive Example

Fast and Accurate Modulation Measurements

Combine the NI Bluetooth Measurement Suite with the NI vector signal transceiver (VST) to achieve industry-leading modulation and spectral measurements.

TX Power Level	*Mean Block RMS EVM (%)*	*Mean Block RMS Magnitude Error (%)*
0	*0.59*	*0.41*

-5	*0.56*	*0.40*
-10	*0.54*	*0.38*
-15	*0.52*	*0.36*

Table 48 Mean Block EVM in loopback using the NI Vector Signal Transceiver

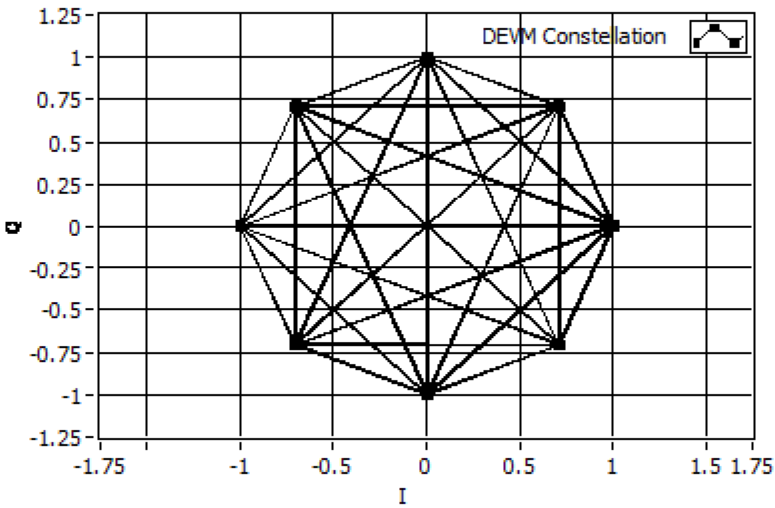


Figure 61 Constellation plot of a 3-DH5 signal.

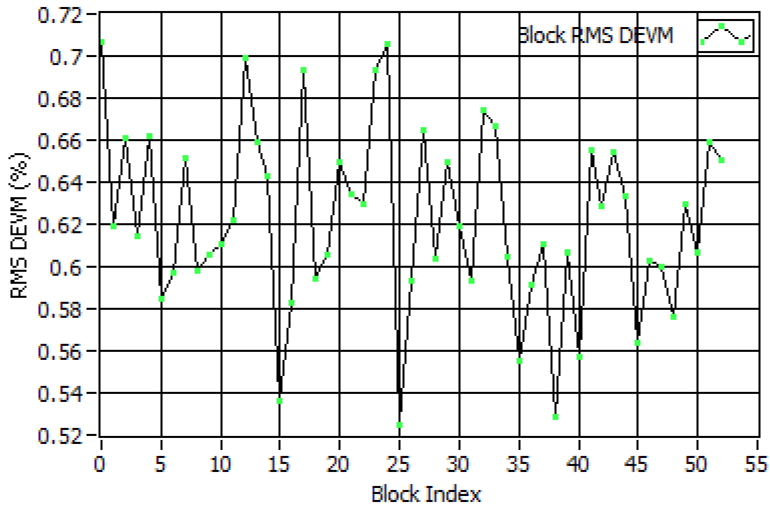


Figure 62 RMS DEVM Measurement Using the NI Bluetooth Measurement Suite

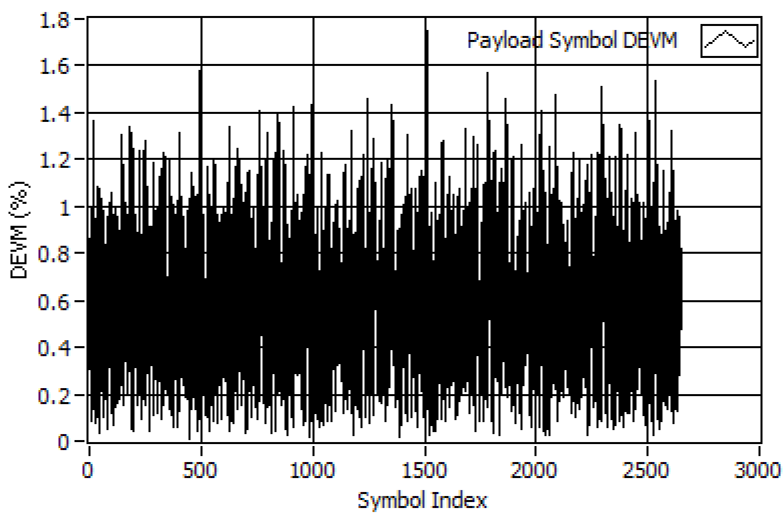


Figure 63 Payload Symbol DEVM (%)

Note: Average time for DEVM measurement is <33ms.

Fast and Accurate Spectral Measurements

Use the NI Bluetooth Measurement Suite to achieve fast and accurate spectral measurements for characterization or production test environments.

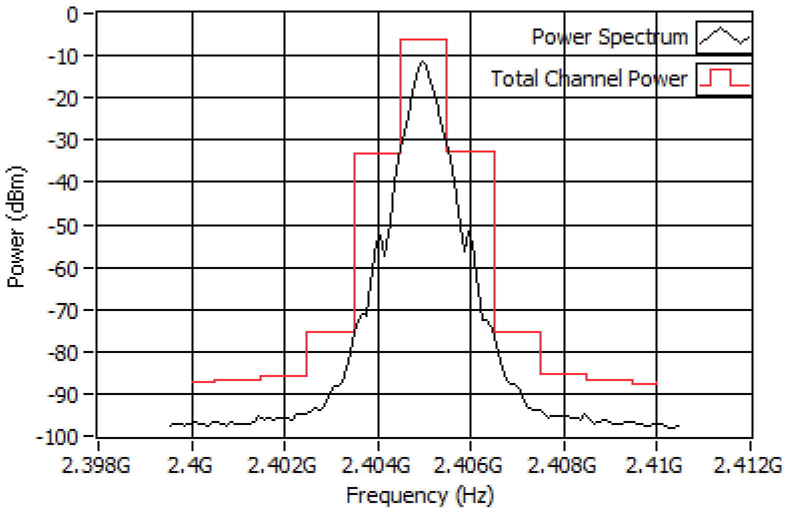


Figure 64 ACP Measurement of a DH1 Packet-Type Bluetooth Signal

Type of Measurement	Value	Measurement time
ACP (79 channels 3-DH5 packet type -25 dBm main ch power)	-79 dBm	< 330 ms
ACP (10 channels, 3-DH5 packet type, -25 dBm main ch power)	-79 dBm	< 170 ms
DF1 (DM1 packet type)	Df1avg = 80.87 KHz	< 8 ms

Table 49 Spectrum measurement speeds using the NI Bluetooth Suite and the VST

Simulation

The NI Bluetooth Measurement Suite enables you to simulate and manipulate Bluetooth signals. You can also add different kinds of impairments to see what are their effects on the signal measurements.

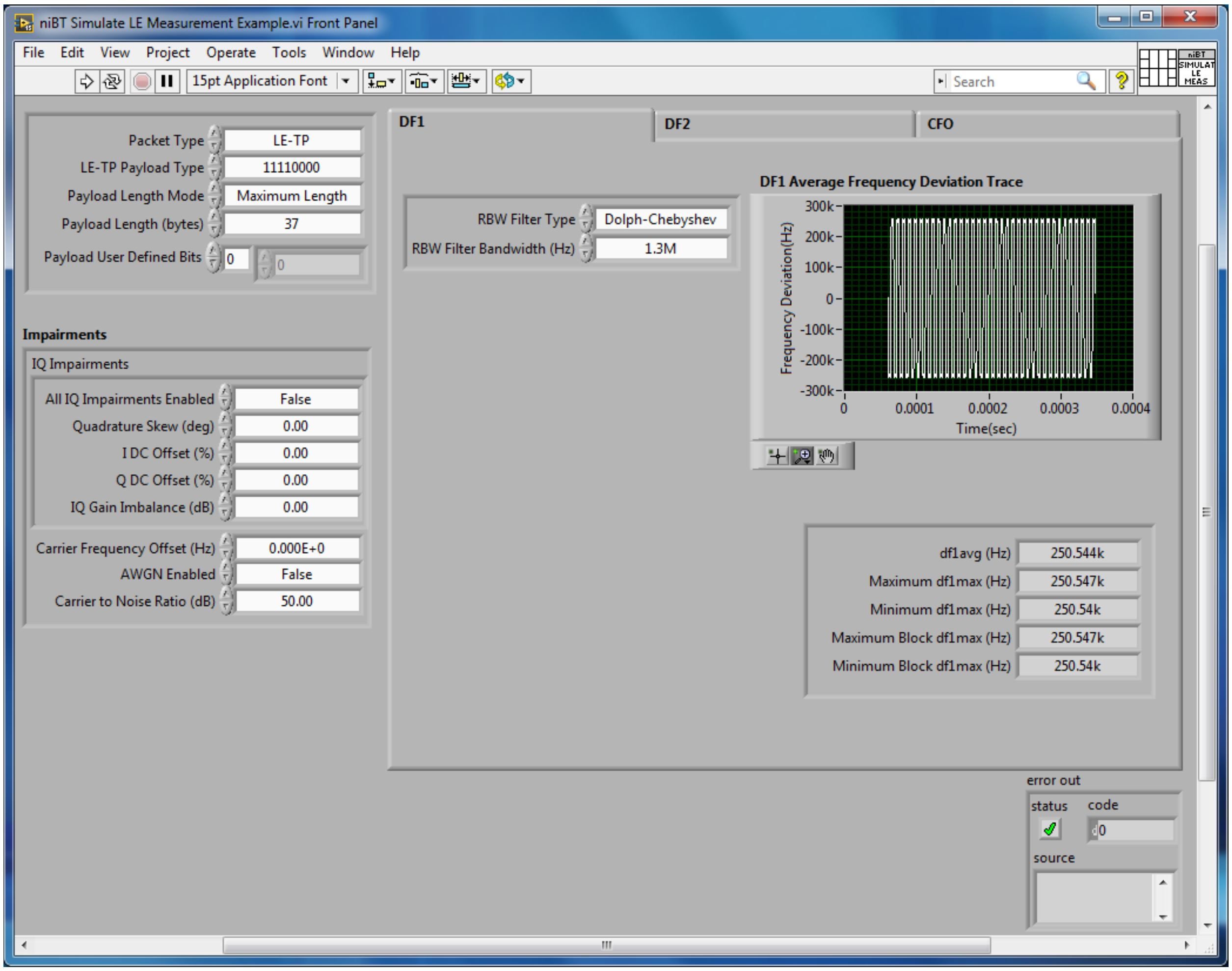


Figure 65 Code to simulate the effects of hardware impairments on the BT signal

Bluetooth Suite - Supported Measurements

Transmit Power

- Total Average Power
- Maximum Average Power
- Minimum Average Power
- Access Code and Header Average Power
- Payload Average Power
- Payload Relative Power

Demodulation Measurements

- DF1 Average Block df1max
- DF1 Average Frequency Deviation Trace
- DF2 Average Block df2max Trace
- DF2 Average Frequency Deviation Trace
- Max ICFT
- Max Carrier Drift
- Max Carrier Drift/50us
- Bits above 185kHz DF2Max Threshold (%)
- Max Payload Block Frequency Offset
- Max Carrier Drift / 55us
- DF2 Block Frequency Offset Trace
- DF2 Maximum Block df2max Trace
- DF2 Minimum Block df2max Trace
- CFO Block Frequency Offset
- CFO Payload Frequency Deviation
- Max ICFT
- Max Carrier Drift
- Max Carrier Drift / 50us
- Max Payload Block Frequency Offset (Hz)
- Max Carrier Drift / 55us

DEVM

- Mean Block RMS DEVM (%)
- Maximum Block RMS DEVM (%)
- Mean Symbol DEVM (%)
- Maximum Symbol DEVM (%)
- 99% DEVM (%)
- Mean Block RMS Magnitude Error (%)
- Maximum Block RMS Magnitude Error (%)
- Mean Block RMS Phase Error (deg)
- Maximum Block RMS Phase Error (deg)
- Mean Packet Initial Frequency Offset (Hz)
- Maximum Packet Initial Frequency Offset (Hz)
- Mean Block Absolute Frequency Offset (Hz)
- Maximum Block Absolute Frequency Offset (Hz)
- Mean Block Relative Frequency Offset (Hz)
- Maximum Block Relative Frequency Offset (Hz)
- Symbols below 99% DEVM Threshold (%)
- Impairments: IQ Gain Imbalance (dB)
- Impairments: Quadrature Skew (deg)
- Impairments :I DC Offset (%)
- Impairments: Q DC Offset (%)
- BER (%)
- Sample Population Used
- FER %
- Number of Frames Used

Spectral Measurements

- Peak Power
- TxP Average
- Power versus Time
- Bandwidth
- TxSpectrum
- ACP
- EDRInBandEmission
- LEInBandEmission
- Raw IQ Data
- Waveform Spectrum

Bluetooth mode	**Measurement Description**	**Identifier**	**RF-PHY TS.3.0/4.0(LE) Section**	**NI Bluetooth Toolkit 16.0**
Basic Rate (BR) test cases	Output power	TRM/CA/01/C	*5.1.3*	✓
	Power density	TRM/CA/02/C	*5.1.4*	×
	Power control	TRM/CA/03/C	*5.1.5*	×
	Tx output spectrum-frequency range	TRM/CA/04/C	*5.1.6*	✓
	Tx output spectrum-20 dB bandwidth	TRM/CA/05/C	*5.1.7*	✓
	Tx output spectrum-adjacent channel power	TRM/CA/06/C	*5.1.8*	✓
	Modulation characteristics	TRM/CA/07/C	*5.1.9*	✓
	Initial carrier frequency tolerance (ICFT)	TRM/CA/08/C	*5.1.10*	✓
	Carrier frequency drift	TRM/CA/09/C	*5.1.11*	✓
Enhanced Data Rate (EDR) test cases	Enhanced data rate relative transmit power	TRM/CA/10/C	*5.1.12*	✓
	Enhanced data rate carrier frequency stability and modulation accuracy	TRM/CA/11/C	*5.1.13*	✓
	Enhanced data rate differential phase encoding	TRM/CA/12/C	*5.1.14*	×
	Enhanced data rate in-band spurious emission	TRM/CA/13/C	*5.1.15*	✓
	Enhanced power control	TRM/CA/14/C	*5.1.16*	×
Low Energy (LE) test cases	Output power at normal operating conditions (NOC)	TRM-LE/CA/01/C	6.2.1	✓
	Output power at extreme operating conditions (EOC)	TRM-LE/CA/02/C	6.2.2	✓
	In-band emissions at NOC	TRM-LE/CA/03/C	6.2.3	✓
	In-band emissions at EOC	TRM-LE/CA/04/C	6.2.4	✓
	Modulation characteristics	TRM-LE/CA/05/C	6.2.5	✓
	Carrier frequency offset and drift at NOC	TRM-LE/CA/06/C	6.2.6	✓
	Carrier frequency offset and drift at EOC	TRM-LE/CA/07/C	6.2.7	✓

✓- Supported measurement

× - Currently unsupported

Table 50. NI Bluetooth Toolkit Transmitter (TX) Tests

Bluetooth mode	Measurement Description	Identifier	RF-PHY TS.3.0/4.0(LE) Section	NI Bluetooth Toolkit 16.0
Basic Rate (BR) test cases	Sensitivity – single-slot packets	RCV/CA/01/C	5.1.17	✓
	Sensitivity - multi-slot packets	RCV/CA/02/C	5.1.18	✓
	Channel interference (C/I) performance	RCV/CA/03/C	5.1.19	✓*
	Blocking performance	RCV/CA/04/C	5.1.20	✓*
	Inter-modulation performance	RCV/CA/05/C	5.1.21	✓*
	Maximum input level	RCV/CA/06/C	5.1.22	✓*
Enhanced Data Rate (EDR) test cases	Enhanced data rate sensitivity	RCV/CA/07/C	5.1.23	✓
	Enhanced data rate BER floor sensitivity	RCV/CA/08/C	5.1.24	✓
	Enhanced data rate C/I performance	TP/RCV/CA/09/C	5.1.25	✓*
	Enhanced data rate maximum input level	RCV/CA/10/C	5.1.26	✓*
Low Energy (LE) test cases	Receiver sensitivity at NOC	RCV-LE/CA/01/C	6.3.1	✓
	Receiver sensitivity at EOC	RCV-LE/CA/02/C	6.3.2	✓
	C/I and receiver selectivity performance	RCV-LE/CA/03/C	6.3.3	✓*
	Blocking performance	RCV-LE/CA/04/C	6.3.4	✓*
	Intermodulation performance	RCV-LE/CA/05/C	6.3.5	✓*
	Maximum input signal level	RCV-LE/CA/06/C	6.3.6	✓
	PER Report Integrity	RCV-LE/CA/07/C	6.3.7	✓

✓- Supported measurement
✗ - Currently unsupported
✓* - Requires additional hardware

Table 51. NI Bluetooth Toolkit Receiver (RX) Tests

Production Test of Bluetooth Devices with the Wireless Test System (WTS)

With industry-leading measurement speed and the flexibility to engage in multi-standard, multi-DUT, and parallel test, the WTS integrates easily into a Bluetooth manufacturing line using ready-to-run reference test sequences, integrated DUT control, and remote automation control. Each of these features provides quicker and more cost-effective system deployment and, when combined with the WTS's shorter test times, a lower cost of test.

- Multi-DUT/Multi-port configurations
- Support for either 8 or 16 ports
- Provides ruggedness, integration, and port scalability while leveraging PXI platform for future-proofing

Figure 66. NI Wireless Test System

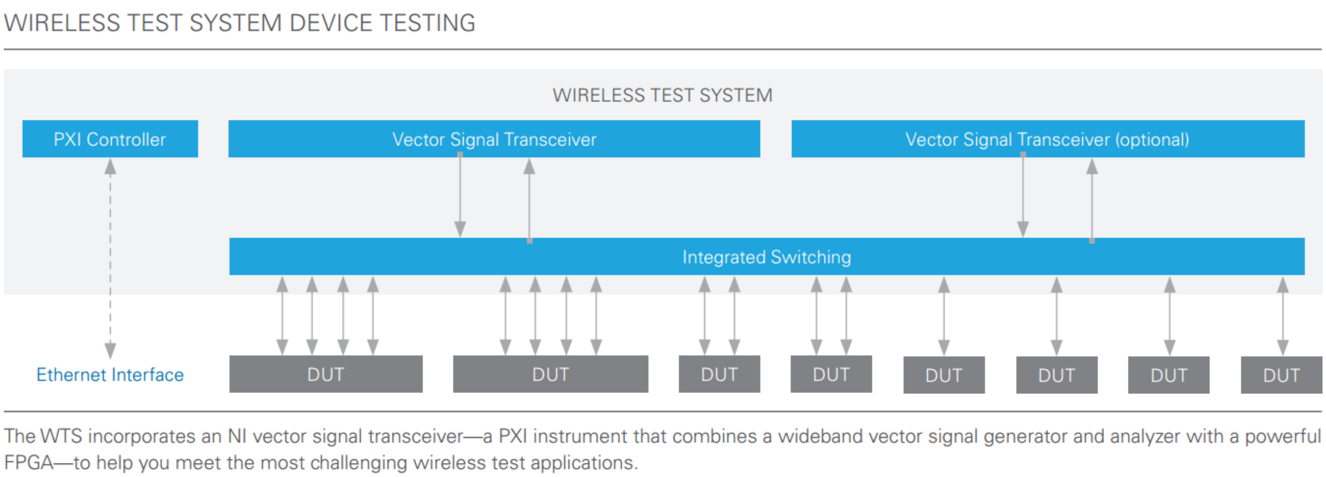


Figure 67 Wireless Test System Device Testing

Develop, execute, and deploy automated test and validation systems faster with the Wireless Test Module (WTM), an extension of TestStand, the Industry-Standard Test Executive. Combine the WTS with the WTM software to create new test sequences faster and simplify complex measurement routines.

If your test setup relies on your own or a Third-Party test executive, you can easily integrate the WTS into your test executive by using the SCPI remote automation interface. Gain the measurement speed benefits of the WTS while minimizing changes to your test software and infrastructure.

Furthermore, if you depend on the test tools that chipset vendors provide, such as Qualcomm, you can start using the WTS as a measurement solution right away. Because these software tools natively support the WTS, get started testing a new wireless device without additional test software development.

7. Appendix C. Symbols and Acronyms

8-DPSK - 8-ary differentially encoded phase shift keying
ACL - Asynchronous connectionless link
ACP - Adjacent channel power
BER - Bit error rate
CRC - Cyclic redundancy check
C/I - Carrier-to-interference
dB - Decibels
dBc - Decibels relative to the carrier frequency
dBm - Decibels relative to 1 milliwatt
DEVM - Differential error vector magnitude
DPSK - Differential phase shift keying
DSSS Direct sequence spread spectrum
DUT - Device under test
eSCO - Extended SCO
EDR - Enhanced data rate
EIRP - Equivalent isotropically radiated power
EVM - Error vector magnitude
EUT - Equipment under test
FCC - Federal Communications Commission
FEC - Forward error correction
FHSS - Frequency hopping spread spectrum
FSK - Frequency Shift Keying
GFSK - Gaussian frequency shift keying
Hz - Hertz or cycles per second
ICFT - Initial Carrier Frequency Tolerance
ISM - Industrial, Scientific, and Medical frequency band
LM - Link manager
LMP - Link Manager Protocol
OQPSK - Offset QPSK
PAN - Personal area network
PER - Packet Error Rate
PLL Phase Lock Loop
π/4-DQPSK - π/4 rotated differential encoded QPSK
PRBS - Pseudo random bit sequence

PSK - Phase shift keying
QPSK - Quadrature phase shift keying
RBW - Resolution Bandwidth
RCV - Receiver tests
RF - Radio frequency
RMS - Root mean square
RSSI - Receiver signal strength indicator
SCO - Synchronous connection-oriented link
SIG - Bluetooth Special Interest Group
TP - Test purposes
TRM - Transmitter tests
TSS/TP - Test suite structure and test purposes
TDD - Time division duplex scheme
VBW - Video Bandwidth
VSA - Vector Signal Analyzer
VSG - Vector Signal Generator

8. References

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