Bluetooth Low Energy – Regulatory Aspects Document (RAD)

***Bluetooth*® Informational Publication**

- **Version:** 1.01
- **Version Date:** 2023-03-23
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Abstract:

This paper provides guidance and supporting information relating to Bluetooth Low Energy (LE) technology and the Bluetooth SIG’s understanding of RF regulations that apply in various geographic regions. This is an informational guide only and is a substitute for neither the Bluetooth Core Specification nor the applicable regulations in the regions discussed.

Version History

Version Number	Date	Comments
1.01	2023-03-23	Version 1 Regulatory Aspects Document

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1 About this document

Bluetooth Low Energy (LE) is one of two Bluetooth radio frequency (RF) variants, the other being Bluetooth BR/EDR.

All products that use Bluetooth technology must go through a Bluetooth SIG process called *Qualification*. This involves gathering information about a product and the features of Bluetooth technology it uses and executing a series of associated Test Suites to validate compliance of the implementation with the applicable Bluetooth specifications.

Separate from the SIG Qualification program, every device containing a radio is subject to a set of regulations of one or more types. Examples include radio regulatory (RF) requirements, Electromagnetic Compatibility (EMC) requirements, and radio exposure requirements. This document focuses on RF requirements since they significantly impact the radio architecture design and what is permitted in areas such as output power and system duty cycle. These types of issues in turn affect implementation decisions and the development of the Bluetooth specifications.

Products must satisfy applicable regulations regarding the use of RF spectrum in the relevant markets. Compliance with market access requirements falls outside the scope of the Bluetooth SIG's work. Successful SIG qualification of a product does not necessarily mean that a product will satisfy the specific RF regulations of the applicable regulatory bodies. In regulatory product testing, the observable behavior of the complete product is tested, not individual protocol layers.

The general principle for regulatory testing is that every product is tested against the regulatory RF requirements that apply at the time.

The primary objective of this document is to provide guidance and supporting information relating to Bluetooth Low Energy (LE) technology and the Bluetooth SIG's understanding of RF regulations that apply in various geographic regions. This is an informational guide only and is neither a substitute for the Bluetooth Core Specification [2] and the applicable regulations in the regions discussed nor a complete RF regulatory tutorial. It is assumed that the reader has basic technical knowledge of Bluetooth technology and of RF in general.

Sections 3 through 7 of this paper describe Physical Layer and Link Layer capabilities and variables of Bluetooth LE relevant to the RF properties. These include transmission power, channel use, timing, frequency hopping and adaptive behaviors. Information relating to Bluetooth BR/EDR is sometimes provided for the purposes of comparison.

Bluetooth LE and the standardized applications that use it are defined by a series of specifications of different types. Understanding what those specification types are and how they relate to each other is important to finding the right information, and this is covered in Section 3.

Operating systems and APIs sit between applications and the Bluetooth LE stack and often impose constraints on how Bluetooth technology can be used. It is worth appreciating that this is the case and that the existence of a Bluetooth LE feature in an implementation does not necessarily mean it will ever be fully exhibited in a device that uses that implementation.

Regulators sometimes use terminology differently from how it is used in Bluetooth specifications. This document uses terminology as defined in the Bluetooth Core Specification [2] except in Section 8 which provides information on the terminology used by regulators and assistance in understanding how to interpret it in the context of Bluetooth LE.

Note: This paper relates to Bluetooth LE technology as defined in the Bluetooth Core Specification [2] up to and including version 5.4.

Note: When reviewing regulatory requirements worldwide and comparing those to the Bluetooth Core Specification [2], it is important to understand that units used may differ from one regulatory domain to another. In this document, regulatory requirements published using different units have been converted to the units used in the Bluetooth Core Specification [2] to enable easier comparisons.

See Appendix B for more information on this issue.

This is not a Bluetooth specification; therefore, the established Bluetooth SIG specification language conventions for use of the words ***shall***, ***shall not***, ***must***, ***should***, ***should not***, ***may***, and ***can*** do not apply to this document.

2 Historical overview

Bluetooth technology has been around since the year 1999. Initially created to allow two devices to exchange data wirelessly without needing any other intermediate networking equipment, it quickly found a role in products such as wireless mouses and hands-free car kits. The latter is an audio product, and audio proved to be a game changer for this original version of Bluetooth technology. This first version of Bluetooth technology is known formally as Bluetooth BR (Basic Rate) and uses GFSK modulation. Later, a higher data rate version, known as Bluetooth EDR (Enhanced Data Rate), using PSK modulation, was added. The symbol rate for all modulation modes is 1 Msym/s. The gross air data rate is 1 Mb/s for Basic Rate, 2 Mb/s for EDR2 using π/4-DQPSK, and 3 Mb/s for EDR3 using 8DPSK.

Bluetooth Low Energy (LE) was introduced in 2010 as a simpler alternative to Bluetooth BR/EDR, appearing in version 4.0 of the Bluetooth Core Specification[1] [2].

One of the original design goals for this new Bluetooth technology variant was to be highly efficient in its use of power. Devices that ran off small, coin-sized batteries for days or weeks or more were envisaged and that drive for energy efficiency explains many of the defining characteristics of Bluetooth LE. In particular, the design assigns asymmetrical capabilities and responsibilities to devices, ensuring that devices with a relatively plentiful power source such as a large smartphone battery do more of the heavy lifting than peer devices running on coin cell batteries.

Since the first version of Bluetooth LE, the specification has grown extensively to address new use cases, notably LE Audio. The resulting rich feature set and many ways of using Bluetooth LE must be carefully considered when it comes to regulatory compliance. Bluetooth LE supports both point-to-point communication between two devices and broadcast communication, which allows one device to transmit data to a large number of receivers simultaneously. Broadcast communication is also the foundation of Bluetooth mesh networking, which allows networks of thousands of devices to be created, each one able to communicate with any other device in the network.

Bluetooth LE supports one-to-one communication between two devices by both connection-oriented communication and connectionless communication. Bluetooth LE also supports one-to-many communication by connectionless broadcasting.

[1] The Bluetooth specifications are introduced in Section 3.

3 The Bluetooth LE specifications

A thorough understanding of Bluetooth LE requires intimate familiarity with the applicable specifications. The architecture, procedures, and protocols of Bluetooth LE are defined in full by one key specification called the *Bluetooth Core Specification* [2]. How products use Bluetooth technology is defined by collections of specifications of two special types known as *profiles* and *services*. Profiles and services help enable products to be interoperable at the application layer.

Figure 3.1 illustrates the Bluetooth LE specification types and their relationships.

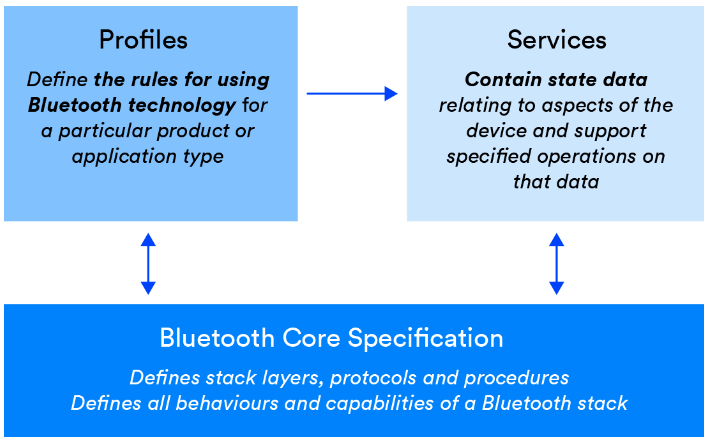


Figure 3.1: The Bluetooth LE specifications

3.1 The Bluetooth Core Specification

The Bluetooth Core Specification [2] is the primary specification for both Bluetooth LE and Bluetooth BR/EDR. It defines the architecture of the technology and its layers; it describes and defines its key features, and it defines the formal procedures underpinning important operations and the protocols with which devices can communicate at a given layer of the stack. It is a necessarily large specification.

The Bluetooth Core Specification [2] defines how Bluetooth technology works and the requirements for developers when implementing a Bluetooth stack or one or more of its features.

3.2 Profile specifications

Profile specifications (or just *profiles*) define which parts of the Core Specification are used by particular product types or use cases and how they are used. For example, the Heart Rate Profile defines the use of the Bluetooth Core by heart rate monitor products. As a result, heart rate data collectors (for example, smartphone applications) are interoperable with heart rate monitor devices from different manufacturers.

The majority of Bluetooth LE profiles are relatively simple and tend to describe how the Generic Access Profile (GAP) is used for device discovery and how communication takes place between two devices over a Link Layer connection using the procedures defined in the Generic Attribute Profile (GATT).

That said, some profiles are more complicated than others. For example, the Bluetooth LE Audio technology (LE Audio) is a generalized framework that includes multiple profiles. The LE Audio profiles can be viewed as modules that define the use of the Bluetooth Core by particular aspects of LE Audio, and they allow requirements that are common to many audio product types to be centralized in dedicated profile specifications such as the Basic Audio Profile (BAP) and Common Audio Profile (CAP).

Bluetooth mesh technology is also defined in a profile specification. This defines a mesh networking protocol stack supported by the lowest layers of the Bluetooth Core stack (the Physical Layer and Link Layer) and uses other Core parts such as GAP and GATT.

3.3 Service specifications

A service specification can be thought of as defining one aspect of a server device's behavior.

State data on servers resides in formally defined data items known as *characteristics* and *descriptors*. Characteristics and descriptors are grouped inside constructs known as *services*. Services provide a context within which to assign meaning and behaviors to the characteristics and descriptors that they contain.

A service specification defines a single service along with its characteristics and descriptors. The behaviors to be exhibited by the device hosting the service in response to various conditions and state data values are defined in the service specification.

Profile specifications indicate the services that must or may be implemented by a product of the relevant type. They can also impose additional service-related requirements for the client, the server, or both.

4 The Bluetooth LE stack

4.1 High-level architecture

The Bluetooth LE stack consists of a number of layers and functional modules, some of which are mandatory and some of which are optional. These parts of the stack are distributed across two major architectural blocks known as the *host* and the *controller,* and a standard logical interface defines a way in which these two components may communicate.

The host is often something such as an operating system. The controller is often a system on a chip. However, this is not necessarily the case, and the Bluetooth specifications do not mandate any such implementation details. What is important is that the host and controller act as separate logical containers in the architecture that *may* be implemented in physically separate components, with a standard interface (referred to as the *Host Controller Interface*) defined for communication between them. This allows a Bluetooth system to consist of host and controller components from different manufacturers.

Figure 4.1 illustrates the Bluetooth LE stack, its layers, and their distribution across the host and controller components. It should be noted that only the Physical Layer and the Link Layer have direct relevance to the regulatory issues discussed in this document. Other information about the Bluetooth LE stack is provided here for context.

The Host Controller Interface (HCI) indicates the logical interface between them but is not a physical component. HCI can be implemented in many ways in terms of the underlying physical transport, but the logical or functional interface is always the same.

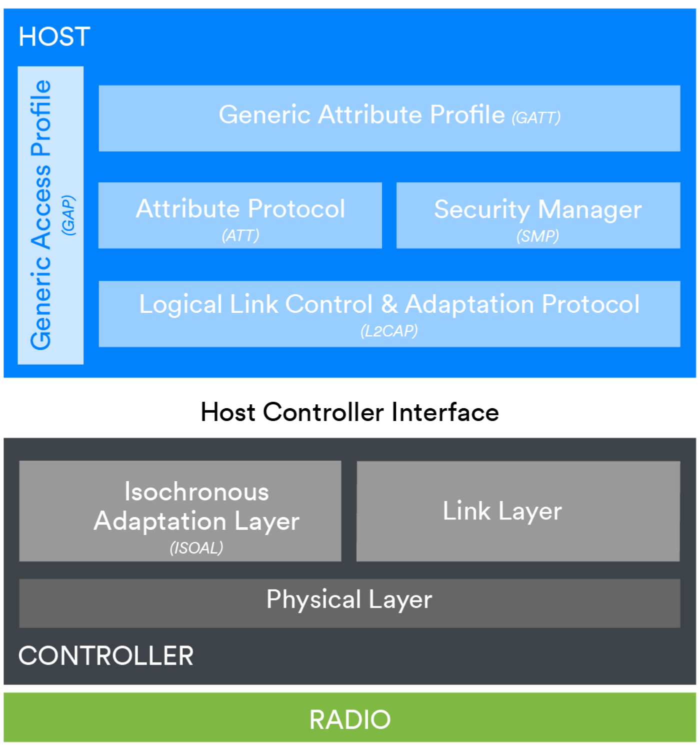


Figure 4.1: The Bluetooth LE stack

The Bluetooth mesh profile uses the Bluetooth LE controller with Link Layer and Physical Layer. The host part includes a collection of specialized layers that implement the Bluetooth mesh protocols and procedures. In addition, the host may include any of those layers shown in the host part of Figure 4.2 that are required to support other product requirements such as the ability to form connections.

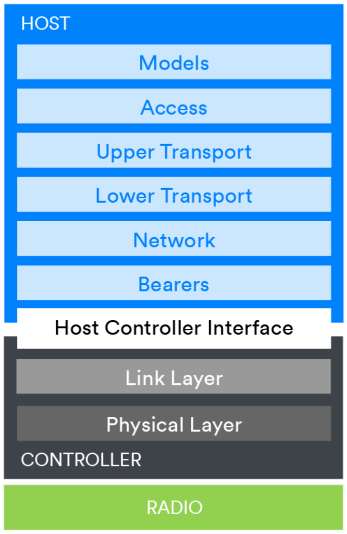


Figure 4.2: A simplified depiction of the Bluetooth mesh stack

4.2 The layers at a glance

A summary of the key responsibilities and features of each layer of the Bluetooth LE stack as depicted in Figure 4.1 as follows:

Layer	Key Responsibilities
Generic Access Profile (GAP)	Defines operational modes and procedures that may be used in a non-connected state, such as how to use advertising for connectionless communication and device discovery. Defines security levels and some user interface standards.
Generic Attribute Profile (GATT)	Defines high-level data types known as services, characteristics, and descriptors in terms of underlying attributes in the attribute table.
Attribute Protocol (ATT)	A protocol used for the discovery and use of data held by the server in a logical data structure known as the attribute table.
Security Manager Protocol (SMP)	A protocol used during the execution of security procedures such as pairing.
Logical Link Control and Adaptation Protocol (L2CAP)	Provides data channel multiplexing services over RF connections, segmentation, and reassembly of large SDUs, and enhanced error detection and retransmission facilities.
Host Controller Interface (HCI)	Provides an interface for bi-directional communication of commands and data between the host component and the controller.
Isochronous Adaptation Layer (ISOAL)	Allows different frame durations to be used by devices using isochronous channels.
Link Layer	Defines air interface packet formats, bit stream processing procedures such as error checking, a state machine and protocols for over-the-air communication, and link control. Defines several distinct ways of using the underlying radio for connectionless, connection-oriented, and isochronous communication, known as logical transports.
Physical Layer	Defines all aspects of Bluetooth technology that are related to the use of radio (RF), including modulation schemes, frequency bands, channel use, transmitter, and receiver characteristics. Two combinations of Physical Layer parameters are defined and are referred to as the LE 1M and LE 2M PHYs. A further PHY, LE Coded, is defined. Despite the name, LE Coded uses the same Physical Layer parameters as LE 1M but applies forward error-correction coding and pattern mapping in the Link Layer.

Table 4.1: Summary of the key responsibilities and features of each layer of the Bluetooth LE stack

4.3 Bluetooth LE Audio architecture

The Bluetooth LE Audio architecture is defined by a series of specifications that are collectively known as the Generic Audio Framework (GAF), along with top level specifications. By default, it is used with the Low Complexity Communication (LC3) codec. The LE Audio architecture is depicted in Figure 4.3.

A detailed review of the details of the LE Audio specifications is outside the scope of this document. For details of the specifications, see [48]. Further reading about the Bluetooth LE Audio architecture is available in [47].

The dotted boxes indicate sets of profiles and services which work together. In most cases there is a one-to-one relationship between a profile and a service, although in the case of the Basic Audio Profile (BAP) and the Voice Control Profile (VCP), one profile can operate using three different services.

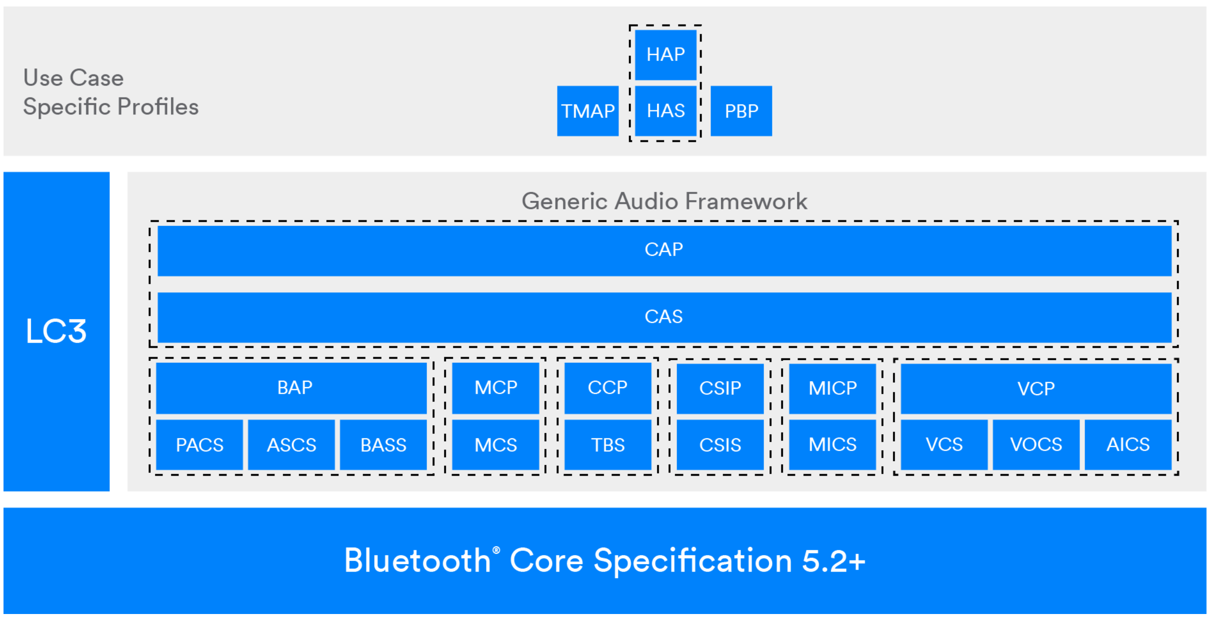


Figure 4.3 - Overview of the Bluetooth LE Audio Specifications

The Public Broadcast Profile (PBP) is a profile for broadcasted LE audio. It operates without a connection between the audio Source and the audio Sink(s). The lack of a traditional client-server relationship between devices leads to that the profile operates without the need for an associated service specification.

4.3.1 Public Broadcast Profile (PBP)

The Public Broadcast Profile defines how a Broadcast Source (PBS) uses extended advertising data to signal that it is transmitting broadcast audio streams that can be discovered and rendered by Broadcast Sink devices that support commonly used audio configurations.

The extended advertisements (see Section 7.6.2.3) and the associated periodic advertising train (see Section 7.6.3.3) for the Broadcast Isochronous Group (BIG) (see Section 7.6.5.3) is transmitted by the Broadcast Source if it is in the Streaming state.

All devices that are actively broadcasting sends their BIGInfo structure in the ACAD field (see Section 7.6.3) of the periodic advertising train. This provides the information needed by a receiving device to detect the audio broadcast and determine the timing parameters of the BIS.

A Broadcast Sink synchronizes to the Periodic Advertising train and subsequently to an associated broadcast audio stream.

4.3.2 Auracast™

Qualified PBP devices can utilize Auracast™ trademarks licensed from the Bluetooth SIG (see [49]). In the case where a device is a Public Auracast™ Transmitter, it is required to broadcast a Standard Quality Public Audio Broadcast stream.

See Section 9 for example calculations corresponding to the Standard Quality Public Broadcast Audio and the High Quality Public Audio Broadcast configurations.

5 The Generic Access Profile (GAP) and device roles

5.1 The significance of GAP

The operational modes that the Link Layer provides (see Section 7.6) determine the permissible ways in which radio channels can be used. The Physical layer defines how RF itself may be used.

While these two layers of the Bluetooth LE stack ultimately determine how Bluetooth LE uses the 2.4 GHz radio spectrum, devices assume roles defined by the Generic Access Profile (GAP), and these roles define different ways to use Bluetooth LE scheduling, which can significantly influence RF activity. An appreciation of GAP roles and terminology may therefore be useful in understanding observed behaviors.

5.2 Generic Access Profile (GAP)

GAP defines four device roles. The role assumed by a device is either defined in an applicable Bluetooth profile specification or is a consequence of an implementation decision in cases where no standard profile applies.

The four GAP roles are:

1. Broadcaster
2. Observer
3. Peripheral
4. Central

It should be observed that the Link Layer also uses the terms Peripheral and Central for Link Layer roles. However, when used in the context of GAP, the terms have a different meaning compared with their use in the context of the Link Layer. There is, however, a correlation between the two in that when a device assumes the role of GAP Peripheral, then its Link Layer role is that of the Peripheral; likewise, when it assumes the GAP Central role, then the Link Layer role is Central.

A **Broadcaster** uses either one of Advertising Broadcast, Periodic Advertising Broadcast, or Broadcast Isochronous operational modes to transmit packets. Connections are not supported. A Broadcaster must include a transmitter component but is not required to contain a receiver.

An **Observer** performs scanning and receives packets broadcast by a device in the Broadcaster or Peripheral role but cannot form a connection with other devices. Either passive scanning or active scanning may be performed. If active scanning is performed, the Observer may respond to received advertising packets by transmitting PDUs that request further information from the advertising device. An Observer must include a receiver component but is not required to contain a transmitter.

A **Peripheral** can accept a connection request from a device acting in the Central role. Typically, this is preceded by the Peripheral transmitting advertising packets, which facilitate device discovery and indicate the advertising device's availability to be connected. With a connection established, the Peripheral receives packets at the Link Layer from the Central device and may or may not respond since connection parameter values may allow the Peripheral to save power by responding to only a subset of the packets received from the Central. A Peripheral must contain both a transmitter and a receiver.

A **Central** can send connection requests to a Peripheral that is in a suitable state (as defined by the Link Layer state machine). Having formed a connection, the Central transmits packets at the Link Layer addressed to the connected Peripheral during *connection events*. A Central must contain both a transmitter and a receiver.

6 The Physical Layer

The Physical Layer of Bluetooth LE defines how the radio transmitter/receiver encodes and decodes digital data for transmission and receipt, and other radio-related parameters and requirements that apply.

6.1 Frequency band

Bluetooth LE operates in the 2.4 GHz unlicensed band, using the frequency range 2402 MHz to 2480 MHz, which is divided into 40 channels, each with a spacing of 2 MHz. The Link Layer and the data transport architecture define how channels are used.

Figure 6.1 shows the Bluetooth LE channel indices. Channels with index values 37, 38, and 39 are used as primary advertising channels, while the remaining channels are used for general purposes. Section 7.1 describes the channels further, and Section 7.6.2 covers Bluetooth LE advertising.

Channel Index	37		1	2	3	4	5	6	7	8	9	10	38	11	12	13	14	15	16	17
Centre Frequency	2402	2404	2406	2408	2410	2512	2414	2416	2418	2420	2422	2424	2426	2428	2430	2432	2434	2436	2448	2440

Channel Index	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	39
Centre Frequency	2442	2444	2446	2448	2450	2452	2454	2456	2458	2460	2462	2464	2466	2468	2470	2472	2474	2476	2478	2480

Figure 6.1: Bluetooth LE channels

6.2 PHY variants

Three modulation scheme variants are defined. Each variant is referred to as a *PHY* and has a name.

1. The LE 1M PHY uses a symbol rate of 1 Msym/s with a required frequency deviation of at least 185 kHz and uses no special coding. The nominal channel bandwidth is 1 MHz. All devices must support the LE 1M PHY.
2. The LE 2M PHY is similar to LE 1M but uses a symbol rate of 2 Msym/s and has a required frequency deviation of at least 370 kHz. The nominal channel bandwidth is 2 MHz. Support for the LE 2M PHY is optional.
3. The LE Coded PHY uses a symbol rate of 1 Msym/s, but packets are subject to a coding that consists of two processes. The first to be applied is a convolutional encoder called Forward Error Correction (FEC). Output from the FEC encoder is then spread by a process called the pattern mapper. The bit output sequence produced by the pattern mapper depends on a parameter called *S*, which takes a value of 2 or 8 that typically is set by the host. The LE Coded PHY increases the effective range of transmissions at the expense of significantly increased packet length and reduced application data rate. The nominal channel bandwidth is 1 MHz. Support for the LE Coded PHY is optional. FEC and the pattern mapper are defined in the Link Layer specification in [2].

A comparison of the three PHYs (with both permitted values of S for LE Coded) appears in Table 6.1.

	LE 1M	LE Coded with S=2	LE Coded with S=8	LE 2M
Symbol Rate	1 Msym/s	1 Msym/s	1 Msym/s	2 Msym/s
Protocol Data Rate	1 Mb/s	500 kb/s	125 kb/s	2 Mb/s
Symbols per Bit	1	2	8	1
Bits per symbol	1	0.5	0.125	1
Error Detection	CRC	CRC	CRC	CRC
Error Correction	NONE	FEC	FEC	NONE
Requirement	Mandatory	Optional	Optional	Optional

Table 6.1: PHY comparison

6.3 Time-division

A Bluetooth LE radio is a half-duplex device capable of transmitting and/or receiving but not both at the same time. However, all PHYs are used in a Time Division Duplex (TDD) scheme to give the appearance of a full-duplex radio.

6.4 Transmitter characteristics

6.4.1 Transmission power

The Physical Layer (Vol 6 Part A in [2]) specifies transmitter characteristics for Bluetooth LE.

Regulatory bodies in different parts of the world may override these requirements, and implementers must determine that devices comply with applicable local regulations.

The Bluetooth Core Specification [2] defines a number of *power classes* for Bluetooth LE. Power classes are expressed in terms of P_{max}, the maximum output power at the antenna connector that a PHY implementation supports. Table 6.2: Bluetooth LE power classes contains information from Table 3.1 in Volume 6, Part A, Section 3 of the Bluetooth Core Specification [2]. It should be noted that power class declaration as part of SIG qualification may not be the same as the power declaration required by regional regulations.

Power Class	Requirements
1	100 mW (+20 dBm) ≥ P_{max} > 10 mW (+10 dBm)
1.5	10 mW (+10 dBm) ≥ P_{max} > 2.5 mW (-20 dBm)
2	2.5 mW (+4 dBm) ≥ P_{max} > 1 mW (0 dBm)
3	1 mW (0 dBm) ≥ P_{max} > 0.01 mW (-20 dBm)

Table 6.2: Bluetooth LE power classes

6.4.2 Spurious emissions

The Bluetooth Core Specification defines requirements for in-band spurious emissions when transmitting (see Volume 6, Part A, Section 3.2 in [2]) in terms of *adjacent channel power* values and associated frequency offsets.

The Bluetooth Core Specification does not specify spurious out-of-band emission requirements. Section 3.2.3 in [2] states that “The equipment manufacturer is responsible for the ISM out-of-band spurious emissions requirements in the intended countries of sale”.

7 The Link Layer

7.1 Overview of the Link Layer

The Link Layer (LL) has many responsibilities. It defines several types of packets that are transmitted over the air and an associated air interface protocol. Its operation is subject to a well-defined state machine. Depending on the state, the Link Layer may operate in several quite different ways, driven by events of many types. Numerous control procedures affecting a link's state or link usage parameters are defined.

The Link Layer determines the subset of RF channels (see Section 6.1) to be used for a given purpose and uses the following names:

Subset Name	Channel Indices
Primary advertising channels	37, 38, and 39
General-purpose channels	0 to 36

Table 7.1: RF channel, subset names and channel indices

How these channel subsets are used and under what circumstances is described for each operational mode in Section 7.6.

Radio channel selection and classification are also defined in the Link Layer specification in [2].

The Link Layer supports both connected and connectionless communication. It supports both point-to-point communication between two devices and one-to-many broadcast communication from one device concurrently to a potentially large number of receiving devices.

Transmission timing is governed by a system of events of various types and other timing rules. Details of applicable timing events are explained in Section 7.6.

7.2 Packets

7.2.1 General information

The Link Layer defines two packet types for use with the uncoded PHYs (LE 1M and LE 2M) or with the LE Coded PHY. The two packet types are depicted in Figure 7.1 and Figure 7.2.

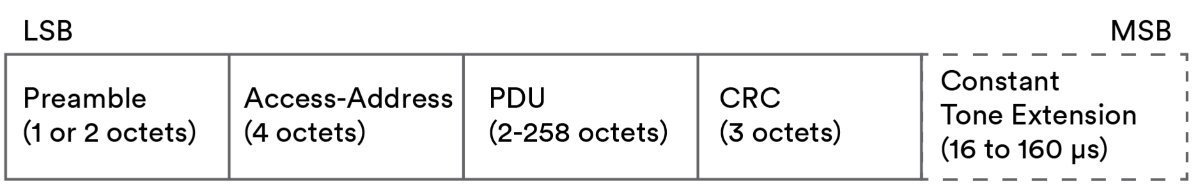


Figure 7.1: Link Layer packet format for PHYs LE 1M and LE 2M

The Constant Tone Extension (CTE) field is optional, and its use is associated with direction finding.

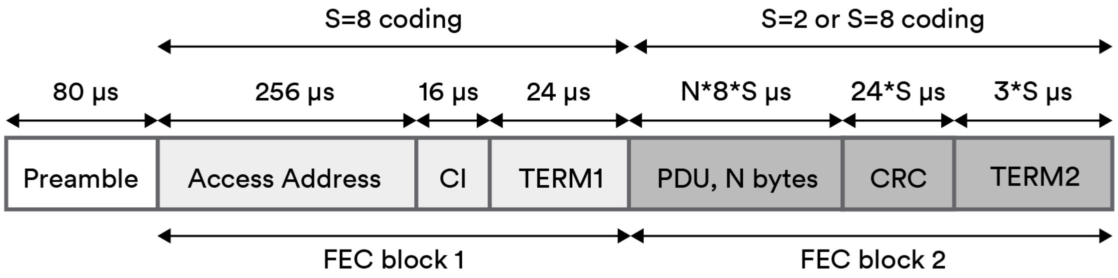


Figure 7.2: Link Layer packet format for the LE Coded PHY

The time to transmit a single Link Layer packet depends on the PHY and the packet length. The packet length depends on the PDU type contained within the packet, and the PDU length depends on its payload. The type of PDU contained within a packet depends on the *physical channel* in use and applicable PDU formats. *Physical channel* is a concept explained in Section 7.5.

When using the LE Coded PHY, the coding process increases the packet length. There are two parts to the process, first the *Forward Error Correction* (FEC) encoder and second the *Pattern Mapper*. The FEC encoder outputs two bits for every input bit. The Pattern Mapper is used with a parameter that the Bluetooth Core Specification [2] names *S*. S takes a value of 2 or 8. A value of S=2 does not increase the number of bits received from the FEC encoder, whereas a value of S=8 quadruples the number of bits again. All Link Layer packet fields after the preamble are coded. Some fields are always coded using S=8, whereas others are coded using either S=2 or S=8. See Figure 7.2 for details.

7.2.2 Transmission duration and uncoded PHYs

A Link Layer packet transmitted using an Uncoded PHY (LE 1M or LE 2M) and without the CTE field takes 44 µs to 2128 µs to transmit.

It should be noted that if one of the Bluetooth direction finding methods, Angle of Arrival (AoA) or Angle of Departure (AoD) is in use, then some transmitted packets include the CTE field. CTE adds up to 168 µs to the transmission time of packets.

7.2.3 Transmission duration and coded PHYs

The LE Coded PHY always uses a 1 Msym/s modulation, and packets take a minimum of 462 µs and a maximum of 17040 µs to transmit.

The CTE field is not permitted when the LE Coded PHY is used.

7.3 State machine

The Link Layer is governed by a state machine, which is shown in Figure 7.3.

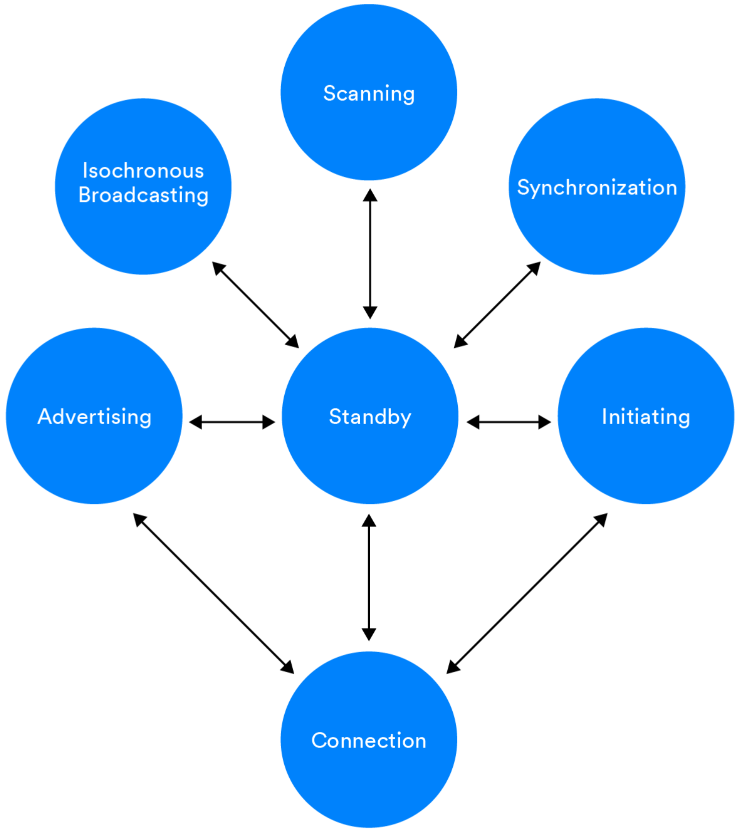


Figure 7.3: The Link Layer state machine

When in the Connection state, two important device roles are defined. These are the *Central* role and the *Peripheral* role. A device that initiates a connection and transitions from the Initiating state to the Connection state assumes the Central role. A device that accepts a connection request and transitions from the Advertising state to the Connection state assumes the Peripheral role.

When two devices are connected, the Central device controls timing and channel map and transmits first. The same is true for the advertiser in the periodic advertising mode and the broadcaster of a Broadcast Isochronous Group (BIG).

An instance of the state machine may be in only one state at a time. A Link Layer implementation may support more than one state machine instance concurrently. Refer to the Link Layer specification in [2] for full details of each state.

7.4 Channel selection

As Section 6.1 describes, Bluetooth LE divides the 2.4 GHz frequency band into 40 channels. The Link Layer controls how those channels are used, and this in turn depends on the overall way Bluetooth LE is used for communication (the *operational* mode–this is covered in Section 7.5).

Bluetooth LE uses spread spectrum techniques in various ways to communicate data via multiple channels over time. This reduces the chances of collisions, making communication more reliable.

7.4.1 Algorithms

Except for non-periodic advertising (see Section 7.6.2), all Bluetooth LE operational modes make use of a standard channel selection algorithm to at least some extent. During the history of Bluetooth LE, two channel selection algorithms have been defined: *channel selection algorithm #2 (CSA#2),* added in v5.0 of the Core Specification, and *channel selection algorithm #1 (CSA#1)*, which was introduced in v4.0. CSA#1 has some limitations in the statistical distribution of used channels when the number of available channels is small, and CSA#2 addresses this issue. Details of both algorithms are found in the Bluetooth Core Specification [2] (Volume 6, Part B, Sections 4.5.8.2 and 4.5.8.3).

Note: CSA#1 is still supported, but its use is not recommended in new products. Use of CSA#2 is always preferred.

A channel selection algorithm selects a channel from among the general-purpose channels or a smaller subset at each invocation.

The channel selection algorithms use information in a channel map that classifies each of the general-purpose channels as *used* or as *unused*. The channel selection algorithm avoids channels being designated as *unused*. This avoidance of channels from the unused category has important consequences in certain regulatory domains. See Section 8.

By default, all general-purpose channels are designated *used,* but devices in some roles may use implementation-specific techniques to assess how well each channel functions. If it is determined that one or more channels are not working well, then their classification in the channel map may be set to *unused*. Conversely, if an *unused* channel is later found to be working well, then its classification can be updated in the channel map to *used*. Channel map updates may be shared with other devices, depending on the operational mode.

Sometimes the term *adaptive frequency hopping* is used as an informal shorthand for the use of one of the channel selection algorithms together with channel assessment and the channel map.

The use of channel assessment data by the channel selection algorithms makes it possible (depending on implementation aspects outside the scope of the Bluetooth Core Specification [2]) for a Bluetooth LE device to use only the optimal subset of available channels and so, for example, coexist effectively with other wireless technologies that use statically allocated channels. This is the *adaptive* aspect of the Bluetooth *adaptive frequency hopping* system.

How channels are used and how and when channel selection and assessment takes place within each of the applicable operational modes is explained in Section 7.6.

Note: Regulations may define adaptive frequency hopping and related terminology differently from the Bluetooth Core Specification [2]. Section 8 of this document highlights such differences. It is recommended that regulations regarding spectrum use in target markets are reviewed early in the product development lifecycle, as this may inform certain implementation decisions.

7.4.2 Channel selection #2 frequency occupation probability

This section describes the Channel Selection #2 algorithm RF channel occupation probability. *U* is the number of used RF channels.

The theoretical expected (or average) channel occupancy probability is given by the following:

$$\frac{100\%}{U} \cong \begin{cases} 2.7\%\ for\ U = 37\ used\ RF\ channels \\ 6.7\%\ for\ U = 15\ used\ RF\ channels \end{cases}$$

The Channel Selection #2 kernel repeats the sequence after 65536 (2^{16}) selections and has about 65000 different sequences. Figure 7.4, Figure 7.5, and Figure 7.6 show simulations of the channel occupancy and consecutive channel density (channel hop distribution) when there are 37 used channels at increasing event numbers for one of the roughly 65000 different sequences.

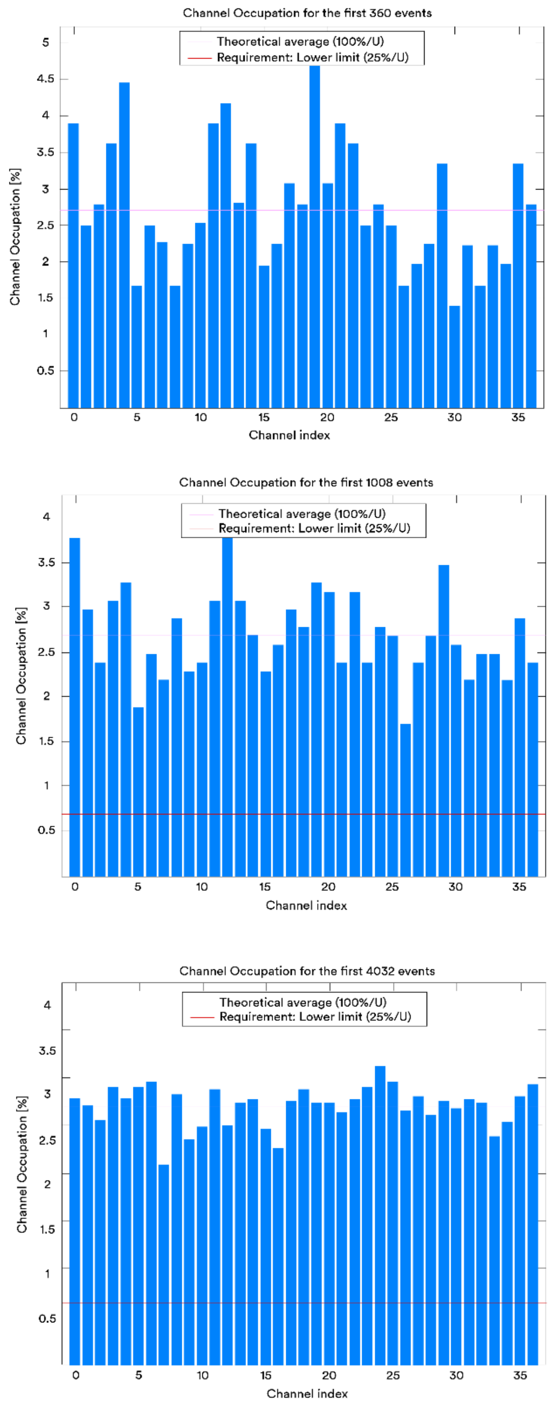


Figure 7.4: Simulation of how channel occupancy gets distributed over an increasing number of events (from 360 events to 4032 events) es

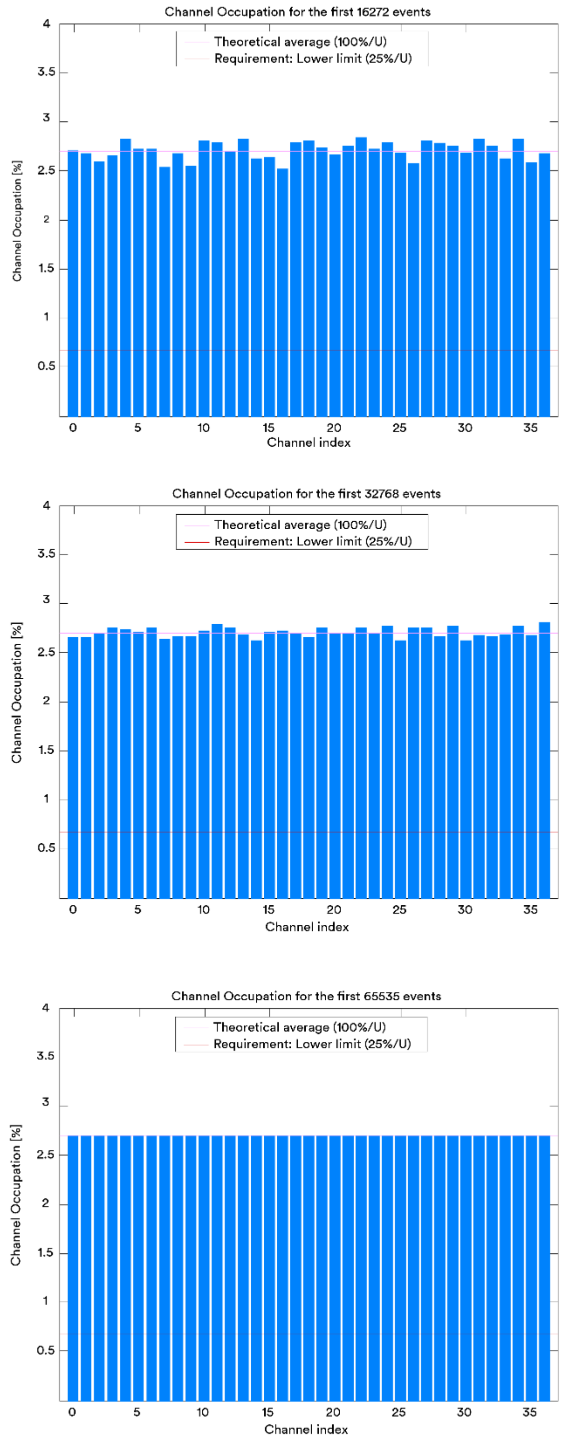


Figure 7.5: Simulation of how channel occupancy gets distributed over an increasing number of events (from 16272 events to 65535 events)

The simulations show that the LE Channel Selection #2 converges fast to the expected theoretical values. As mentioned above, the Channel Selection #2 algorithm wraps around after 65536 (2^{16}) events. The wraparound occurs each 8.2 minutes, when the minimum connection interval of 7.5 ms is utilized. As an example, it should also be noted that for a connection with the minimum connection interval, there are about 175.8 wraparounds or 11,520,000 events each day.

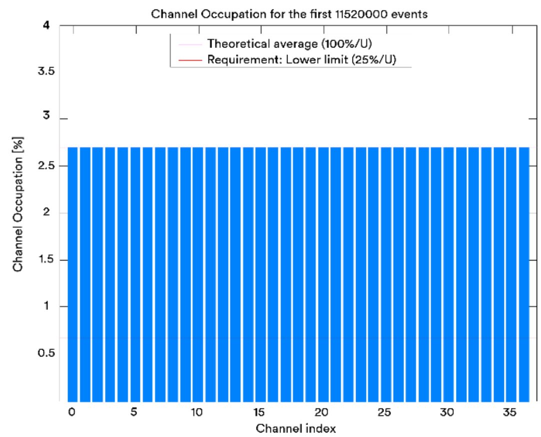


Figure 7.6: Simulation of channel occupancy distribution after 11,520,000 events

Above is shown the corresponding simulations for 11,520,000 events (175.8 wraparounds). The wraparounds do not have an influence on the statistical properties.

7.4.3 Channel selection algorithms and device roles

The device that maintains the channel map depends on the operational mode.

Operational mode	Device that maintains the channel map
LE Connected Asynchronous (LE ACL)	Central
LE Periodic Advertising Broadcast (PADVB)	Broadcaster
Connected Isochronous	Central
Broadcast Isochronous	Broadcaster

Table 7.2: Operational mode and the respective device that maintains the channel map

7.5 The data transport architecture

The architecture section of the Bluetooth Core Specification [2] defines several concepts that collectively constitute the *Bluetooth data transport architecture*. Key among these concepts are the physical channel, physical link, logical link, and logical transport. It further defines how these can be combined for use in support of different application types or *operational modes*, each with particular characteristics regarding issues such as topology, timing, reliability, power, and channel use. Each operational mode and information useful in the context of RF and regulatory issues is covered in Section 7.6.

A physical channel defines one of four different ways of communicating using Bluetooth technology. For example, the LE piconet physical channel supports point-to-point communication between connected devices.

A physical link is based on a single, specific physical channel and defines certain characteristics of that link such as the use or the power control. A device may have multiple Physical Links of the same or different types operating in parallel.

Logical links and logical transports have various parameters that are designed to provide a suitable means of supporting a particular set of data communication requirements over a physical link, using a particular physical channel type. Section 7.6 provides information about such parameters and their effect.

For example, reliable, bi-directional, point-to-point communication in Bluetooth LE uses the LE asynchronous connection-oriented logical (ACL) transport with either an LE-C link for control data or an LE-U link for user data, over a physical link based on the LE Piconet physical channel.

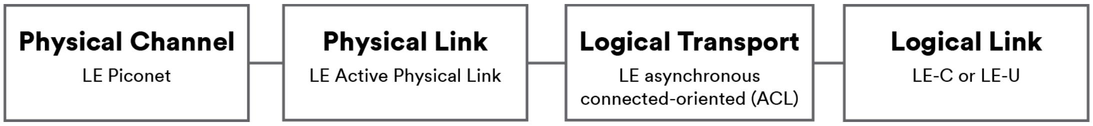


Figure 7.7: Example 1: Relationship between Logical Link (LE-C or LE-U), Logical Transport (ACL), Physical Link, and Physical Channel

As another example, unreliable, unidirectional broadcast communication in Bluetooth LE uses the LE Advertising Broadcast (ADVB) logical transport with either an ADVB-C logical link for control data or an ADVB-U logical link for user data, over a physical link based on the LE Advertising physical channel.

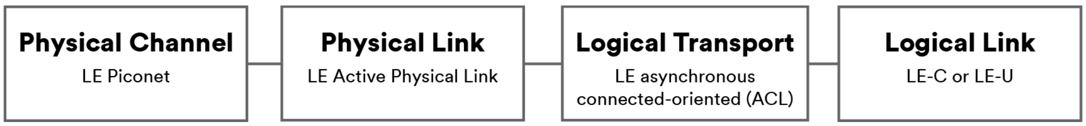


Figure 7.8: Example 2: Relationship between Logical Link (ADVB-C or ADVB-U), Logical Transport (ADVB), Physical Link, and Physical Channel

Five logical transports are available for use with Bluetooth LE. Figure 7.9 depicts them using operational mode names above the formal identifier used in the Bluetooth Core Specification [2].

Figure 7.9: The Bluetooth LE Logical Transports

Different logical transports and their associated physical channels may be used concurrently by a device by interleaving their use in time.

7.6 Bluetooth operational modes

7.6.1 LE Connected Asynchronous (LE ACL)

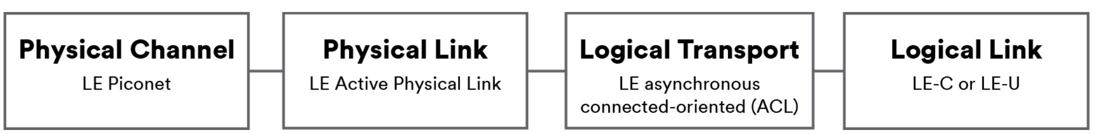


Figure 7.10: Relationship between Logical Link (LE-C or LE-U), Logical Transport (ACL), Physical Link, and Physical Channel

7.6.1.1 Basics

When two Bluetooth LE devices are connected, they are using the *asynchronous connection-oriented logical transport* (LE ACL or simply ACL), which provides for connection-oriented communication of data. ACL connections are generally referred to simply as *connections*.

One device in a connection acts in the *Central* role, initiates the connection, and has primary responsibility over the timing of communication events. The other device in the connection is called the *Peripheral*.

7.6.1.2 Channels

LE ACL channels are selected from the set of general-purpose channels using a channel selection algorithm and with reference to the channel map, as described in Section 7.4. This overall method is informally known as *adaptive frequency hopping*.

The Central device in a connection maintains a *channel map*. This channel map is shared with the Peripheral so that they each have the same information about which channels will be used and which will not.

A Peripheral may also perform its own channel monitoring and, at intervals, send *channel status reports* to the Central device, with each channel's status classified as *good*, *bad*, or *unknown*. The Central may then make decisions about channel classification in the channel map that consider both its own radio conditions and those being experienced by the remote Peripheral device.

The channel selection algorithm is invoked at every *connection event* and results in a new channel being selected for use when transmitting packets during that event. *Connection events* are explained in the next section.

7.6.1.3 Timing

In an ACL connection, packets can be transmitted during a *connection event*. The timing of connection events is based on the value of *connection interval* for that ACL connection. See Section 7.6.1.5 for more items that affect when packets can be transmitted.

The *connection interval* parameter is established when the Central and Peripheral devices connect; it has a value in the range 7.5 ms to 4000 ms and is always a multiple of 1.25 ms. The application layer may specify the connection interval parameter value. The connection interval used by an active connection may be changed without the need to re-establish the connection.

The Central and the Peripheral take turns, with the Central transmitting first and the Peripheral responding. The size and number of packets transmitted by each side during each connection event may vary.

Figure 7.11 shows an example of an exchange of packets, during two connection events with C→P indicating packet transmission by the Central device and P→C by the Peripheral. Note that all packets during a connection event are sent on the same frequency.

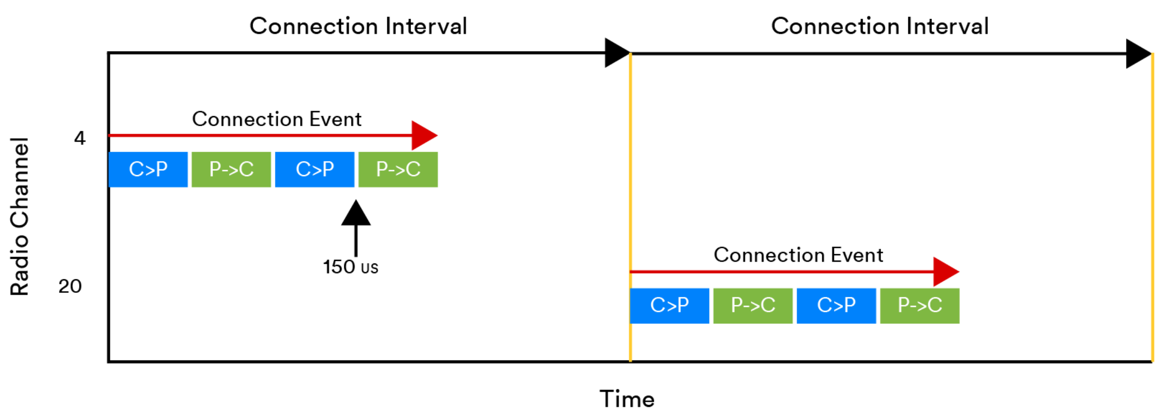


Figure 7.11: Example of basic packet exchange over an LE ACL connection

7.6.1.4 Transmission duration

LE ACL connections may use either of the Link Layer packet formats described in Section 7.2, depending on the PHY in use. Initially, the same PHY must be used by both Central and Peripheral, but the Link Layer defines a procedure called the PHY update procedure, which allows the transmit or receive PHY or both to be changed.

Two applicable PDU formats are defined and named the LL Data PDU and the LL Control PDU.

PDUs of both types have the format depicted in Figure 7.12.

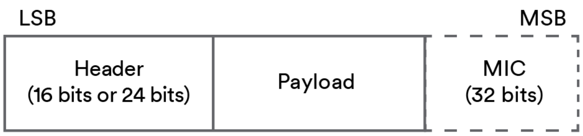


Figure 7.12: The Link Layer data channel PDU format

The header field is 16 bits in length unless the CTE field is appended at the end of the packet, in which case the header is 24 bits long.

MIC is the Message Integrity Check, a field that is only included within encrypted packets.

The length of the Payload field varies from 0 bits to 2008 bits (251 octets).

Maximum transmission times for the largest possible encrypted packets with no CTE field sent using the uncoded PHYs LE 1M and LE 2M are shown in Table 7.3:[2].

	Field Sizes (bits)	
Fields	**LE 1M**	**LE 2M**
Preamble	8	16
Access Address	32	32
LL Data PDU Header	16	16
LL Data PDU Payload	2008	2008
MIC	32	32
CRC	24	24
Total no. of bits	**2120**	**2128**
Transmission Time (µs)	**2120**	**1064**

Table 7.3: Maximum transmission times using LE ACL with uncoded PHYs

Note that when a packet includes the CTE field, there is an additional header field called CTEInfo, which is 8 bits long. This adds an 8 µs (with LE 1M) or 4 µs (with LE 2M) to the transmission time. The CTE itself on the end of the packet adds 16 µs to 160 µs to the transmission time.

2 Further examples of on-air time for various payload lengths are given in the Bluetooth Core Specification in Table 3.3 in Volume 1, Part A, Section 3.3.2.

Maximum transmission times for encrypted packets (which therefore include the MIC field) sent using the LE Coded PHY with each of the parameter S values of 2 or 8 are shown in Table 7.4.

	Field Sizes (bits)	
Fields	**LE Coded (S=2)**	**LE Coded (S=8)**
Preamble	80	80
FEC Block 1	296	296
FEC Block 2 - PDU	4112	16448
**FEC Block 2 - CRC	48	192
FEC Block 2 - TERM2	6	24
Total no. of coded bits	**4542**	**17040**
Transmission Time (µs)	**4542**	**17040**

Table 7.4: Maximum transmission times using LE ACL with the LE Coded PHY

7.6.1.5 Subrated connections

Subrated connections are LE ACL connections that have additional properties assigned to them for increased flexibility regarding the scheduling of packet transmission. The additional properties are called the *subrate factor*, *subrate base event*, and *continuation number*.

The subrated connection properties provide a mechanism for indicating that only a specific subset of connection events (see Section 7.6.1.3) need to be actively used by the connected devices, with the radio not used in other connection events except in case of continuations. A subrated connection can therefore have a short ACL connection interval but still exhibit a low duty cycle.

Figure 7.13 illustrates the basic concepts relating to subrated connections.

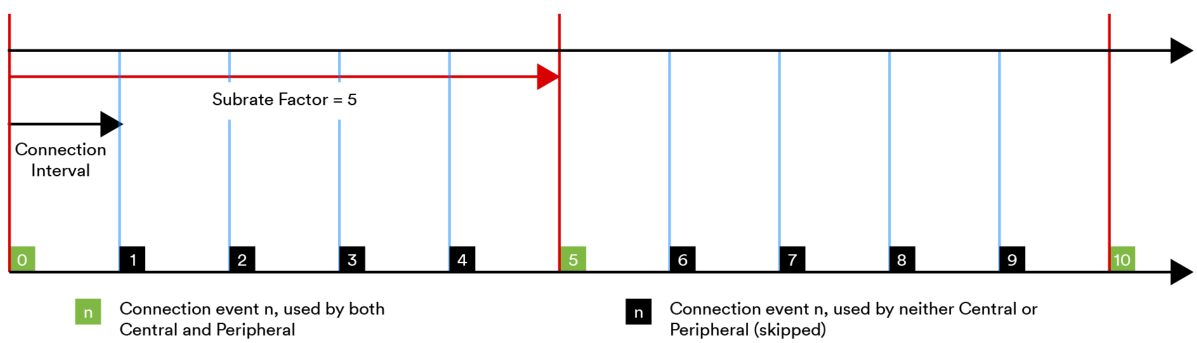


Figure 7.13: Example of a basic subrated connection with subrate factor=5

In this example, only one in every five connection events is used. The other four are skipped, and so there is no radio activity during those connection events. This ratio of used to skipped connection events is determined by the *subrate factor* parameter; in this example, it is set to 5.

The connection event during which the radio is used to transmit and receive Link Layer packets is known as a *subrated connection event*.

Given the relationship between the underlying ACL connection parameters and those that govern connection subrating, a subrated connection can be thought of as having both an underlying connection interval that controls the frequency at which ACL connection events occur and an *effective connection interval*, which determines how often those ACL connection events give rise to packet transmission after the subrating parameters have been applied.

7.6.1.6 PHYs

LE ACL connections may be used with any one of the three PHYs: LE 1M, LE 2M, or LE Coded. Central and Peripheral devices must initially use the same PHY when the connection is first established, but they may subsequently negotiate a change that results in different PHYs being used by each device for packet transmission.

7.6.2 LE Advertising Broadcast (ADVB)

7.6.2.1 Basics

The LE Advertising Broadcast (ADVB) logical transport provides a connectionless communication mode. It may be used to transfer data or to indicate the availability of a Peripheral device to be connected to.

Generally, advertising packets can be received by any scanning device in range and, as such, advertising may be used to concurrently transfer data without a connection to multiple scanning devices in a one-to-many topology. A special form of advertising known as *directed advertising* allows the advertising device to specify one specific scanning device as the recipient.

Advertising itself supports the communication of data in one direction only, from the advertising device to scanning devices. Scanning devices may reply to advertising packets with PDUs that request further information or for a connection to be formed. When a scanning device replies to obtain further information, it is said to be performing *active scanning*. When it does not, it is said to be performing *passive scanning*. When a scanning device replies with a request to establish a connection with the advertising device, it is said to be *initiating*.

Two categories of advertising procedure are defined and are referred to in the Bluetooth Core Specification [2] as *legacy advertising* and *extended advertising*.

Legacy advertising transmits advertising data on the primary advertising channels only and is described in Section 7.6.2.2.

Extended advertising was added in Core version 5.0 (see also Appendix D) and uses both the primary advertising channels and the secondary advertising channels. Extended advertising allows: much larger amounts of data to be broadcast, advertising to be performed to a deterministic schedule, and multiple distinct sets of advertising data governed by different configurations to be transmitted. Extended advertising can be used in either the LE Advertising Broadcast (ADVB) mode or the LE Periodic Advertising Broadcast (PADVB) mode. Section 7.6.2.3 covers extended advertising as used with the ADVB operational mode, and Section 7.6.3 covers the case of extended advertising in periodic broadcast advertising mode, which is also known as *periodic advertising*.

7.6.2.2 Legacy advertising

Legacy advertising and its use of radio channels, transmission timing, maximum transmission durations, and the PHYs that may be used are discussed in this section.

7.6.2.2.1 Channels

Identical copies of legacy advertising packets are transmitted on up to three of the primary advertising channels, one channel at a time, and optionally in some random or pseudo-random sequence. Legacy advertising using the ADV_IND PDU type and the way in which channels are used is illustrated by Figure 7.14.

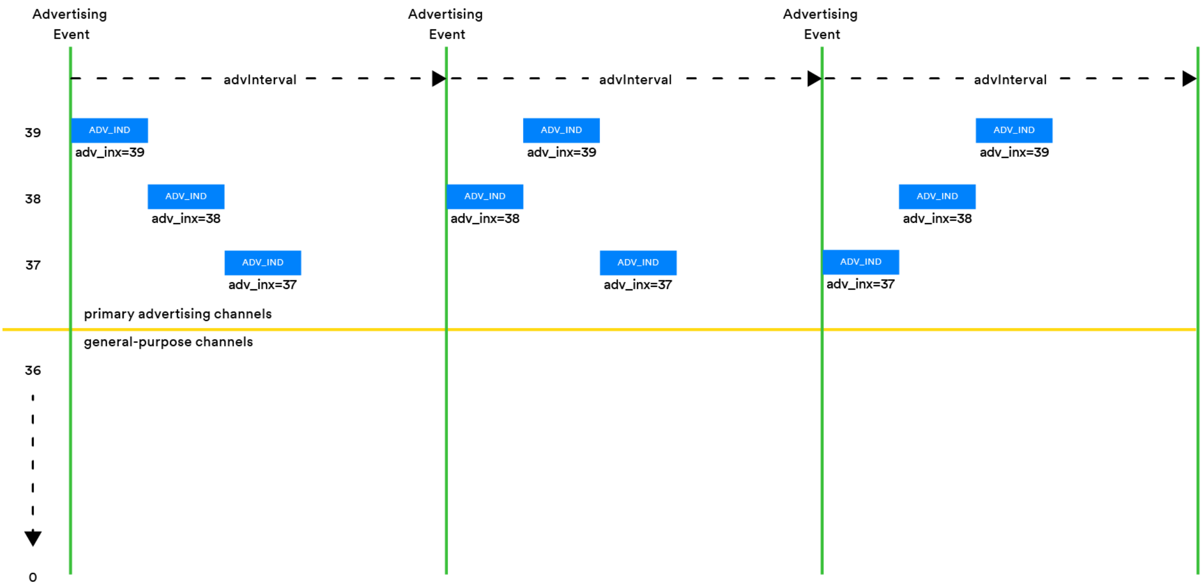


Figure 7.14: Example legacy advertising and channel use by channel index

7.6.2.2.2 Timing

The transmission of legacy advertising packets takes places during *advertising events*. The scheduling of advertising events is controlled by Link Layer timing parameters and is deliberately made slightly irregular to avoid persistent collisions with other advertising devices. A parameter known as *advDelay* is assigned a random or pseudo-random value in the range 0 ms to 10 ms at each advertising event, and this is added to the regular *advertising interval* (*advInterval*) so that advertising events are perturbed in time.

During an advertising event, one or more copies of a packet may be transmitted in sequence on one, two, or three of the primary channels. Typically, all three channels are used.

Figure 7.15 reproduces Figure 4.5 from Volume 6, Part B of the Bluetooth Core Specification [2] and illustrates the effect of the advDelay parameter.

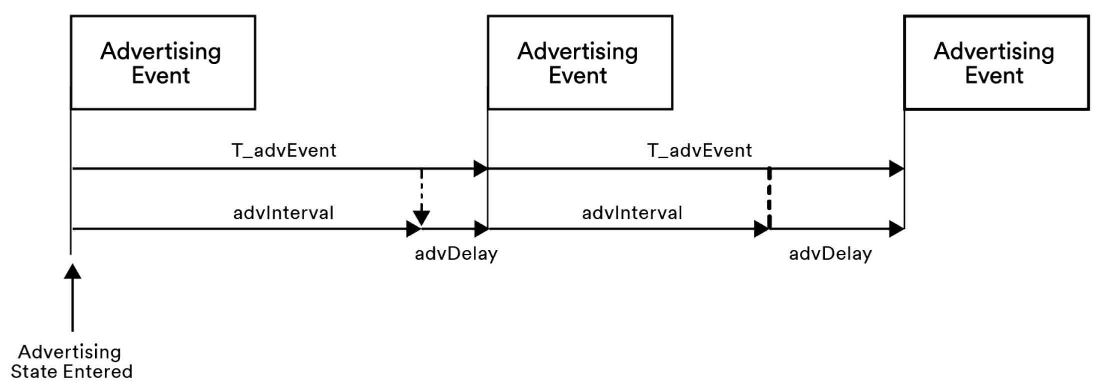


Figure 7.15: Advertising events perturbed in time using advDelay

The time between the start of two consecutive ADV_IND PDUs within the same advertising event must be less than 10 ms as shown in Figure 7.16.

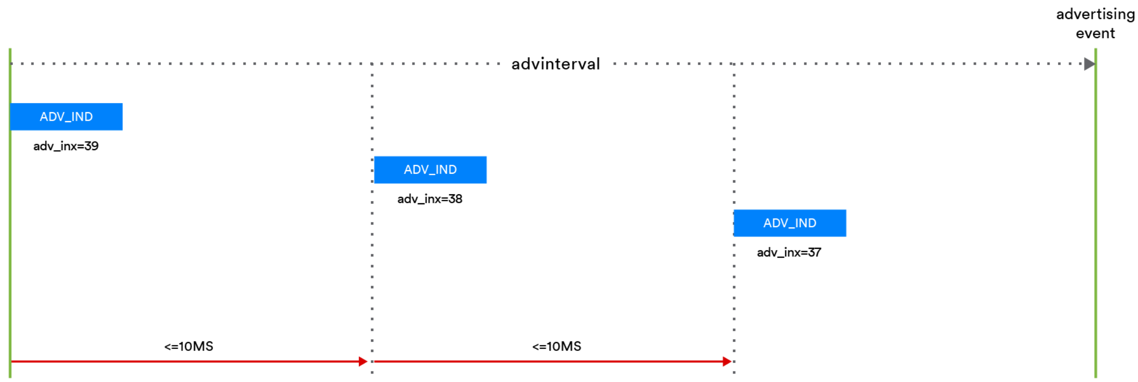


Figure 7.16: Example showing spacing of consecutive ADV_IND transmissions

7.6.2.2.3 Transmission duration

Legacy advertising PDUs are at most 37 octets long. They are always transmitted within Link Layer air interface packets defined for the LE Uncoded PHYs, using the LE 1M PHY. Figure 7.17 shows the structure of such packets with the red border indicating Link Layer uncoded packet fields, a green border indicating the ADV_IND PDU in the packet's PDU field, and the legacy advertising PDU in its payload field in blue.

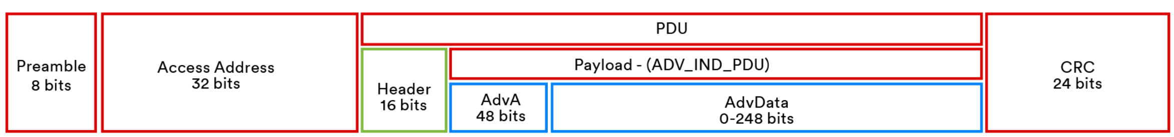


Figure 7.17: ADV_IND advertising PDU in Link Layer air interface packet

As shown, the maximum size of a legacy advertising packet with the ADV_IND PDU is 376 bits. Table 7.5 shows the transmission time for an ADV_IND PDU of maximum permitted size.

	Max Field Sizes (bits)
Fields	**LE 1M**
Preamble	8
Access Address	32
Advertising PDU Header	16
AdvA	48
AdvData	248
CRC	24
Total no. of bits	**376**
Transmission Time (µs)	**376**

Table 7.5: Maximum transmission times for an ADV_IND PDU using the advertising broadcast mode

Legacy advertising defines seven different PDU types used for various purposes and with varying formats and maximum lengths. Table 7.6 shows maximum transmission times for each PDU type.

Packet Sizes for Legacy Advertising PDUs	Max Payload Size (bits)	LL Packet Size (bits)	Transmission Times (µs)
ADV_IND	296	376	376
ADV_DIRECT_IND	96	176	176
ADV_NONCONN_IND	296	376	376
ADV_SCAN_IND	296	376	376
SCAN_REQ	96	176	176
SCAN_RSP	296	376	376
CONNECT_IND	272	352	352

Table 7.6: Maximum transmission times for each legacy advertising PDU type

7.6.2.2.4 PHYs

Legacy advertising PDUs may only be transmitted using the LE 1M PHY.

7.6.2.3 Extended advertising

Extended advertising is more versatile than legacy advertising. Important aspects of this advertising mode together with its use of radio channels, transmission timing, maximum transmission durations and the PHYs that may be used are discussed in this section.

7.6.2.3.1 Channels

Radio channels are used differently from how they are used when performing legacy advertising, with the primary advertising channels carrying no payload data. Instead, payload data is offloaded to the general-purpose channels in separate packets.

Legacy advertising transmits the same payload up to three times on three different primary advertising channels. Extended advertising transmits payload data once only on a general-purpose channel, with a pointer field in packets transmitted on the primary channels referencing it. Although extended advertising adds some protocol overhead, the total amount of data (protocol overhead plus payload) transmitted may be less than in the equivalent case using legacy advertising.

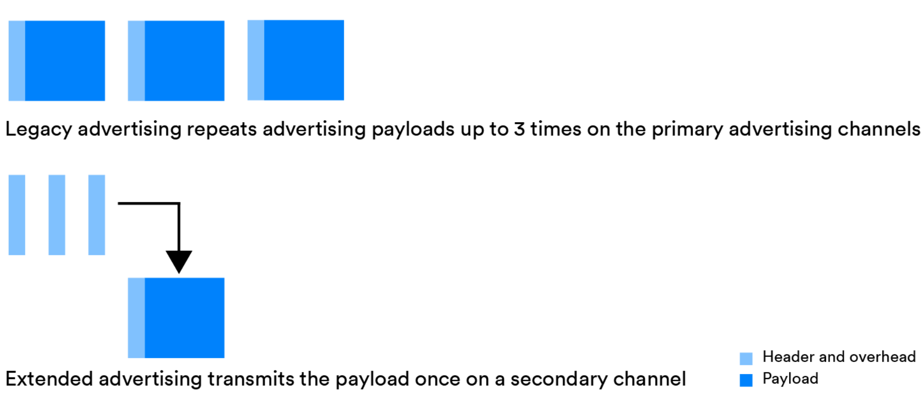


Figure 7.18: Legacy advertising versus extended advertising and payload transmission

Extended advertising allows packets to be up to 255 octets long. This is accomplished in part through offloading the payload to one of the general-purpose channels and using extended advertising PDUs, which can accommodate larger payloads.

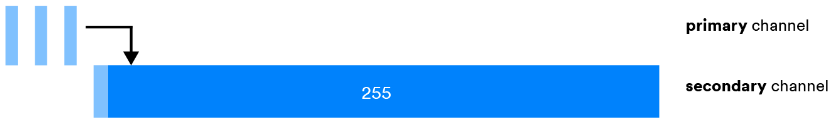


Figure 7.19: Extended advertising supports larger advertising packets and channel offload

When performing extended advertising, only header data is transmitted on the *primary channels*. This includes a field called AuxPtr. The AuxPtr field in an extended advertising packet transmitted on a primary channel references an associated *auxiliary packet* containing the payload that will be transmitted on a general-purpose channel. AuxPtr includes the channel index indicating the channel that the auxiliary packet will be transmitted on, the used PHY, and a timing offset so that receivers know when, where, and how to receive it. Packets transmitted on a general-purpose channel and referenced by the AuxPtr field from a packet on the primary channels are known as *auxiliary packets*, while the referencing packet is known as a *superior packet*. Furthermore, each packet has an associated *subordinate set* of packets. For a particular packet, this is the set of packets consisting of its auxiliary packet and the subordinate set of that auxiliary packet. If a packet has no auxiliary packet, then its subordinate set is empty.

Note: The selection of channels to transmit auxiliary packets on is an implementation concern. The Bluetooth Core Specification [2] recommends that “sufficient channel diversity is used to avoid collisions”[3]. Implementers need to determine that their algorithm will satisfy regulatory bodies.

7.6.2.3.2 Packet chaining

In some circumstances, it is possible for the controller to fragment data and chain packets together with each packet containing a subset of that data. Each chained packet can be transmitted on a different channel, with the AuxPtr header field referencing the next in the chain. A maximum of 1,650 bytes of data may be transmitted in a series of chained packets.

[3] See Section 4.4.2.1 Advertising channel index selection in [2].

Figure 7.20 illustrates the use of packet chaining.

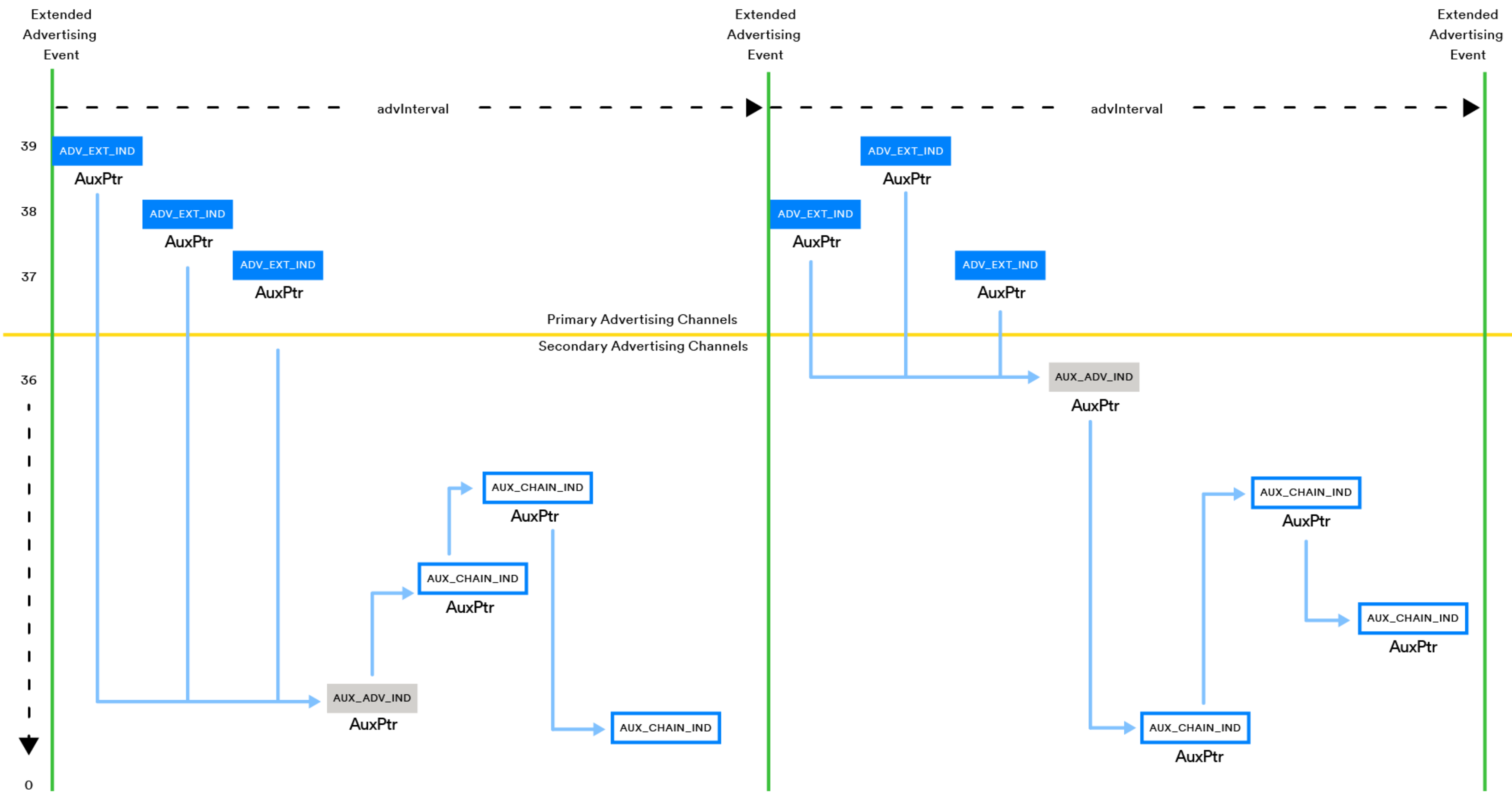


Figure 7.20: Extended advertising with packet chaining example

7.6.2.3.3 Advertising sets

Extended advertising includes a standard mechanism for having multiple, distinct sets of advertising data. Advertising sets have an ID that is used to indicate which set a given packet belongs to, and each set has its own advertising parameters, such as its advertising interval and the PDU type to be used.

Bluetooth Core Specification v5.3 [2] (Volume 6, Part B, Section 4.4.2.10), notes that "*The Link Layer may support multiple advertising sets, with each set having different advertising parameters.... The advertising events for each advertising set are considered a separate instance of the Advertising State and each have their own Advertising Interval*".

7.6.2.3.4 Timing

Extended advertising takes place in *extended advertising events*. An extended advertising event starts at the same time as an advertising event and includes the superior packet with an AuxPtr field and each of the subordinate packets related to it. Given that the start of an extended advertising event coincides with the scheduling of an advertising event, extended advertising events are also perturbed by up to 10 ms in time.

Extended advertising events may overlap under several circumstances. For example, when two ADV_EXT_IND PDUs transmitted in two different advertising events reference the same auxiliary packet via the AuxPtr field as shown in Figure 7.21.

The transmission of packets relating to different advertising sets may be interleaved, and extended advertising events may also overlap in this case.

The set of packets consisting of the first auxiliary packet transmitted in an extended advertising event and each of its subordinate packets transmitted in the same extended advertising event is known as an *auxiliary advertising segment*.

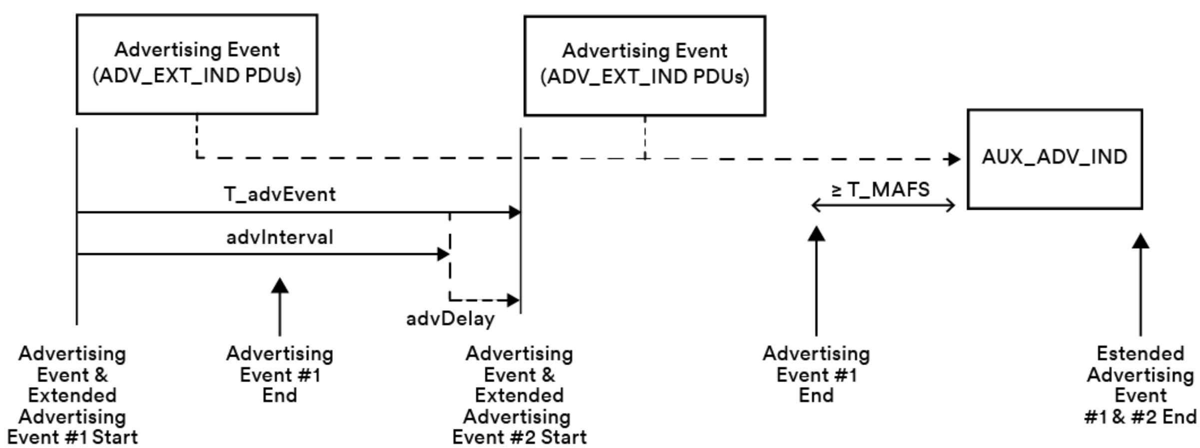


Figure 7.21: Overlapping extended advertising events

7.6.2.3.5 Transmission duration

A number of PDU types are defined for use with extended advertising. Table 7.7 lists the PDU types.

PDU Name	Description
ADV_EXT_IND	Extended advertising
AUX_ADV_IND	Subordinate extended advertising
AUX_CHAIN_IND	Additional advertising data
AUX_SYNC_IND	Periodic advertising data

PDU Name	Description
AUX_SCAN_REQ	Scan request
AUX_SCAN_RSP	Scan response
AUX_CONNECT_REQ	Connection request
AUX_CONNECT_RSP	Connection response

Table 7.7: Extended Advertising PDU Types

The payload of PDUs of type ADV_EXT_IND, AUX_ADV_IND, AUX_SCAN_RSP, AUX_SYNC_IND, AUX_CHAIN_IND, and AUX_CONNECT_RSP are defined by the same format known as the Common Extended Advertising Payload Format. This includes fields such as the AuxPtr field and AdvMode. AdvMode uses two bits to indicate the connectable and scannable properties of the advertising mode rather than this being indicated by distinct PDU types.

Section 4.4.2 of the Link Layer specification chapter for the Low Energy Controller within the Bluetooth Core Specification [2] gives full details of all advertising event types.

There are interdependencies between fields that determine their presence or absence, and this in turn determines the potential maximum length of a PDU. The Bluetooth Core Specification [2], Volume 6, Part B, Section 2.3.4 and related sections should be consulted for details.

Table 7.8 uses the AUX_ADV_IND PDU to illustrate scenarios with the largest possible packets containing this PDU type, depending on the advertising properties in use. It provides maximum field lengths in bits and transmission durations for the PHYs permitted for the AUX_ADV_IND PDU for each possible advertising event type.[4] For example, the first column (Connectable = N, Scannable = N, Directed = N) is for Event Type = non-connectable and non-scannable undirected event type.

[4] Refer to Table 2.5 Common Extended Advertising Payload Format fields, in Section 2.3.1.6 of the Link Layer specification chapter for the Low Energy Controller volume in [2] the Bluetooth Core Specification.

		Advertising Event Type					
Event Type component							
Connectable		N	N	Y	Y	N/A	N/A
Scannable		N	N	N/A	N/A	Y	Y
Directed		N	Y	N	Y	N	Y
Fields	**Max Size**[5]	**Max Field Sizes per Advertising Event Type**					
Advertising PDU Header	16	16	16	16	16	16	16
Extended Header Length	6	6	6	6	6	6	6
AdvMode	2	2	2	2	2	2	2
Extended Header Flags	8	8	8	8	8	8	8
AdvA	48	48	48	48	48	48	48
TargetA	48	0	48	0	48	0	48
CTEInfo	8	0	0	0	0	0	0
AdvDataInfo (ADI)	16	16	16	16	16	16	16
AuxPtr	24	24	24	0	0	0	0
SyncInfo	144	144	144	0	0	0	0
TxPower	8	8	8	8	8	8	8
ACAD	496	256	208	424	376	424	376
AdvData	2032	1528	1528	1528	1528	0	0
PDU size (bits)		2056	2056	2056	2056	528	528
Air interface packet sizes (bits) by PHY							
LE 1M	–	2120	2120	2120	2120	592	592
LE 2M	–	2128	2128	2128	2128	600	600
LE Coded (S=2)	–	4542	4542	4542	4542	1486	1486
LE Coded (S=8)	–	17040	17040	17040	17040	4816	4816
Transmit times (µs) by PHY							
LE 1M	–	2120	2120	2120	2120	592	592
LE 2M	–	1064	1064	1064	1064	300	300
LE Coded (S=2)	–	4542	4542	4542	4542	1486	1486
LE Coded (S=8)	–	17040	17040	17040	17040	4816	4816

Table 7.8: AUX_ADV_IND PDU type: maximum field combinations, lengths, and transmission times

Transmission durations for other extended advertising PDU types can be calculated in a similar way.

7.6.2.3.6 PHYs

Extended advertising may use any of the three PHYs: LE 1M, LE 2M, and LE Coded, except in the case of the ADV_EXT_IND PDU type, which may only be transmitted on the LE 1M PHY or the LE Coded PHY. This is summarized in Table 7.9.

PDU Name	Description	Channels	PHY(s)
ADV_EXT_IND	Extended advertising	primary	LE 1M, LE Coded
AUX_ADV_IND	Subordinate extended advertising	general purpose	LE 1M, LE 2M, LE Coded
AUX_CHAIN_IND	Additional advertising data	general purpose	LE 1M, LE 2M, LE Coded
AUX_SYNC_IND	Periodic advertising synchronization	general purpose	LE 1M, LE 2M, LE Coded

[5] Maximum size of the field across all PDU types and event types

PDU Name	Description	Channels	PHY(s)
AUX_SCAN_REQ	Auxiliary scan request	general purpose	LE 1M, LE 2M, LE Coded
AUX_SCAN_RSP	Auxiliary scan response	general purpose	LE 1M, LE 2M, LE Coded
AUX_CONNECT_REQ	Auxiliary connect request	general purpose	LE 1M, LE 2M, LE Coded
AUX_CONNECT_RSP	Auxiliary connect response	general purpose	LE 1M, LE 2M, LE Coded

Table 7.9: Extended advertising PDUs

7.6.2.4 Comparing legacy advertising and extended advertising

Table 7.10 presents a summary comparison of legacy advertising and extended advertising.

	Legacy Advertising	Extended Advertising	
Max. host advertising data size	31 bytes	1,650 bytes	Extended Advertising supports *fragmentation,* which enables a 50x larger maximum host advertising data size to be supported.
Max. host advertising data per packet	31 bytes	254 bytes	Extended Advertising PDUs use the *Common Extended Advertising Payload Format,* which supports an 8x larger advertising data field.
TX channels	37, 38, 39	0-39	Extended Advertising uses the 37 general-purpose channels ADV_EXT_IND PDU type, which may only be transmitted on the primary advertising channels.
PHY support	LE 1M	LE 1M, LE 2M (excluding ADV_EXT_IND PDUs), LE Coded	All Extended Advertising PDUs may be transmitted using any of the three Bluetooth LE PHYs except for the ADV_EXT_IND PDU, which may be transmitted using the LE 1M or LE Coded PHYs.
Max. active advertising configurations	1	up to 240	Extended Advertising includes *Advertising Sets,* which enable advertising devices to support multiple different advertising configurations at a time and to interleave advertising for each advertising set according to time intervals defined in the sets.
Transmission Scheduling	Irregular with 0 ms-10 ms perturbation	Regular	Extended Advertising includes *Periodic Advertising*, enabling periodic communication of advertising data between transmitters and receivers. This operational mode is covered in Section 7.6.3.

Table 7.10: Comparing legacy and extended advertising

7.6.3 LE Periodic Advertising Broadcast (PADVB)

7.6.3.1 Basics

The LE Periodic Advertising Broadcast mode, abbreviated PADVB in the Bluetooth Core Specification [2], is sometimes referred to simply as *Periodic Advertising*. Periodic advertising is a special case of *extended advertising*.

This mode provides a way to perform advertising that involves the transmission of packets to a deterministic schedule and provides a mechanism that allows other devices to synchronize their scanning for packets with the schedule of the advertising device. Periodic advertising is always non-scannable and non-connectable.

Advertising takes place at fixed intervals called the *periodic advertising interval,* and the advertising data payload may change. A series of AUX_SYNC_IND and associated AUX_CHAIN_IND PDUs is said to form a *periodic advertising train*.

7.6.3.2 Channels

Periodic Advertising uses the general-purpose channels. A channel is selected at the start of each periodic advertising event (see Section 7.6.2.3.4) using channel selection algorithm #2.

Any auxiliary AUX_CHAIN_IND PDU related to an AUX_SYNC_IND PDU has its channel selected using an implementation-specific algorithm. The selected channel and timing offset for the auxiliary packet is specified in the AuxPtr field of the superior packet. See Figure 7.22 for an illustration of PDU types, their relationships, and use of channels.

7.6.3.3 Timing

The *periodic advertising interval* determines how often periodic advertising for a given advertising set can occur. Whenever the periodic advertising interval expires, a *periodic advertising event* is said to begin.

At each periodic advertising event, a single AUX_SYNC_IND PDU is transmitted by the *broadcaster* device followed by zero or more AUX_CHAIN_IND PDUs depending on whether the host-provided payload requires fragmentation. See Figure 7.22.

A scanning device may synchronize with a periodic advertising train in either of two ways. It may either scan for AUX_ADV_IND PDUs and use the contents of the SyncInfo field to establish the periodic advertising intervals, timing offset, and channel information to be used, or it may receive this information over an LE ACL connection from a device which has itself determined this information from AUX_ADV_IND PDUs. This method is known as the Periodic Advertising Sync Transfer procedure.

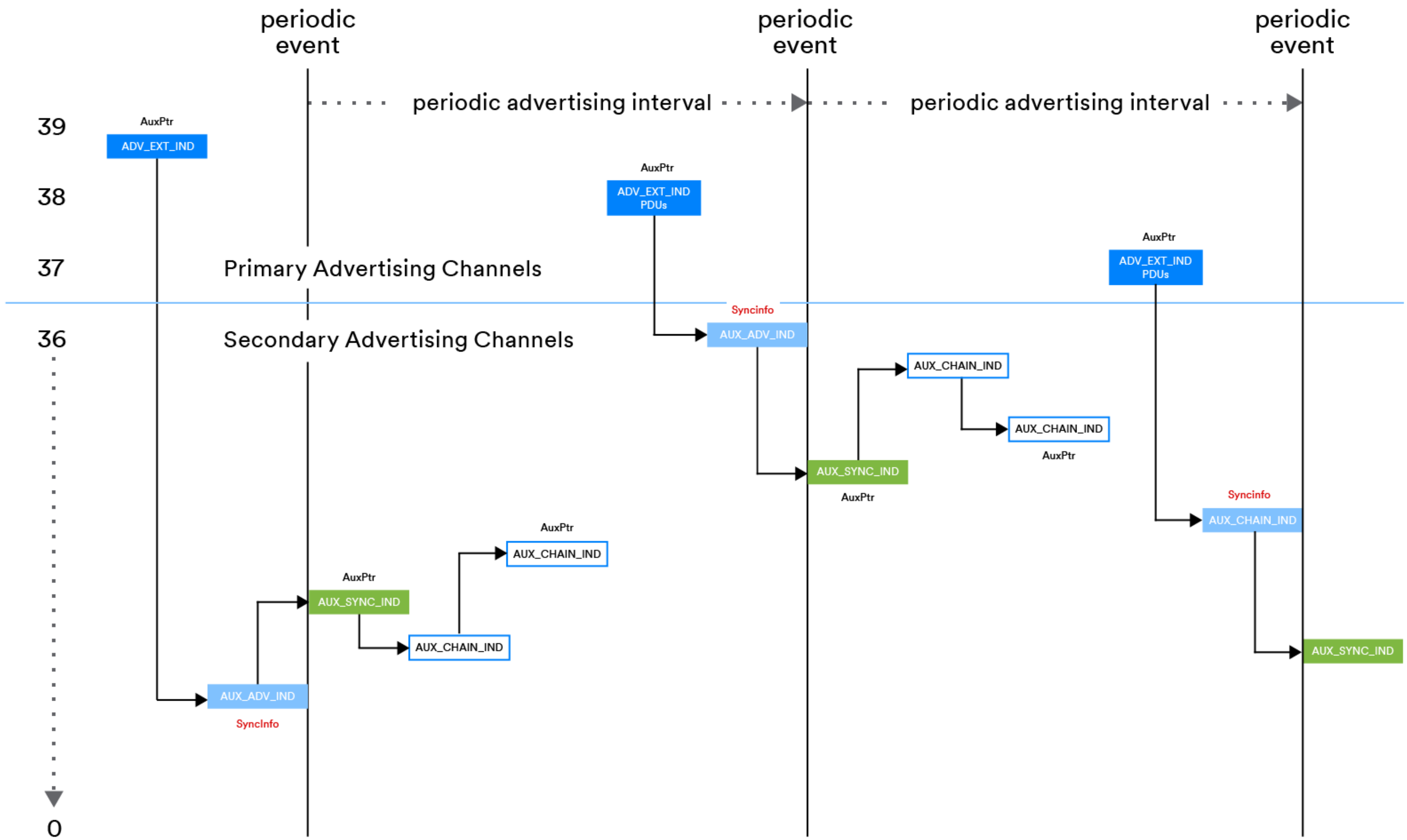


Figure 7.22: Periodic advertising events example

Note that Figure 7.22 has been simplified with potentially multiple ADV_EXT_IND PDUs on different primary advertising channels represented by a single box.

7.6.3.4 Transmission duration

Periodic advertising involves multiple PDU types. The key PDU type always transmitted in every periodic advertising event is AUX_SYNC_IND. The size and therefore airtime used in transmitting AUX_SYNC_IND PDUs can vary significantly.

Table 7.11 [6] provides an illustration of one possible transmit duration using the largest possible AUX_SYNC_IND PDU (without the CTE field) and with an auxiliary PDU such as an associated AUX_CHAIN_IND. The table shows the maximum number of bits consumed by each field and reflect the rules regarding which fields are included in the header of this PDU type under various conditions.

Fields	**Max Field Size (bits)**
Advertising PDU Header	16
Extended Header Length	6
AdvMode	2
Extended Header Flags	8
AdvA	0
TargetA	0
CTEInfo	0
AdvDataInfo (ADI)	16
AuxPtr	24
SyncInfo	0
TxPower	8
ACAD	440
AdvData	2032
PDU size (bits)	**2552**
Air interface packet sizes (bits)	
LE 1M	2616
LE 2M	2624
LE Coded (S=2)	5534
LE Coded (S=8)	21008
Transmit times (µs)	
LE 1M	2616
LE 2M	1312
LE Coded (S=2)	5534
LE Coded (S=8)	21008

Table 7.11: AUX_SYNC_IND PDU type: maximum field combination, lengths, and transmission times

[6] This table is based upon Table 2.6 of the Link Layer specification in the Low Energy Controller Volume of the Bluetooth Core Specification

An example set of transmission times for a large AUX_CHAIN_IND PDU with an associated auxiliary PDU and no CTEInfo data are shown in Table 7.12.

Fields	**Max Field Size (bits)**
Advertising PDU Header	16
Extended Header Length	6
AdvMode	2
Extended Header Flags	8
AdvA	0
TargetA	0
CTEInfo	0
AdvDataInfo (ADI)	16
AuxPtr	24
SyncInfo	0
TxPower	8
ACAD	440
AdvData	2032
PDU size (bits)	**2552**
Air interface packet sizes (bits)	
LE 1M	2616
LE 2M	2624
LE Coded (S=2)	5534
LE Coded (S=8)	21008
Transmit times (μs)	
LE 1M	2616
LE 2M	1312
LE Coded (S=2)	5534
LE Coded (S=8)	21008

Table 7.12: AUX_CHAIN_IND PDU type: maximum field combination, lengths, and transmission times

7.6.3.5 PHYs

Periodic advertising may use any of the three PHYs: LE 1M, LE 2M, and LE Coded. This is summarized in Table 7.13.

PDU Name	**Description**	**Channels**	**PHY(s)**	**Transmitted By**
AUX_SYNC_IND	Periodic advertising indication	periodic	LE 1M, LE 2M, LE Coded	Peripheral
AUX_CHAIN_IND	Additional advertising data	general purpose	LE 1M, LE 2M, LE Coded	Peripheral

Table 7.13: Periodic advertising PDUs and PHYs permitted

7.6.4 LE Periodic Advertising with Responses (PAwR)

7.6.4.1 Basics

The Periodic Advertising with Responses (PAwR) logical transport is similar to the LE Periodic Advertising Broadcast (PADVB) logical transport in several ways:

- PADVB allows application data to be transmitted by one device (the Broadcaster) to one or more receiving devices (the Observers), forming a one-to-many communication topology. The same is true of PAwR.
- PAwR and PADVB both use a connectionless communication method.
- Transmission of advertising packets is periodic with a fixed interval and no random perturbation of the schedule in both cases.
- Observers can establish the periodic transmission schedule used by the Broadcaster from AUX_ADV_IND PDUs or by using the Periodic Advertising Sync Transfer (PAST) procedure.

PAwR differs from PADVB as follows:

- PADVB supports the unidirectional communication of data from a Broadcaster to Observers only. PAwR Observers can transmit response packets back to the Broadcaster. PAwR provides a bi-directional, connectionless communication mechanism.
- Synchronization information for periodic advertising without responses (PADVB) is contained within the SyncInfo field of AUX_ADV_IND PDUs. Synchronization information for periodic advertising with responses (PAwR) is contained within the SyncInfo field and in the ACAD field of AUX_ADV_IND PDUs.
- The PADVB Broadcaster schedules transmissions within advertising events. The PAwR Broadcaster schedules transmissions in a series of events and subevents, and Observers are expected to have synchronized in such a way as to listen during a specific subevent or subevents only.
- The PAwR Broadcaster may use a transmission time slot to send a connection request (AUX_CONNECT_REQ PDU) to a specific device and establish an LE-ACL connection with it. PADVB does not have this capability.
- With periodic advertising without responses (PADVB), application data tends to change only from time to time. PAwR is designed with the expectation that application data will change frequently.
- With PADVB, the same application data is delivered to all Observer devices synchronized to the same advertising set. With PAwR, different data can be delivered to each Observer device or set of Observer devices.
- Support for the Periodic Advertising Sync Transfer (PAST) procedure is optional with PADVB but mandatory with PAwR.

7.6.4.2 Channels

PAwR uses the general-purpose channels. A channel is selected at the start of each PAwR event (see Section 7.6.4.3 for a description of PAwR events and subevents) using channel selection algorithm #2.

Responses to PDUs transmitted in a subevent use the same channel as the received PDU for which they are responses. This includes AUX_SYNC_SUBEVENT_RSP PDUs sent in response to an AUX_SYNC_SUBEVENT_IND PDU and AUX_CONNECT_RSP PDUs that are sent in response to AUX_CONNECT_REQ PDUs.

7.6.4.3 Timing

events). These events occur at fixed intervals, with no random perturbation in scheduling. An event starts every *periodic advertising interval* milliseconds.

Each PAwR event consists of several subevents, and it is during subevents that advertising packets are transmitted. The Host configures the number of subevents per event up to a maximum of 128. A subevent starts every *periodic advertising subevent interval* milliseconds.

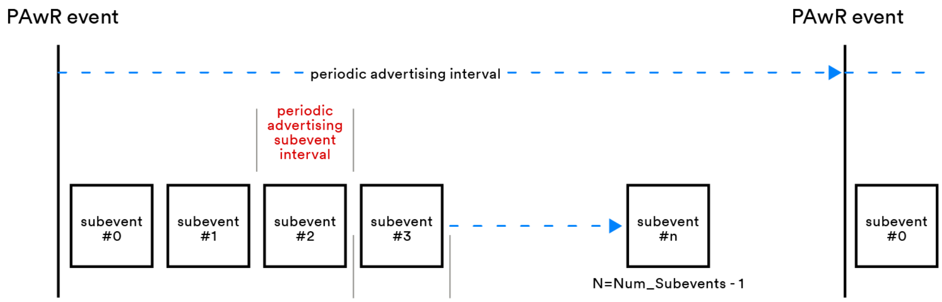


Figure 7.23: PAwR events and subevents

In each subevent, the Broadcaster transmits one packet, which usually contains an AUX_SYNC_SUBEVENT_IND PDU but may instead contain an AUX_CONNECT_REQ PDU. After a delay, known as the Periodic Advertising Response Slot Delay, a series of time slots are reserved within the same subevent for receiving responses from Observer devices. Responses to AUX_SYNC_SUBEVENT_IND PDUs are sent in AUX_SYNC_SUBEVENT_RSP PDUs. The Host configures the number of response slots required. Figure 7.24 illustrates the structure of a PAwR subevent.

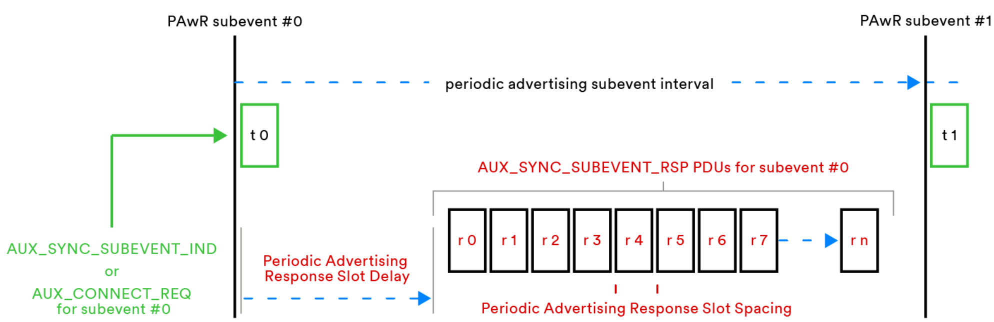


Figure 7.24: A PAwR subevent with response slots

7.6.4.4 Transmission duration

PAwR involves multiple PDU types. The key PDU type, usually transmitted in every periodic advertising subevent, is AUX_SYNC_SUBEVENT_IND. The size and therefore airtime used in transmitting AUX_SYNC_SUBEVENT_IND PDUs can vary, depending on the application and its payload requirements. Note that AUX_SYNC_SUBEVENT_IND PDUs do not have associated AUX_CHAIN_IND PDUs.

An example set of transmission times for an AUX_SYNC_SUBEVENT_IND PDU that contains the largest permitted AdvData field is shown in Table 7.14.

Fields	**Max Field Size (bits)**
Advertising PDU Header	16
Extended Header Length	6
AdvMode	2
Extended Header Flags	8
AdvA	0
TargetA	0
CTEInfo	0
AdvDataInfo (ADI)	16
AuxPtr	0
SyncInfo	0
TxPower	8
ACAD	464
AdvData	2032
PDU size (bits)	**2552**
Air interface packet sizes (bits)	
LE 1M	2616
LE 2M	2624
LE Coded (S=2)	5534
LE Coded (S=8)	21008
Transmit times (μs)	
LE 1M	2616
LE 2M	1312
LE Coded (S=2)	5534
LE Coded (S=8)	21008

Table 7.14: AUX_SYNC_SUBEVENT_IND PDU carrying a payload of maximum theoretical size, fields, maximum lengths, and transmission times

The Electronic Shelf Label (ESL) profile was the first profile to make use of the PAwR logical transport. The AdvData field must contain the Encrypted Data AD type. The latter contains a max 32-bit Randomizer, an encrypted copy of the ESL Payload AD Type that has a maximum length of 50 octets, and a 32-bit Message Integrity Code (MIC). Other AD Types may be included within the Encrypted Data AD type, and others may be included in the AdvData field, unencrypted. The maximum size of the AdvData field applies.

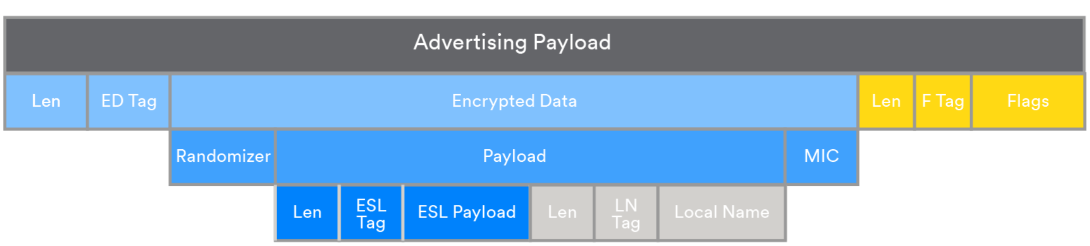


Figure 7.25: Example advertising payload containing ESL Payload data and other AD Types

Typically, however, an ESL Access Point (AP) device will only include the ESL Payload AD Type within Encrypted Data in the advertising payload of AUX_SYNC_SUBEVENT_IND PDUs and no other AD Types. The ACAD field will typically not be used by an ESL AP, and no other unencrypted AD Types will be included in the payload.

Example transmission times for an AP transmission of an AUX_SYNC_SUBEVENT_IND containing the maximum size ESL Payload, no other AD Types, and no ACAD is given in Table 7.15.

Fields	Max Field Size (bits)
Advertising PDU Header	16
Extended Header Length	6
AdvMode	2
Extended Header Flags	8
AdvA	0
TargetA	0
CTEInfo	0
AdvDataInfo (ADI)	16
AuxPtr	0
SyncInfo	0
TxPower	8
ACAD	0
AdvData	464
PDU size (bits)	**520**
Air interface packet sizes (bits)	
LE 1M	584
LE 2M	592
LE Coded (S=2)	1470
LE Coded (S=8)	4752
Transmit times (µs)	
LE 1M	584
LE 2M	296
LE Coded (S=2)	1470
LE Coded (S=8)	4752

Table 7.15: AUX_SYNC_SUBEVENT_IND PDU carrying a typical ESL payload, fields, maximum lengths, and transmission times

7.6.4.5 PHYs

Periodic Advertising with Responses may use any of the three PHYs: LE 1M, LE 2M, and LE Coded. This is summarized in Table 7.16.

PDU Name	Description	Channels	PHY(s)	Transmitted By
AUX_SYNC_SUBEVENT_IND	PAwR subevent indication	periodic	LE 1M, LE 2M, LE Coded	Broadcaster
AUX_SYNC_SUBEVENT_RSP	PAwR subevent response	periodic	LE 1M, LE 2M, LE Coded	Observer

PDU Name	Description	Channels	PHY(s)	Transmitted By
AUX_CONNECT_REQ	Connection request	periodic	LE 1M, LE 2M, LE Coded	Broadcaster
AUX_CONNECT_RSP	Response to connection request	periodic	LE 1M, LE 2M, LE Coded	Observer

Table 7.16: PAwR PDUs and PHYs permitted

7.6.5 Isochronous Communication

7.6.5.1 Basics

Isochronous communication provides a way of using Bluetooth LE to transfer time-bounded data between devices. It provides a mechanism that allows multiple devices, receiving data from the same device at different times, to synchronize their processing of that data. LE Audio uses isochronous communication.

Data is transferred in *isochronous streams,* and streams belong to an *isochronous group*. Devices wait for a period of time to allow all streams that are members of the same group to have the opportunity to receive related packets before processing those packets at the same time. For example, stereo music might be delivered using two streams, one for the left stereo channel and the other for the right stereo channel. The two streams would be members of the same group and, as such, rendering of packets received from the two streams takes place at the same time so that the user hears stereo music as intended.

Two logical transports that use the LE Isochronous physical channel are defined. *Connected Isochronous Streams* (LE CIS or simply *CIS*) use connection-oriented communication and support the bi-directional transfer of data. *Broadcast Isochronous Streams* (LE BIS or simply *BIS*) use connectionless, broadcast communication and provide unidirectional communication of data to multiple receivers.

7.6.5.2 Connected Isochronous

7.6.5.2.1 CIS overview

A single CIS stream provides point-to-point isochronous communication between two connected devices and transfers data in a Link Layer PDU known as the *CIS PDU*.

CIS streams are members of groups called Connected Isochronous Groups (CIGs), each of which contains one or more CISes, up to a maximum of 31. See Figure 7.26.

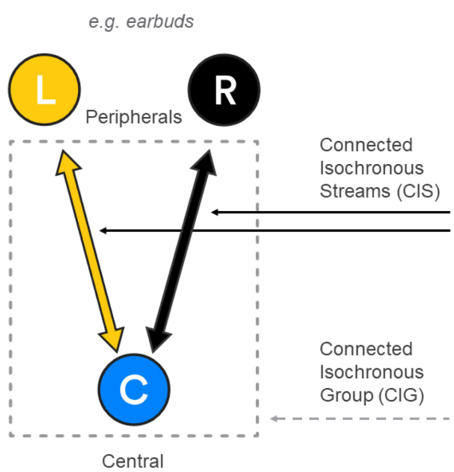


Figure 7.26: A CIG containing two CISes

7.6.5.2.2 Channels

Connected Isochronous Streams transmit all packets on the general-purpose channels. Each CIS has its own pseudo-random hopping sequence whereby every packet may be transmitted on a different channel.

Transmission of packets in a CIS takes place in a series of events and subevents. This is explained further in Section 7.6.5.2.3.

For each event of each CIS, each device invokes Channel Selection Algorithm #2 (see Section 7.4.1) and each invocation generates a sequence of channel indices to be used for the subevents in that event. The frequencies used for two consecutive subevents are always at least 6 MHz apart. The channels for a CIS established between a given pair of Bluetooth LE devices are chosen from the same channel map (i.e., the same set of used channels) as the LE ACL connection between that pair of devices. The Peripheral transmits on the same channel index as the Central.

Figure 7.27 shows an example of channel use in connected isochronous communication.

7.6.5.2.3 Timing

The scheduling of a CIG and its member CISes is governed by a system of CIG events, CIS events, and subevents.

All CISes have an associated LE ACL connection between the same pair of devices as the CIS. This connection is used to send Link Layer control PDUs during the setup of the CIS. In addition, connection events associated with the LE ACL provide an anchor point for calculating the relative timing of CIS events and subevents. The LE ACL connection must remain active for the lifetime of the associated CIS.

A CIG event signals the start of the scheduling of activity across the CISes that belong to the CIG, and this occurs at the *anchor point* of the first CIS in the group. CIG events occur at an interval specified in a parameter called *ISO_Interval*.

The first CIS in the group has its CIS event scheduled to coincide with the CIG event. Other CISes in the group have their CIS events scheduled using an offset parameter called CIS_Offset that is specified during CIS establishment.

Each CIS event is divided into one or more subevents. The number of subevents in use is indicated in a stream parameter called *NSE*. In a connected isochronous stream, during a subevent, the Central transmits (TX) once, and the Peripheral responds (RX) as shown in Figure 7.27.

Subevents are spaced apart by a duration whose value is specified in a CIS parameter called Sub_Interval. Sub_Interval is always set to zero if there is only one subevent per CIS event; otherwise, it is at least 400 microseconds but less than the ISO_Interval.

Each CIS may be serviced sequentially during a CIG Event, or the subevents of different CISes may be interleaved. An example of a CIG that contains three CISes, each of which is serviced sequentially, is shown in Figure 7.27.

Figure 7.27: CIS events and subevents example

7.6.5.2.4 Transmission duration

CIS Data PDUs are transmitted during CIS subevents. A CIS Data PDU has the general format and length of an Isochronous Physical Channel PDU as shown in the context of a Link Layer air interface packet in Figure 7.28.

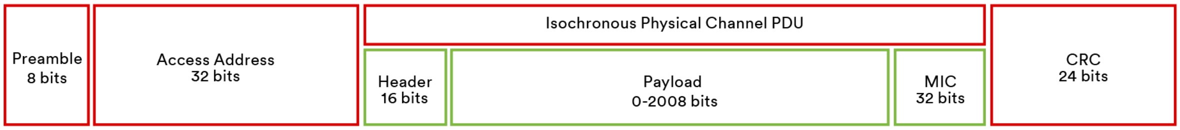


Figure 7.28: Isochronous Physical Channel PDU

MIC is included only if the PDU is encrypted.

For the purposes of illustration, the transmission time of a large, encrypted CIS Data PDU in a Link Layer packet is shown in Table 7.17.

Fields	**Max Field Size (bits)**
Header	16
Payload	2008
MIC	32
PDU Size (bits)	**2056**
Air interface packet sizes (bits)	
Air interface packet size (LE 1M)	2120
Air interface packet size (LE 2M)	2128
Air interface packet size (LE Coded, S=2)	4542
Air interface packet size (LE Coded, S=8)	17040
Transmit times (μs)	
LE 1M transmit time	2120
LE 2M transmit time	1064
LE Coded (S=2) transmit time	4542
LE Coded (S=8) transmit time	17040

Table 7.17: Maximum lengths and transmission times for isochronous physical channel PDUs in a CIS

7.6.5.2.5 PHYs

CIS streams may use any of the three PHYs: LE 1M, LE 2M, or LE Coded. The PHY used for transmitting and the PHY used for receiving packets need not be the same. Note that LE Audio applications are most likely to use the LE 2M PHY to minimize airtime.

7.6.5.3 Broadcast Isochronous

7.6.5.3.1 BIS overview

A BIS stream provides broadcast isochronous communication between one transmitter (source) and many receiver (sink) devices. Data is transmitted in Link Layer PDUs known as *BIS Data PDUs*. Optional control information is transmitted in *BIS Control PDUs*.

BIS streams are members of groups called Broadcast Isochronous Groups (BIGs), each of which may contain one or more BISes. A BIS is a member of one BIG only. See Figure 7.29.

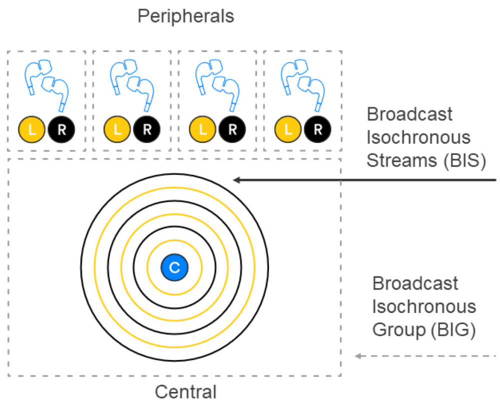


Figure 7.29: A BIG containing two BISes

There is a maximum of 31 BISes per BIG. Multiple BIGs may be created by the Central device, with each being a separate instance of the Link Layer state machine. Available airtime and other implementation details will often reduce these limits to lower values, however.

Broadcast Isochronous communication permits communication in one direction only, from the broadcasting device to the receiving device(s). As such, there is no acknowledgment protocol for reliability. Instead, Broadcast Isochronous communication defines a retransmission system, which allows multiple copies of the same data to be transmitted in some order and pattern.

7.6.5.3.2 Channels

Broadcast Isochronous Streams transmit all packets on the general-purpose channels. Each BIG has its own channel map. CSA#2 is invoked for each BIS event, and each invocation generates channel indices to be used in each subevent. That is, each BIS has a separate hopping sequence wherein every packet transmitted may be on a different channel. The frequencies used for two consecutive subevents are always at least 6 MHz apart.

Broadcast Isochronous events and subevents are explained in Section 7.6.5.3.3. Figure 7.30 shows an example of channel use in broadcast isochronous communication.

7.6.5.3.3 Timing

The scheduling of a BIG and its member BISes is governed by a system of BIG events, BIS events, and subevents. In addition, a special *control subevent* is defined for the transmission of control PDUs relating to the entire BIG. Control subevents are optional.

A BIG event signals the start of the scheduling of activity across the BISes that belong to the BIG. BIS events start at intervals that are a multiple of the value specified in a BIG, a parameter called *BIS_Spacing*, from the start of the BIG (known as the *BIG anchor point*).

Each BIS event is divided into one or more subevents. The number of subevents in use is indicated in a stream parameter called NSE. During a subevent, the broadcasting device transmits a single packet. Communication is unidirectional, and there is no requirement to reserve time in which to receive packets. Subevents are spaced apart by a duration whose value is specified in a BIG parameter called *Sub_Interval*.

As is the case with CIGs, the scheduling of BIS events within a BIG may either be sequential or interleaved.

A BIG event may include a *control subevent*, which is always scheduled as the final subevent in the BIG.

Figure 7.30 shows an example of the BIG and BIS events and subevents, scheduled in the sequential arrangement. A BIG control subevent is transmitted at the end of the second BIG event.

Figure 7.30: BIG/BIS event scheduling example

7.6.5.3.4 Transmission duration

Broadcast isochronous communication uses the same isochronous physical channel PDU format as connected isochronous communication. Therefore, transmit times for large packets are the same. The example figures that were presented in Section 1.1.1.1.1 are repeated here for convenience.

Fields	**Field Size (bits)**
Header	16
Payload	2008
MIC	32
PDU Size (bits)	**2056**
Air interface packet sizes (bits)	
Air interface packet size (LE 1M)	2120
Air interface packet size (LE 2M)	2128
Air interface packet size (LE Coded, S=2)	4542
Air interface packet size (LE Coded, S=8)	17040
Transmit times (µs)	
LE 1M transmit time	2120
LE 2M transmit time	1064
LE Coded (S=2) transmit time (µs)	4542
LE Coded (S=8) transmit time (µs)	17040

Table 7.18: Maximum lengths and transmission times for isochronous physical channel PDUs in a BIS

7.6.5.3.5 PHYs

A BIS may use any of the Bluetooth LE PHYs. Note that LE Audio applications are most likely to use the LE 2M PHY to minimize airtime.

8 Regulatory requirements

8.1 Introduction

Table 8.1 summarizes the geographical area covered in this document along with the associated wireless regulatory requirements for each region.

Geographical Sales Area	Wireless Regulatory Requirement Applied	Testing Standard
US / Canada (FCC / RSS)	FCC 15.247 [11], 15.249 [10], 15.209 [44] RSS 247 [27], RSS 210 [29], RSS-Gen [28]	ANSI C63.10 [26], ANSI C63.4- 2014 [25]
The European Union and the United Kingdom [7]	EN 300 328 [4] (Wideband data ≤20 dBm) EN 300 440 [6] (Non-specific SRD ≤10 dBm)	In EN 300 328 [4] In EN 300 440 [6]
Japan	Japanese Radio Law (JRL) [18] ARIB STD-T66 [1]	Appendix 43 to Ordinance No. 37 Applicable test methods for 2.4 GHz band advanced low power data communication system [15] Appendix 1 to Ordinance No. 37 Test methods for spurious emission or unnecessary emission intensity [16]
Korea	Korean Radio Waves Act [19], Radio Equipment Rules Decree No. 63, 24 December 2020 MSIT Notice 2022-20 Technical standard for wireless equipment for stations that can be established without notification [20]	KS X 3123:2019 Annex P Wireless equipment conformity evaluation test method [21]
China	MIIT Notice 2002 No.353 (SRRC requirements, in effect until 15 October 2023) [23]	EN 300 328 v1.7.1 (2006) [8] GB/T 12572-2008 Universal requirements and measurement methods of parameters for radio transmitting equipment [3]
	MIIT Notice 2021 No.129 (SRRC requirements, in effect from 1 January 2022, mandatory from 15 October 2023) [22]	Official CCSA test standard not available; EN 300 328 v2.2.2 test may suffice

Table 8.1: Geographical area - Applicable regulatory RF standard and testing standard

8.1.1 Worst-case/most demanding mode of operation

It is commonly required that a device meets the requirements under conditions that represent the most demanding mode of operation for that device with regard to the requirement to be tested. This means that the manufacturer taking the device to testing needs to understand what those conditions are (e.g., may be application driven) and can set up the device in such a way that it is tested in this mode of operation. This can be a particular challenge when testing for timing related requirements such as channel occupancy time. When the Equipment Under Test (EUT) operates using Isochronous Channels (which is the case for LE Audio), there are particular challenges in achieving the worst-case mode of operation together with a companion device (see Section 9 for additional details).

For example, EN 300 328 requires that measurements are performed with the device under test using its normal mode of operation, unless otherwise specified. Furthermore, the device must be operated under its worst-case conditions for each required test. All Bluetooth operational modes and other implementation choices that a device might make use of during its normal intended operation must therefore be understood and compared against the EN 300 328 test conditions to determine the worst-

[7] Following Brexit, the UK relies on its own legislation, but the technical requirements are currently aligned with those in the European Union. The approval process is, however, unique to the UK (see further details in Section 8.2.7).

case device configuration for the test at hand. As discussed in Section 8.2.2.3 EN 300 328 receiver category, the sum of all transmissions from all Link Layer instances is relevant when determining the worst-case usage for a device.

8.1.1.1 Low, Mid, High channels

Where the terms *Low*, *Mid,* or *High* are used when indicating channels to be involved in tests, the following guidance applies:

Low	The lowest applicable channel
Mid	The middlemost applicable channel
High	The highest applicable channel

Table 8.2: Low, Mid, High channel guidance

8.2 The European Union and the United Kingdom

8.2.1 Introduction

This section focuses on the RF regulatory requirements for the European Union. It describes the regulations and how they apply to Bluetooth LE.

Background on the EU regulatory landscape is given in Section 8.2.6.

The United Kingdom is a special case addressed in Section 8.2.7.

8.2.1.1 European Union (EU) Radio Equipment Directive

Radio equipment placed on the market within the Member States of the European Union must satisfy the *essential requirements*[8] of the Radio Equipment Directive (RED) 2014/53/EU [40]. The essential requirements cover various topics, including safety and health, electromagnetic compatibility, and efficient use of radio spectrum to avoid harmful interference. In addition, depending on the category of radio equipment, there may be additional requirements covering issues such as interoperability, access to emergency services, and compliance regarding the combination of radio equipment and software.

The legal foundation for radio certification in Europe is article 3.2 in the RED.

8.2.1.2 Cybersecurity for radio equipment

On 12 January 2022, Commission Delegated Regulation 2022/30/EU [41] was published in the Official Journal of the European Union (OJEU). It was signed into law on 29 October 2021. Commission Delegated Regulation 2022/30/EU expands upon the essential requirements of the RED covered by Article 3(3) points (d), (e), and (f). These points relate to device cybersecurity and will develop into a new set of requirements for radio equipment within the European Union. The new regulation will apply from 1 August 2024. The SIG plans to provide guidance on how cybersecurity needs to be considered for Bluetooth devices in a future publication.

8.2.1.3 Demonstrating compliance with the RED

The complete product and not just an RF module must demonstrate compliance with the essential requirements of the RED.

Should there be a change in the regulations or the harmonized standard that was used for a self-declaration of conformity, then it is a legal requirement to demonstrate, by re-testing, continued conformity with the essential requirements of the RED using the latest regulations/harmonized standard to continue to offer the product for sale within the EU. For details, refer to the EU Blue Guide [42].

There are three approaches by which compliance with the essential requirements of the RED can be demonstrated. These are detailed in Articles 16 and 17 and the associated Annexes II, III, and IV of the RED and discussed in the following subsections.

8.2.1.3.1 Harmonized standards approach for demonstrating compliance

In the case of Bluetooth devices, the most common approach used is Conformity Assessment Module A in RED Annex II. This approach requires the product to be tested at a certified test house against the requirements and to use the testing procedures specified in the relevant European Telecommunications Standards Institute (ETSI) harmonized standard. If it passes all the relevant tests in the harmonized standard, then the manufacturer can make a self-declaration of conformity with the essential requirements of the RED. There is a presumption of conformity with the essential requirements of the

[8] See Article 3 of the RED

RED for devices that are compliant with all relevant requirements in a relevant ETSI harmonized standard.

Two ETSI harmonized standards exist that are relevant for products operating in the 2.4 GHz band: EN 300 328 [4] and EN 300 440 [6].

EN 300 440 is a generic harmonized standard for a wide range of short-range devices operating in frequency bands within the range 1 GHz to 40 GHz. In the 2.4 GHz band, it may be used on products with a maximum Effective Isotropic Radiated Power (EIRP) of 10 dBm. EN 300 440 relies on Listen Before Talk (LBT), which devices using Bluetooth LE are generally not well suited to utilize. Therefore, the details of EN 300 440 are not discussed further in this document.

EN 300 328 is the tailor-made standard for 2.4 GHz operation and may be used on products with a maximum EIRP of 20 dBm. It is the preferred harmonized standard to apply to Bluetooth devices and is discussed further in later sections.

8.2.1.3.2 Other approaches for demonstrating compliance

In cases where there is no harmonized standard available or where it cannot be applied in full, or where the manufacturer does not wish to use the standard, then one of the following approaches must be used:

- Conformity assessment Modules B and C in RED Annex III, or
- Conformity assessment Module H described in Annex IV of the RED

In both cases, a *Notified Body* must be engaged. A Notified Body is an organization designated by an EU Member State to conduct conformity assessments to determine if a product meets all relevant legal requirements. The conformity assessment process involves testing, inspection, and certification. In the case of radio products, the Notified Body will assess if the product submitted for evaluation complies with the essential requirements of the RED. If that is the case, the Notified Body will issue an EU-type examination certificate, and the manufacturer can then generate a declaration of conformity permitting the product to be made available in the EU.

The EU has mutual recognition agreements with several countries around the world, which state the conditions under which the EU and vice versa will accept conformity assessments. This means that for certain countries, a Notified Body assessment against the essential requirements of the RED can be performed locally rather than requiring the services of an EU-based Notified Body. The European Commission (EC) maintains an up-to-date list of EU Notified Bodies and their approved areas of expertise as well as a list of mutual recognition agreements and associated approved non-EU Notified Bodies in the New Approach Notified and Designated Organizations (NANDO) Information System.

8.2.2 EN 300 328 overview

8.2.2.1 Classification of Bluetooth LE devices according to EN 300 328

In comparison to the FCC, the EN standards are more detailed. The EN standards regulate the receiver more comprehensively than any other regulation. Operating at and above 10 dBm requires adaptivity, which is another unique requirement compared to other markets. The technical parameters for which the EN standards define compliance are defined in EG 203 336 [5].

EN 300 328 classifies devices into the following types:

- Frequency Hopping Spread Spectrum (FHSS) equipment
- Other types of Wideband Data Transmission equipment, i.e., non-FHSS devices

The requirements vary depending on this classification, on whether the device meets the adaptivity requirement, and on whether the device operates with an RF output of +10 dBm EIRP or more.

8.2.2.1.1 Adaptivity

Each device type is further classified as either *adaptive* or *non-adaptive*. Non-adaptive requirements apply to adaptive equipment operating in non-adaptive mode.

All devices with RF Output power of +10 dBm EIRP or above are subject to an adaptivity requirement that is satisfied by complying with one of the two adaptivity mechanisms: Detect and Avoid (DAA) or Listen Before Talk (LBT). The adaptive frequency hopping in Bluetooth Low Energy may be assessed against DAA in EN 300 328. LBT is suited to other wireless standards, such as IEEE 802.11 [13].

Note: While the Bluetooth Core Specification [2] describes Bluetooth technology as being an Adaptive Frequency Hopping Spread Spectrum system, the ETSI EN 300 328 harmonized standard has its own specific requirements for the behavior that a device must demonstrate in operation for it to be categorized as an adaptive FHSS device. Care must therefore be taken to determine whether a product should be classified for ETSI regulatory purposes as adaptive FHSS or whether instead it falls into another device category of EN 300 328. To make such determination requires an understanding of the Bluetooth operational modes used and other implementation choices, which fall outside of the Bluetooth Core Specification.

Devices that can operate in both non-adaptive and adaptive modes, either FHSS or Wideband Data Transmission, must be tested in all those modes. EN 300 328 describes in full all of the operating parameters and device information that a manufacturer must state before testing, which must be included in a test report. This means that when using the approach in Section 8.2.1.3.1, statements about the type of device and its operating parameters will be encompassed in the legal declaration of RED compliance via the test report. As described in Article 18 of the RED, by doing this, the manufacturer or a representative authorized in writing to act on the manufacturer's behalf assumes full responsibility for the device complying with the RED requirements: "…by drawing up the EU declaration of conformity, the manufacturer shall assume responsibility for the compliance of the radio equipment with the requirements laid down in this Directive…."

8.2.2.2 Bluetooth power classes and EN 300 328

Section 6.4.1 describes how the Bluetooth Core Specification categorizes Bluetooth LE devices into one of four power classes according to their maximum RF output power level at the antenna connector.

In EN 300 328, equipment is categorized according to Receiver Category, which is a combination of maximum RF output power (mean EIRP of the equipment, which includes any antenna gain), whether it is adaptive or non-adaptive, and a measure of resource usage called Medium Utilization. Note that the definition of RF output power in EN 300 328 (refer to Section 8.2.4.1) is different from the definition in the Bluetooth Core Specification.

The Receiver Category determines the levels of the wanted and blocking signals and the blocking frequencies that must be used when performing the mandatory receiver blocking tests required by Section 5.4.11 of EN 300 328. Receiver blocking requirements define an EUT's capability to receive a wanted signal on its operating channel in the presence of an unwanted input signal (blocking signal). Note that the out-of-band blocking procedure and requirements in the Bluetooth Core Specification, which are required for Bluetooth Qualification, are different from the approach and requirements mandated in the EN 300 328 standard.

8.2.2.3 EN 300 328 receiver category

<u>Receiver Category 1</u> is for:

- Equipment compliant with the adaptivity requirements in [4], with maximum RF output power > +10 dBm EIRP

Receiver Category 2 is for:

- Non-adaptive equipment, with a Medium Utilization > 1% and ≤ 10% irrespective of the maximum RF output power, or
- Equipment (either adaptive or non-adaptive) with a maximum RF output power > 0 dBm EIRP and ≤ +10dBm EIRP

Receiver Category 3 is for:

- Non-adaptive equipment with a maximum Medium Utilization factor of 1% irrespective of the maximum RF output power, or
- Equipment (either adaptive or non-adaptive) with a maximum RF output power of 0 dBm EIRP

The Receiver Category must be specified by the manufacturer submitting a device for test and must be recorded in the test report that forms part of the self-declaration of conformity with the essential requirements of the RED. The test report therefore also carries with it all of the formal legal responsibilities associated with such a declaration. A device that can operate in different modes resulting in different receiver categories must comply with the requirements for each applicable receiver category.

Medium Utilization is a power-scaled duty cycle value to evaluate the use of spectrum by what EN 300 328 defines as non-adaptive devices. The expression for Medium Utilization, which is a percentage, is given by:

Medium Utilization = (RF Output Power in mW / 100 mW) x Duty Cycle as a percentage

EN 300 328 defines how the duty cycle is calculated for both non-adaptive FHSS and non-adaptive wideband data transmission devices. EN 300 328 uses different observation periods to determine the duty cycle depending upon whether a non-adaptive FHSS or non-adaptive wideband data transmission device is being considered.

Note that it is possible for the Bluetooth LE Link Layer to interleave separate instances of the Link Layer state machine, for example, for unrelated advertising events or for multiple Broadcast Isochronous Groups (BIGs) and their associated periodic advertising trains. The sum of all transmissions from all Link Layer instances is relevant when determining spectrum usage for a device, for example, with respect to Medium Utilization.

8.2.3 EN 300 328 requirement breakdown

EN 300 328 can be broken down into the following technical requirements. The technical requirements that apply depend on the type of certification that is chosen.

The tables in this section are a summary of highlights and may not be a complete reflection of EN 300 328. The text of EN 300 328 takes precedence.

8.2.3.1 EN 300 328 FHSS conformance requirements

Requirement Reference in [4]	Requirement	Applicability
RF output power (see Section 8.2.4.1) (4.3.1.2 in [4])	≤20 dBm EIRP	All FHSS
Duty Cycle (DC), Tx-sequence, Tx-gap (see Section 8.2.4.2) (4.3.1.3 in [4])	DC is the ratio of TxON to the observation period Observation period: AVG dwell time × 100, or AVG dwell time × 2 × Number of hopping frequencies (N); whichever is the greatest Max Tx-sequence ≤ 5 ms and Min Tx-gap 5 ms	Non-adaptive FHSS ≥ 10 dBm
	≤15 ms in 15*N ms on any hopping frequency, with 95% confidence	Non-adaptive FHSS

Requirement Reference in [4]	**Requirement**	**Applicability**
Accumulated transmit time (see Section 8.2.4.3) (4.3.1.4.3.1 in [4])	N is the minimum number of hopping frequencies used	
	≤400 ms in 400*N ms, with 95% confidence	Adaptive FHSS
Frequency Occupation (see Section 8.2.4.3) (4.3.1.4.3.1, 4.3.1.4.3.2 in [4])	Occupy each channel once per 4 × dwell time × no. of hopping channels in use, OR ((1/U) * 25%) < Occupation Probability < 77% where U = no. of hopping frequencies in use Where dwell time equals the time between frequency changes for FHSS equipment	All FHSS
Minimum no. hopping channels (see Section 8.2.4.3) (4.3.1.4.3.1 in [4])	≥ MAX [5; 15/HFS(MHz)]	Non-adaptive FHSS
Hopping Frequency Separation (HFS) (see Section 8.2.4.4) (4.3.1.5.3.1 in [4])	HFS ≥ BW ≥ 100 kHz BW = the bandwidth that contains 99% of the power of the signal when considering a single hopping frequency	Non-adaptive FHSS [9, 10]
Minimum no. hopping channels (see Section 8.2.4.3) (4.3.1.4.3.2 in [4])	≥ MAX [15; 15/HFS(MHz)]	Adaptive FHSS
Hopping Frequency Separation (see Section 8.2.4.4) (4.3.1.5.3.2 in [4])	≥100 kHz	Adaptive FHSS
Medium Utilization (MU) (see Section 8.2.4.5) (4.3.1.6.2 in [4])	≤10% where MU = (P/100 mW) x DC P = Output power (mW), DC = Duty Cycle	Non-adaptive FHSS[11] ≥ 10 dBm
Adaptivity, LBT (see Section 8.2.4.6.1) (4.3.1.7.2.2 in [4])	Initial Clear Channel Assessment (CCA): At start of every dwell time or new transmission on the same hopping frequency within the dwell time	Adaptive (LBT) FHSS
	Initial CCA duration: ≥ MAX[COT/500; 18 µs] If channel unavailable, either jump to next frequency or perform Extended CCA: ≥ RANDOM[Initial CCA duration, COT/20]	
	Channel Occupation time (COT) ≤ 60 ms	
	Channel Occupation time (COT) per hop 400 ms/ hop, CCA forced every 60 ms If Dwell time < 60 ms, then maximum COT is the Dwell time	
Adaptivity, DAA (see Section 8.2.4.6.2) (4.3.1.7.2.3 in [4])	Channel evaluation: Before transmitting	Adaptive (DAA) FHSS
	Channel Occupation time (COT): Less than 40 ms, non-contiguously	
	Channel Occupation time (COT) per hop: 400 ms is the limit per hop, with each COT < 40 ms + IDLE min[COT/20, 100 usec]	
	Evaluation interval per channel: COT	
	Occupied Hop Frequency Unavailability: ≥ MAX[COT*5*U;1 sec] (U = hops in use)	
Adaptivity Detection threshold (see Section 8.2.4.6) (4.3.1.7.2.2, 4.3.1.7.3.2 in [4])	-70 dBm/MHz @ 20 dBm, with lower Pout -70 dBm/MHz + 10 × log10 (100 mW / Pout)	Both LBT and DAA Adaptive FHSS
Short Control Signaling Transmissions (see Section 8.2.4.7) (4.3.1.7.4.2 in [4])	Max TxOn / (TxOn+TxOff) ratio of 10% within any 50 ms or dwell time, whichever is shorter	Optional with adaptive FHSS

[9] A non-adaptive FHSS device operating in a mode with an output power level that is less than +10 dBm only requires a hopping frequency separation that is greater than 100 kHz.

[10] Special considerations are required when making use of the 2M PHY; see Section 8.2.5.9.

[11] Also applies to adaptive-FHSS devices operating in a non-adaptive mode.

Requirement Reference in [4]	**Requirement**	**Applicability**
Occupied Channel Bandwidth (OCBW) (see Section 8.2.4.8) (4.3.1.8.3 in [4])	99% of power in signal = OCBW maximum 5 MHz if non-adaptive and ≥ 10 dBm	–

Table 8.3: EN 300 328 FHSS conformance requirements

8.2.3.2 EN 300 328 Non-FHSS conformance requirements

Note that in the case where an adaptive non-FHSS device switches to a non-adaptive non-FHSS mode of operation, then in that mode of operation, all of the non-adaptive device requirements apply. For some of the important considerations, reference should be made to Sections 8.2.5.2.1, 8.2.5.2.2 and 8.2.5.6. Devices that only make use of the Primary Advertising Channels will have to be qualified according to the non-FHSS requirements; see Section 8.2.5.2.1.

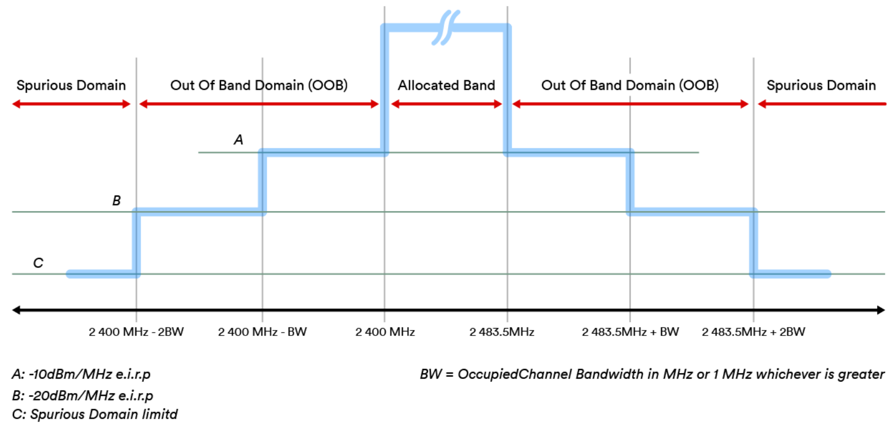
Requirement Reference in [4]	**Requirement**	**Applicability**
RF output power (see Section 8.2.4.1) (4.3.2.2 in [4])	≤20 dBm EIRP	All non-FHSS
Power Spectral Density (see Section 8.2.4.1) (4.3.2.3.3 in [4])	10 dBm/MHz EIRP	All non-FHSS
Duty Cycle (see Section 8.2.4.2) (4.3.2.4.3 in [4])	Ratio between TxON to a 1 s observation period	Non-adaptive non-FHSS [12] ≥ 10 dBm
Tx-sequence (see Section 8.2.4.2) (4.3.2.4.3 in [4])	Max 10 ms	Non-adaptive non-FHSS ≥ 10 dBm
Tx-gap (see Section 8.2.4.2) (4.3.2.4.3 in [4])	MAX [3.5 ms, Tx-sequence]	Non-adaptive non-FHSS ≥ 10 dBm
Medium Utilization (see Section 8.2.4.5) (4.3.2.5.3 in [4])	10% where MU = (P/100 mW) x DC P = Output power (mW), DC = Duty Cycle	Non-adaptive non-FHSS ≥ 10 dBm
Adaptivity, DAA (see Section 8.2.4.6.2) (4.3.2.6 in [4])	Channel evaluation: Before transmitting	Adaptive (DAA) non-FHSS
	Channel Occupation time (COT): ≤40 ms	
	Idle period after transmission MAX[100 µs, 5% of COT]	
Adaptivity, LBT-Frame based (see Section 8.2.4.6.1) (4.3.2.6.3.2.2 in [4])	Initial CCA: Before transmission, use energy detect	Adaptive (LBT, Frame based) non-FHSS
	Initial CCA duration: ≥ 18 µs If channel unavailable, move channel	
	Initial CCA: Before transmission, use energy detect	
Adaptivity, LBT-Load based (see Section 8.2.4.6.1) (4.3.2.6.3.2.2 in [4])	Based on Clear Channel Assessment (CCA) mode using energy detect as described in IEEE 802.11 (all details see the standard)	Adaptive (LBT, Load based) non-FHSS
Adaptivity Detection threshold (see Section 8.2.4.6) (4.3.2.6.2.2, 4.3.2.6.3.2 in [4])	-70 dBm/MHz @ 20 dBm, with lower Pout -70 dBm/MHz + 10 × log10 (100 mW / Pout)	Both LBT and DAA non-FHSS
Short Control Signaling Transmissions (see Section 8.2.4.7) (4.3.2.6.4.2 in [4])	Max TxOn / (TxOn+TxOff) ratio of 10% within 50 ms	Adaptive non-FHSS
Occupied Channel Bandwidth	99% of power in signal = OCBW maximum 20 MHz if non-adaptive and > 10 dBm	All non-FHSS

[12] Also applies to adaptive non-FHSS devices operating in a non-adaptive mode.

Requirement Reference in [4]	Requirement	Applicability
(see Section 8.2.4.8) (4.3.2.7 in [4])		

Table 8.4: EN 300 328 Non-FHSS conformance requirements

8.2.3.3 EN 300 328 requirements common to FHSS and non-FHSS operation

Requirement Reference in [4]	Requirement		
Transmitter unwanted emissions, OOB (see Section 8.2.4.9) (4.3.1.9.3, 4.3.2.8.3 in [4])			
Transmitter unwanted emissions, spurious (see Section 8.2.4.10) (4.3.1.10.3, 4.3.2.9.3 in [4])	**Frequency range**	**Maximum power**	**Bandwidth**
	30 MHz to 47 MHz	-36 dBm	100 kHz
	47 MHz to 74 MHz	-54 dBm	100 kHz
	74 MHz to 87.5 MHz	-36 dBm	100 kHz
	87.5 MHz to 118 MHz	-54 dBm	100 kHz
	118 MHz to 174 MHz	-36 dBm	100 kHz
	174 MHz to 230 MHz	-54 dBm	100 kHz
	230 MHz to 470 MHz	-36 dBm	100 kHz
	470 MHz to 694 MHz	-54 dBm	100 kHz
	694 MHz to 1 GHz	-36 dBm	100 kHz
	1 GHz to 12.75 GHz	-30 dBm	1 MHz
Receiver spurious emissions (see Section 8.2.4.11) (4.3.1.11, 4.3.2.10 in [4])	**Frequency range**	**Maximum power**	**Bandwidth**
	30 MHz to 1 GHz	-57 dBm	100 kHz
	1 GHz to 12.75 GHz	-47 dBm	1 MHz
Receiver Blocking (see Section 8.2.4.12) (4.3.1.12.3, 4.3.2.11.3 in [4])	≤10% PER or FER, if that can be performed, else “no loss of function for intended use”		
	Receiver cat. 1: • Adaptive equipment with a maximum RF output power > 10 dBm	Blocking signal @ -34 dBm | Wanted signal 2380, 2504 MHz | -133 dBm + 10 × log10(OCBW)) or -68 dBm whichever is less, or Pmin + 26 dB 2300, 2330, 2360, 2524, 2584, 2674 MHz | (-139 dBm + 10 × log10(OCBW)) or -74 dBm whichever is less, or Pmin + 20 dB	
	Receiver cat. 2: • Adaptive or non-adaptive [> 0 dBm, < 10 dBm] • Non-adaptive with MU [> 1%, < 10%]	Blocking signal @ -34 dBm | Wanted signal 2380, 2504, 2300, 2584 MHz | -139 dBm + 10 × log10(OCBW)+ 10 dB) or -64 dBm whichever is less, or Pmin + 26 dB	
	Receiver cat. 3: • Adaptive or non-adaptive < 0 dBm • Non-adaptive with MU < 1%	Blocking signal @ -34 dBm | Wanted signal 2380, 2504, 2300, 2584 MHz | -139 dBm + 10 × log10(OCBW)+ 20 dB) or -54 dBm whichever is less, or Pmin + 30 dB	

Requirement Reference in [4]	**Requirement**
Geolocation capability (see Section 8.2.4.13) (4.3.1.13, 4.3.2.13 in [4])	If the device has geolocation for regulatory configuration, then it is not configurable to the user.

Table 8.5: EN 300 328 requirements common to FHSS and non-FHSS operation

8.2.4 Applicable EN 300 328 FHSS requirements

The test plan for FHSS equipment depends on two main decision points:

1. Is maximum output power ≥ 10 dBm, and
2. Does it comply with the adaptivity requirements of the standard?

Besides that, it should be noted that in the case where an adaptive non-FHSS device switches to a non-adaptive non-FHSS mode of operation, then in that mode of operation, all of the non-adaptive device requirements apply.

		Utilized equipment type in certification		
Parameter (requirement clause in [4])	**Test Clause [4]**	**<10 dBm**	**≥10 dBm Adaptive**	**≥10 dBm Non-Adaptive**
RF output power (see Section 8.2.4.1) (4.3.1.2 in [4])	5.4.2.2.1.2	Applies	Applies	Applies
Duty Cycle, Tx-sequence, Tx-gap (see Section 8.2.4.2) (4.3.1.3 in [4])	5.4.2.2.1.3	N/A	N/A[13]	Applies
Accumulated Transmit Time, Frequency Occupation, and Hopping Sequence (see Section 8.2.4.3) (4.3.1.4 in [4])	Statistical analysis or 5.4.4	Applies	Applies	Applies
Hopping Frequency Separation (see Section 8.2.4.4) (4.3.1.5 in [4])[14]	5.4.5	Applies	Applies	Applies
Medium Utilization (MU) factor (see Section 8.2.4.5) (4.3.1.6 in [4])	5.4.2.2.1.3, 5.4.2.2.1.4	N/A	N/A[15]	Applies
Adaptive FHSS using LBT (see Section 8.2.4.6.1) (4.3.1.7.2 in [4]) (LBT is typically not meaningful for Bluetooth technology)	5.4.6.2.1.2	N/A	N/A	N/A
Adaptive FHSS using DAA (see Section 8.2.4.6.2) (4.3.1.7.3 in [4]) (DAA may be meaningful to Bluetooth technology)	5.4.6.2.1.2	N/A	Applies	N/A
Short Control Signaling Transmissions (see Section 8.2.4.7) (4.3.1.7.4 in [4])	5.4.6.2.1.2	N/A	Applies	N/A
Occupied Channel Bandwidth (see Section 8.2.4.8) (4.3.1.8 in [4])[16]	5.4.7.2.1 (conducted) 5.4.7.2.2 (radiated)	Applies	Applies	Applies
Transmitter unwanted emissions in the Out-Of-Band domain (see Section 8.2.4.9) (4.3.1.9 in [4])	5.4.8.2.1 (conducted) 5.4.8.2.2 (radiated)	Applies	Applies	Applies
Transmitter unwanted emissions in the spurious domain (see Section 8.2.4.10) (4.3.1.10 in [4])	5.4.9.2.1 (conducted) 5.4.9.2.2 (radiated)	Applies	Applies	Applies
Receiver spurious emissions (see Section 8.2.4.11) (4.3.1.11 in [4])	5.4.10.2.1 (conducted) 5.4.10.2.1 (radiated)	Applies	Applies	Applies
Receiver Blocking (see Section 8.2.4.12) (4.3.1.12 in [4])	5.4.11	Applies	Applies	Applies
Geolocation capability (see Section 8.2.4.13) (4.3.1.13 in [4])	Declaration Only	If supported	If supported	If supported

Table 8.6: Applicability of requirement versus utilized equipment type in certification as FHSS equipment

8.2.4.1 RF output power

Applicability: All types of FHSS equipment

Definition: Clause 4.3.1.2 in [4]

RF output power: The RF output power is defined as the mean EIRP of the equipment during a transmission burst.

Requirement:

1. The maximum RF output power in EN 300 328 is +20 dBm.
2. The maximum RF output power is declared by the manufacturer. The results are equal to or less than the value declared by the manufacturer. This applies for any combination of power level and intended antenna assembly.
3. For Non-adaptive FHSS equipment, the manufacturer is required to meet the requirement for the Medium Utilization (MU) factor described in clause 4.3.1.6 and verified by the conformance test in 4.3.1.6.4.

Test Standard and Clause: 5.4.2.2.1.2 [4]

EUT Operational Mode: The EUT transmitting modulated carriers hopping on all channels. Tested with highest power on all modulation schemes and data rates supported to observe the EUT's worst-case configurations.

For further considerations, see Section 8.2.5.6.

8.2.4.2 Duty cycle, Tx-sequence, Tx-gap

Applicability: Non-adaptive FHSS ≥ 10 dBm

Definition: Clause 4.3.1.3 in [4]

Duty Cycle: The ratio of the total transmitter on-time to an observation period, where the observation period is:

1. The average dwell time multiplied by 100; or
2. The average dwell time multiplied by 2 times the number of hopping frequencies (N); whichever is greater

Tx-sequence: A period during which a single transmission or multiple transmissions may occur, and which is followed by a Tx-gap. The transmissions within a single Tx-sequence may take place on the same hopping frequency or on multiple hopping frequencies.[17]

Tx-gap: A period during which no transmissions occur on any of the hopping frequencies.

Requirement:

Duty Cycle ≤ declared by the manufacturer, where Tx-sequence ≤ 5 ms and Tx-gap ≥ 5 ms

Test Standard and Clause: 5.4.2.2.1.3 in [4]

[13] Adaptive FHSS devices may have more than one adaptive mode. They may also operate in a non-adaptive mode, but if they do so, then they must also comply with all of the non-adaptive FHSS requirements.
[14] Note: To qualify as a non-adaptive FHSS device, the adjacent hopping frequency separation must be equal to or greater than the occupied channel bandwidth. See also Section 8.2.5.9.
[15] Applies if the adaptive device operates in a non-adaptive mode.
[16] See additional detail in Section 8.2.5.9.
[17] For some of the considerations relevant to both Tx-sequence and Tx-gap, refer to Sections 8.2.5.6.1 and 8.2.5.6.2

EUT Operational Mode: The EUT transmitting modulated carriers hopping on all channels. Tested on all modulation schemes and data rates supported to observe the worst-case configurations.

8.2.4.3 Accumulated Transmit Time, Frequency Occupation, and Hopping Sequence

Applicability: All types of FHSS equipment

Definition: Clause 4.3.1.4.3.1 in [4] for non-adaptive FHSS and clause 4.3.1.4.3.2 in [4] for adaptive FHSS.

Accumulated Transmit Time: The total of the transmitter on-times during an observation period, on a particular hopping frequency.

Frequency Occupation: The number of times that each hopping frequency is occupied within a given period. A hopping frequency is considered to be occupied when the equipment selects that frequency from the hopping sequence. The equipment may be transmitting, may be receiving, or may stay idle during the Dwell Time spent on that hopping frequency.

Hopping Sequence: The pattern of the hopping frequencies used by the equipment.

Requirement:

Non-adaptive frequency hopping equipment

Accumulated Transmit Time:

≤15 ms in N*15 ms on any hopping frequency with 95% probability.

Observed during testing on two randomly selected channels.

Hopping Sequence:

The hopping sequence(s) are to contain at least N hopping frequencies where N is MAX[5; 15/HFS(MHz)], where minimum HFS (Hopping Frequency Separation) is equal to the Occupied Channel Bandwidth with a minimum of 100 kHz.

Adaptive frequency hopping equipment

Accumulated Transmit Time: 400 ms in N*400 ms with 95% probability. Observed during testing on two randomly selected channels. Adaptive Frequency Hopping equipment operates over a minimum of 70% of the band.

Frequency Occupation:

Option 1: Occupy each channel once per 4 * dwell time * number of hopping channels in use, OR

Option 2: ((1/U) * 25%) < Occupation Probability < 77% where U = no. of hopping frequencies in use.

Note: Compliance to the Frequency Occupation requirement can be demonstrated through statistical analysis using simulation or mathematical analysis. See Section 7.4.2 for more information on this topic.

Test Standard and Clause: 5.4.4 in [4]

EUT Channels Measured: A minimum of two active hopping frequencies chosen arbitrarily from the actual hopping sequence. The frequencies on which the test was performed are recorded.

EUT Operational Mode: The EUT transmitting modulated carriers hopping on all channels. Tested with maximum duty cycle on all modulation schemes and data rates supported to observe the worst-case configurations.

Resolution BW: Circa 50% of Occupied Channel Bandwidth

Video BW: ≥Resolution BW, RMS

Detector: RMS

For further considerations, see also Section 8.2.5.8.

8.2.4.4 Hopping frequency separation

Applicability: All types of FHSS equipment

Definition: The frequency separation between two adjacent hopping frequencies (clause 4.3.1.5).

Requirement:

Non-adaptive FHSS

≥ Occupied Channel Bandwidth, (the bandwidth that contains 99 % of the power of the signal, see clause 4.3.1.8 [4]), where hopping frequency separation is ≥100 kHz.

Adaptive FHSS equipment

≥100 kHz in separation, if Hopping Frequency Separation < Occupied Channel Bandwidth (the bandwidth that contains 99 % of the power of the signal, see clause 4.3.1.8 [4]), and >100 kHz, the equipment can operate in non-adaptive mode on those frequencies (i.e., in the presence of interference on those frequencies, even though this frequency separation is less than required for purely non-adaptive devices). The equipment must continue to operate in an adaptive mode on all other hopping frequencies.

Test Standard and Clause: 5.4.5 in [4]

EUT Operational Mode: This is either tested on fixed frequencies (Option 1 in the test clause) with or without modulated carrier, or in normal hopping mode (Option 2).

EUT channel measured: On two adjacent hopping frequencies. The frequencies on which the test was performed is recorded.

Resolution BW: 1% of the span

Video BW: 3 x Resolution BW

Detector: Peak

Frequency Span: Sufficient to cover the complete power envelope of both hopping frequencies

8.2.4.5 Medium Utilization (MU) factor

Applicability: Non-adaptive FHSS equipment

Definition: A measure to quantify the amount of resources (power and time) used by non-adaptive equipment, defined by the formula:

MU = (Pout / 100 mW) × DC

where:

MU is Medium Utilization factor in %.

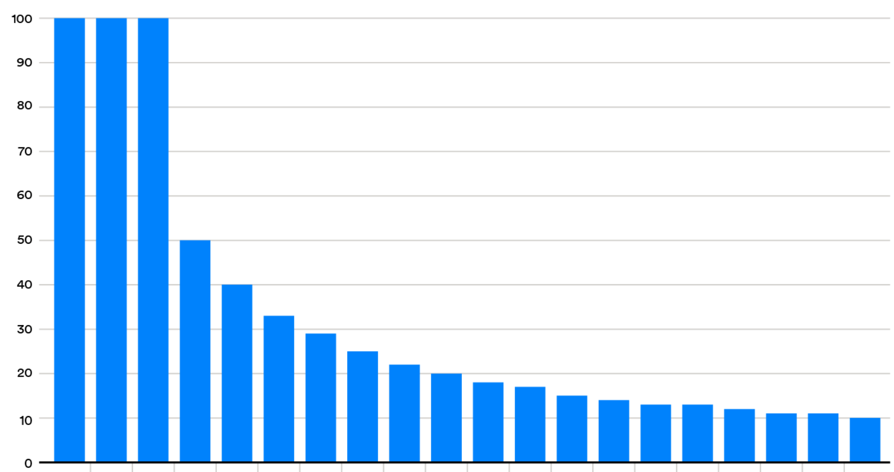
Pout is the RF output power in mW.

DC is the Duty Cycle in %.

Requirement: Medium Utilization factor for non-adaptive FHSS equipment is ≤10%.

Note: To benefit from this requirement with a system duty cycle higher than 10%, the requirement forces a tradeoff in the maximum output power that can be enabled. For example: at DC = 10% maximum Pout is 100 mW, but with DC = 20% maximum Pout is 50 mW. With DC = 50%, maximum Pout is limited to 20 mW. See Figure 8.1.

Section 8.2.5.8 discusses the channel selection algorithms' use of *used* and *unused* channels and the issues that must be considered to help enable the requirement regarding the minimum number of hopping frequencies for a non-adaptive FHSS device to be met.



Duty Cycle %	1	5	10	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Pout (mW)	100	100	100	50	40	33	29	25	22	20	18	17	15	14	13	13	12	11	11	10

Figure 8.1: Max possible output power, relative to Duty Cycle with MU=10%

Test Standard and Clause: 5.4.2.2.1.3 in [4]

EUT Operational Mode: The EUT transmitting modulated carriers hopping on all channels. Tested on all modulation schemes, output power and data rates supported to observe the EUT's worst-case configurations.

8.2.4.6 Adaptivity (adaptive FHSS)

Applicability: Adaptive FHSS equipment with RF Output power ≥ 10 dBm

Definition: Equipment using a mechanism that allows it to adapt to its radio environment by identifying frequencies that are being used by other equipment.

There are two mechanisms in Adaptive FHSS, which are LBT (Listen-Before-Talk) and DAA (Detect And Avoid). Adaptive FHSS equipment should implement either or both of the mechanisms. It is allowed to switch dynamically between the two adaptive modes (clause 4.3.1.7 in [4]).

8.2.4.6.1 Adaptive FHSS using LBT

Applicability: Usually not relevant to Bluetooth technology.

Requirements Clause: 4.3.1.7.2 in [4]

Wanted signal mean power from companion device	Unwanted CW signal frequency (MHz)	Unwanted CW (dBm)
Sufficient to maintain the link [18] [19]	2395 or 2488.5 [20]	-35 [21]

Table 8.7: FHSS LBT equipment - Unwanted Signal parameters

Test Clause: 5.4.6.2.1.2 in [4]

8.2.4.6.2 Adaptive FHSS using DAA

Applicability: Usually applicable to Bluetooth technology.

Requirements Clause: 4.3.1.7.3 in [4]

Test Clause: 5.4.6.2.1.2 in [4]

EUT Operational Mode: Tested in normal operation with a companion device.

Resolution BW: Next available setting below the measured Occupied Channel Bandwidth

Video BW: ≥ Resolution BW

Detector: RMS

Sweep time: Sufficient to cover the period over which the Channel Occupancy Time is spread out

Wanted signal mean power from companion device	Unwanted CW signal frequency (MHz)	Unwanted CW (dBm)
Sufficient to maintain the link [22] [23]	2395 or 2488.5 [24]	-35 [25]

Table 8.8: FHSS DAA equipment - Unwanted Signal parameters

[18] OCBW is in Hz.
[19] A typical conducted value that can be used in most cases is -50 dBm/MHz.
[20] The highest frequency should be used for testing operating channels within the range 2400 MHz to 2442 MHz, while the lowest frequency should be used for testing operating channels within the range 2442 MHz to 2483.5 MHz.
[21] The level specified is the level at the UUT receiver input assuming a 0 dBi antenna assembly gain. In case of conducted measurements, this level has to be corrected for the (in-band) antenna assembly gain (G). In case of radiated measurements, this level is equivalent to a power flux density (PD) in front of the UUT antenna.
[22] OCBW is in Hz.
[23] A typical conducted value that can be used in most cases is -50 dBm/MHz.
[24] The highest frequency should be used for testing operating channels within the range 2400 MHz to 2442 MHz, while the lowest frequency should be used for testing operating channels within the range 2442 MHz to 2483.5 MHz.
[25] The level specified is the level at the UUT receiver input assuming a 0 dBi antenna assembly gain. In case of conducted measurements, this level has to be corrected for the (in-band) antenna assembly gain (G). In case of radiated measurements, this level is equivalent to a power flux density (PD) in front of the UUT antenna.

8.2.4.7 Short control signaling transmissions

Applicability: Adaptive equipment may have Short Control Signaling Transmissions.

Definition: Transmissions used by Adaptive FHSS equipment to send management and control signals without sensing the hopping frequency for the presence of other signals.

Requirement: If implemented, Short Control Signaling Transmissions have a maximum TxOn / (TxOn + TxOff) ratio of 10% within any observation period of 50 ms or within an observation period equal to the dwell time, whichever is less.

EUT Operational Mode: Tested in normal operation with a companion device.

Test Clause: Tested within the procedure for the Adaptivity testing in clause 5.4.6.2.1.2 in [4].

8.2.4.8 Occupied channel bandwidth

Definition: The bandwidth that contains 99% of the power of the signal (clause 4.3.1.8 in [4])

Applicability: All types of FHSS equipment

Test Clause: 5.4.7 in [4]

EUT Operational Mode: The EUT transmitting modulated carriers hopping on a single Hopping Frequency

EUT channel measured: Low and High

Resolution BW: 20 kHz

Detector: RMS

Requirement:

1. The Occupied Channel Bandwidth (OCBW) falls completely within the 2.4 GHz band.
2. For non-adaptive equipment using modulations other than FHSS and with EIRP >10 dBm, the occupied channel bandwidth is <20 MHz.

8.2.4.9 Transmitter unwanted emissions in the out-of-band domain

Applicability: All types of FHSS equipment

Definition: Transmitter unwanted emissions in the out-of-band domain are emissions when the equipment is in Transmit mode, on frequencies immediately outside the necessary bandwidth, which results from the modulation process, but excluding spurious emissions.

Test Clause: 5.4.8.2.1 in [4] defines the conducted test method. 5.4.8.2.2 in [4] supplements a radiated test.

EUT Operational Mode: The EUT transmitting modulated carriers hopping on all channels. Tested with maximum duty cycle on all modulation schemes and data rates supported to observe the worst-case configurations.

Resolution BW: 1 MHz

Video BW: 3 MHz

Detector: RMS

Requirement: The transmitter unwanted emissions in the spurious domain are not to exceed the values given in Table 8.9.

Equipment BW=1 MHz	Equipment BW=2 MHz	Limit (dBm/MHz)
BR/EDR	**LE**	
2399–2400	2399–2400	-10
2398–2399	2396–2399	-20
< 2398	< 2396	-30
2483.5–2484.5	2483.5–2485.5	-10
2484.5–2485.5	2485.5–2487.5	-20
> 2485.5	> 2487.5	-30

Table 8.9: Transmitter limits for spurious emissions

8.2.4.10 Transmitter unwanted emissions in the spurious domain

Applicability: All types of FHSS equipment

Definition: Emissions outside the allocated band and outside the out-of-band domain as indicated in Table 8.10 when the equipment is in Transmit mode

EUT Operational Mode: The EUT is configured to operate under its worst-case situation with respect to output power. Tested with maximum duty cycle on all modulation schemes.

1. Measurements may be performed when normal hopping is disabled. In this case, measurements need to be performed when operating at the lowest and the highest hopping frequency.
2. Otherwise, the measurement is performed during normal operation with hopping enabled.

Test Clause: 5.4.9.2.1 in [4] defines the conducted test method. 5.4.9.2.2 supplements a radiated test, using the test setup defined in annex B. The applicable measurement procedures in annex C are used. Alternatively, a test fixture may be used. The test procedure is as described under clause 5.4.9.2.1 in [4].

Resolution BW: 100 kHz (30 MHz–1 GHz), 1MHz (1 GHz–12.75 GHz)

Detector: Peak

Requirement: The transmitter unwanted emissions in the spurious domain is not to exceed the values given in Table 8.10.

Frequency range (MHz)	Maximum power (dBm)	Resolution Bandwidth (kHz)
30–47	-36	100
47–74	-54	100
74–87.5	-36	100
87.5–118	-54	100
118–174	-36	100
174–230	-54	100
230–470	-36	100
470–694	-54	100
694–1000	-36	100
1000–12750	-30	1000

Table 8.10: Transmitter limits for spurious emissions

Note: In case of equipment with antenna connectors, these limits apply to emissions at the antenna port (conducted). For emissions radiated by the cabinet or emissions radiated by integral antenna equipment (without antenna connectors), these limits are ERP for emissions up to 1 GHz and EIRP for emissions above 1 GHz.

8.2.4.11 Receiver spurious emissions

Applicability: All types of FHSS equipment

Definition: Emissions at any frequency when the equipment is in receive mode.

EUT Operational Mode: Tested on all modulation schemes, with the EUT in receive-only mode. The spectrum is searched for emissions that exceed the limit values given in Table 8.11 or that come within 6 dB below these limits. Each occurrence is recorded.

1. Measurements may be performed when normal hopping is disabled. In this case, measurements need to be performed when operating at the lowest and the highest hopping frequency.
2. Otherwise, the measurement is performed during normal operation with hopping enabled.

EUT channel measured: Low and High

Resolution BW: 100kHz (30 MHz–1 GHz); 1MHz (1 GHz–12.75 GHz)

Detector: Peak

Test Clause: The test procedure is as described under clause 5.4.10.2.1 [4]. 5.4.10.2.1 [4] defines the conducted test method; 5.4.10.2.2 [4] supplements with a radiated test, using the test setup defined in annex B. The applicable measurement procedures in annex C are used. Alternatively, a test fixture may be used. The test procedure is as described under clause 5.4.10.2.1 in [4].

Requirement: The spurious emissions of the receiver are not to exceed the values given in Table 8.11.

Frequency range (MHz)	Maximum power (dBm)	Resolution Bandwidth (kHz)
30–1000	-57	100
1000–12750	-47	1000

Table 8.11: Spurious emission limits for receivers

Note: For equipment with antenna connectors, these limits apply to emissions at the antenna port (conducted). For emissions radiated by the cabinet or emissions radiated by integral antenna equipment (without antenna connectors), these limits are ERP for emissions up to 1 GHz and EIRP for emissions above 1 GHz.

8.2.4.12 Receiver blocking

Applicability: All types of FHSS equipment

Definition: A measure of the ability of the equipment to receive a wanted signal on its operating channel without exceeding a given degradation in the presence of an unwanted signal (blocking signal) on frequencies other than those of the operating band.

Requirements depend on the Category of the receiver.

Receiver Category	Limit
1	Adaptive equipment, maximum RF output power > 10 dBm EIRP
2	Adaptive or non-adaptive equipment, maximum RF output power between > 0 dBm and ≤ 10 dBm EIRP, or non-adaptive equipment with MU > 1% and < 10%
3	Adaptive or non-adaptive equipment, maximum RF output power ≤ 0 dBm EIRP, non-adaptive equipment with MU ≤ 1%

Table 8.12: Receiver category

Receiver Performance: PER or FER less than or equal to 10%

If the equipment does not support the performance of a PER or a FER test, then the minimum performance criterion is no loss of the wireless transmission function needed for the intended use of the equipment.

Test Clause: 5.4.11 [4]

EUT Operational Mode: Tested on all modulation schemes. Connected with a companion device. Equipment that can change their operating channel automatically (adaptive channel allocation), and where this function cannot be disabled, is tested as FHSS equipment.

Requirement: The Blocker is at –34 dBm, with a CW blocking signal in all cases and at the blocking signal frequencies listed in Table 8.13.

Receiver Category	Wanted signal mean power from companion device (dBm) [26] [27]	Blocking signal frequency (MHz)
1	(-133 dBm + 10 × $\log_{10}$(OCBW)) or -68 dBm whichever is less [28]	2380 2504
	(-139 dBm + 10 × $\log_{10}$(OCBW)) or -74 dBm whichever is less [29]	2300 2330 2360 2524 2584 2674
2	(-139 dBm + 10 × $\log_{10}$(OCBW) + 10 dB) or (-74 dBm + 10 dB) whichever is less [28]	2380 2300 2504 2584
3	(-139 dBm + 10 × $\log_{10}$(OCBW) + 20 dB) or (-74 dBm + 20 dB) whichever is less [30]	2380 2300 2504 2584

Table 8.13: Limits on receiver blocking (all categories)

[26] OCBW is in Hz.

[27] The level specified is the level at the UUT receiver input assuming a 0 dBi antenna assembly gain. In case of conducted measurements, this level has to be corrected for the (in-band) antenna assembly gain (G). In case of radiated measurements, this level is equivalent to a power flux density (PFD) in front of the UUT antenna with the UUT being configured/positioned as recorded in clause 5.4.3.2.2.

[28] In the case of radiated measurements using a companion device where the level of the wanted signal from the companion device cannot be determined, a relative test may be performed using a wanted signal up to Pmin + 26 dB where Pmin is the minimum level of wanted signal required to meet the minimum performance criteria as defined in this section in the absence of any blocking signal.

[29] In the case of radiated measurements using a companion device where the level of the wanted signal from the companion device cannot be determined, a relative test may be performed using a wanted signal up to Pmin + 20 dB where Pmin is the minimum level of wanted signal required to meet the minimum performance criteria as defined in this section in the absence of any blocking signal.

[30] In the case of radiated measurements using a companion device where the level of the wanted signal from the companion device cannot be determined, a relative test may be performed using a wanted signal up to Pmin + 30 dB where Pmin is the minimum level of wanted signal required to meet the minimum performance criteria as defined in this section in the absence of any blocking signal.

8.2.4.13 Geolocation capability

Applicability: Only if capability as defined exists.

Definition: A feature of the equipment to determine its geographical location with the purpose to configure itself according to the regulatory requirements applicable at the geographical location where it operates.

Requirement: The geographical location determined by the FHSS equipment is not to be accessible to the user in a way that would allow the user to alter it.

8.2.4.14 ETSI adaptivity requirements implications for the EUT's adaptivity algorithm

The ETSI adaptivity using DAA requirements in [4] 4.3.1.7.3.2 on Channel Occupancy Time (COT) and Idle Period provide the foundation for reaction time (described in Section 8.2.4.14.1) and silent time (described in Section 8.2.4.14.2) capabilities that each EUT's implemented adaptivity algorithm has to enable. Specifics about the Channel Occupancy Time (COT) and silent time (unavailability) requirements are outlined in Section 8.2.3.1 while testing of this is discussed in Section 8.2.4.6.2.

8.2.4.14.1 Reaction time

The ETSI adaptivity time requirements in subclause 4.3.1.7.3 of [4] define the requirement for maximum allowed Channel Occupancy Time (COT) on a given hopping frequency. The Channel Occupancy Time (COT) is a function of the system duty cycle and the number of channels used.

Subclause 5.4.6.2.1.2 of [4] indicates to stop transmissions on a hopping frequency in response to an interfering signal above the specified threshold level within a period equal to the maximum Channel Occupancy Time. Therefore, we derive the reaction time (for stopping transmission in response to an interfering signal above the specified threshold level) required of the implemented channel assessment algorithm to be:

Reaction Time = $\frac{Channel\_Occupancy\_Time \times num\_channels}{Duty\_Cycle}$ where Channel_Occupancy_Time ≤ 40 ms.

For maximum duty cycle and reaction time limit for Bluetooth BR/EDR, see Table 8.14. These maximum values are calculated based on hopping through all 79 channels using every transmission opportunity with the maximum allowed packet lengths for transmissions.

Note: The reaction time limit is shown here to aid in collection of test results.

Mode	Channels	Max Duty Cycle	Limit (s)
Bluetooth BR/EDR, 5-slot packets	79	83.3%	3.79

Table 8.14: Example maximum duty cycle and reaction time test limit for Bluetooth BR/EDR with Adaptive FHSS using DAA assuming 79 channels in use and maximum traffic For the maximum duty cycles and limits for Bluetooth Low Energy modes of operation with selected configurations for Bluetooth Low Energy Audio use cases, see Section 9.

8.2.4.14.2 Silent time

Silent time is the minimum amount of time to remain silent after removing a channel. It is relative to the Channel Occupancy Time (COT) and number of channels and is not duty cycle dependent. After the silent time, the channel is no longer considered blocked, and transmissions may resume as soon as the device deems appropriate, irrespective of whether the interference is still present. When transmission resumes, the COT begins accumulating again.

Silent Time = $MAX\ [1, 5 \times COT \times Num\_Channels]$ seconds

As an example, when the number of MHz removed is 6 MHz, the silent time for different modes of operation is shown in Table 8.15.

Mode	COT	Channels	Channels Removed	Silent Time (s)
BR/EDR	40 ms	79	6	14.6
Bluetooth Low Energy	40 ms	37	3	6.8

Table 8.15: Example silent time test limits for Bluetooth with Adaptive FHSS using DAA

Note: The expected silent period limit is shown here to aid in collection of test results. Real-world testing might see a different number of channels unavailable depending on how well shielded the test environment is from external interference sources, which would influence the silent period limit.

8.2.4.15 EN 300 328 test and EUT conditions table

Table 8.16 summarizes the adaptive FHSS requirements, using DAA, for an EUT operating above 10 dBm.

Requirement [4]	Test Clause [4]	Channels Required	Modulations	Notes
RF output power (see Section 8.2.4.1) (4.3.1.2 in [4])	5.4.2.2.1.2	All (see notes)	All modulations and date rates	For FHSS modulation, measurements during normal operation, operating on all hopping frequencies.
Accumulated transmit time, Frequency occupation, Hopping sequence (see Section 8.2.4.3) (4.3.1.4 in [4])	5.4.4 accumulated transmit time	Two (active) hopping frequencies	All modulations	Frequency Occupation and Hopping Sequence may be passed with statistical analysis.
Hopping frequency separation (see Section 8.2.4.4) (4.3.1.5 in [4]) (see also Section 8.2.5.9 for the impact of the 2M PHY on this parameter)	5.4.5	Any two adjacent hopping frequencies	All modulations	Test procedure states that special test software may be used to transmit on specific channels.
Adaptivity using DAA (adaptive frequency hopping) (see Section 8.2.4.6.2) (4.3.1.7.3 in [4])	5.4.6.2.1.2	All	All modulations	Tested in normal operation with a companion device.
Short Control Signaling Transmissions (see Section 8.2.4.7) (4.3.1.7.4 in [4])	5.4.6.2.1.2	All (see note)	All modulations. Applicable to Bluetooth LE.	Tested within the Adaptivity using DAA test.
Occupied Channel Bandwidth (see Section 8.2.4.8) (4.3.1.8 in [4])	5.4.7	Low, High	All modulations	EUT on fixed frequency transmitting modulated carrier.
Transmitter unwanted emissions in the Out Of Band domain (see Section 8.2.4.9) (4.3.1.9 in [4])	5.4.8.2.1	All	All modulations (see note)	Tested in normal hopping mode. The EUT is configured to operate under its worst-case situation with respect to output power. Tested with maximum duty cycle on all modulation schemes.
Transmitter unwanted emissions in the spurious domain (see Section 8.2.4.10) (4.3.1.10 in [4])	5.4.9.2.1	Low/High	All modulations	The EUT configured to operate in worst-case of output power. Test with maximum duty cycle on all modulation schemes. Measurements may be performed with hopping disabled. In this case, measurements need to be performed when operating at the lowest and the highest hopping frequency Otherwise, the measurement is performed during normal operation (hopping).

Requirement [4]	**Test Clause** [4]	**Channels Required**	**Modulations**	**Notes**
Receiver spurious emissions (see Section 8.2.4.11) (4.3.1.11 in [4])	5.4.10.2.1	Low/High	All modulations	Tested with EUT in receive-only mode. • Measurements may be performed with hopping disabled and operating at the lowest and the highest hopping frequency. • Otherwise, the measurement is performed during normal hopping operation.
Receiver Blocking (see Section 8.2.4.12) (4.3.1.12 in [4])	5.4.11	Low / High, or All (normal operation)	All modulations	Tested with a companion device. Tested as FHSS if the adaptive channel cannot be disabled.

Table 8.16: EN300 328 ≥ 10 dBm test requirements and EUT conditions

8.2.5 Bluetooth operating modes and European regulations

8.2.5.1 Considerations for LE Connected Asynchronous

See Section 8.2.5.7 and Section 8.2.5.8 for considerations relevant to LE Connected Asynchronous mode.

8.2.5.2 Considerations for LE Advertising Broadcast

8.2.5.2.1 Legacy advertising

Legacy advertising events involve the transmission of data on up to three of the primary advertising channels and their associated frequencies. In this mode of operation, a Bluetooth Low Energy device does not meet the minimum number of hopping frequencies for an FHSS radio according to EN 300 328. This means that when using legacy advertising, a device may only comply with the Wideband Data Transmission device limits in EN 300 328.

The advInterval parameter, shown in Figure 7.15 in Section 7.6.2.2.2, controls the time between the start of two consecutive advertising events and can be as small as 20 ms.

Legacy advertising always uses the LE 1M PHY, so the maximum RF output power for legacy advertising is limited to slightly more than +10 dBm EIRP as explained in Section 8.2.5.6.2.

If transmitting at or above +10 dBm EIRP, then see additional requirements described in Section 8.2.5.6.

8.2.5.2.2 LE extended advertising

Whether LE extended advertising meets the EN 300 328 requirements for FHSS is dependent on certain implementation choices such as the strategy involved in the fragmentation of host advertising data payloads for transmission in multiple packets, and characteristics of the advertising data being transmitted such as its periodicity, if any.

An extended advertising event consists of an advertising event (which typically uses all three of the primary channels) and a series of one or more associated packets that form an auxiliary advertising segment, transmitted on one or more general-purpose channels. The number of general-purpose channels used depends on the implementation in two ways: whether the advertising data is sent in one large auxiliary packet or broken into multiple smaller packets, and how the implementation chooses general-purpose channel(s) for the auxiliary packet(s). The choice of general-purpose channel(s) used for the auxiliary advertising segment is implementation dependent. Using the same general-purpose channel for all auxiliary PDUs of all extended advertisements is permitted by the Bluetooth Core Specification, though not recommended.

The Bluetooth Core Specification provides flexibility in how advertising events and extended advertising events are used. For example, different advertising sets can be interleaved such that an advertising event, 1, on the three primary channels is interleaved (sent) between a different advertising event, 2, on the same three primary channels and advertising event 2's auxiliary advertising segment. In the case of overlapping extended advertising events, the equipment also has a consecutive series of advertising events because multiple advertising events share the same auxiliary advertising segment, as shown in Figure 7.21: Overlapping extended advertising events

See Section 8.2.5.8 and Section 8.2.5.9 for considerations.

If transmitting at or above +10 dBm EIRP, see additional requirements described in Section 8.2.5.6.

The advInterval, shown in Figure 7.20 in Section 7.6.2.3.2, controls the time between the start of two consecutive advertising events in the same advertising set and can be as small as 20 ms. As discussed in Section 7.6.2.3.3, there can be multiple advertising sets, each a separate instance of the Link Layer state machine. This should be considered when determining issues such as Medium Utilization.

Regarding packet chaining (see Section 7.6.2.3.2), if the Controller chooses to fragment host advertising data, then how to choose the size of each fragment is an implementation concern, although it is recommended that the Controller minimize the number of fragments. It should be noted that the Controller implementation of fragmentation can affect time-specific metrics such as Dwell Time and Accumulated Transmit Time.

8.2.5.3 Considerations for Periodic Broadcast Advertising

If AUX_ADV_IND PDUs are regularly broadcast to carry the SyncInfo field, then (as shown in Figure 7.22: Periodic advertising events in Section 7.6.3.3) each periodic advertisement is a combination of extended advertising events (see considerations in Section 8.2.5.2.2) and periodic advertising events consisting of an AUX_SYNC_IND PDU optionally followed by one or more AUX_CHAIN_IND PDUs. Each AUX_SYNC_IND (transmitted at the start of each periodic advertising interval) hops to a new general-purpose channel selected according to CSA#2. But as with extended advertising, choice of general-purpose channel(s) for any AUX_CHAIN_IND PDUs within the periodic advertising interval is implementation dependent.

If SyncInfo is not broadcast, then extended advertising events are not used to support periodic broadcast advertising mode.

8.2.5.4 Considerations for Isochronous communication

Regulatory aspects of using Isochronous communication are discussed in Section 9.

8.2.5.5 Considerations for Bluetooth mesh devices

Mesh Profile v1.0 supports two types of bearers over which mesh messages may be transported:

- Advertising bearer
- GATT bearer

The advertising bearer uses non-connectable and non-scannable undirected advertising events. See Section 8.2.5.2 for relevant considerations when the advertising bearer is used.

The GATT bearer uses LE ACL connections. See Section 8.2.5.1 for relevant considerations when the GATT bearer is used.

8.2.5.6 Transmit power

8.2.5.6.1 FHSS devices

FHSS devices are required to have an RF output with a mean equivalent isotropic radiated power (EIRP) equal to or less than +20 dBm.

Adaptive FHSS devices operating with an RF output of +10 dBm EIRP or more are required to use either Detect And Avoid (DAA) in full compliance with the technical requirements of EN 300 328, or the device must use Listen Before Talk (LBT) in full compliance with the technical requirements of EN 300 328. Note that adaptivity as defined in the Bluetooth Core Specification’s channel selection algorithms (see Section 7.4.1) is confined to how channel remapping works in response to channel assessment made by the implementation. The specifics of the channel assessment are left to each implementation. On its own, Bluetooth Core Specifications compliance satisfies neither DAA nor LBT as defined in EN 300 328 and so compliance is left to implementation.

Non-adaptive FHSS devices operating with an RF output of +10 dBm EIRP or more are subject to a requirement on Medium Utilization (MU) to limit the amount of resources (power and time) used. A maximum Tx-sequence time (the time frame during which one or multiple RF transmissions may be made) of 5 ms applies. This must be immediately followed by a Tx-gap time (time frame during which no RF transmissions can be made) with a minimum duration of 5 ms.

8.2.5.6.2 Non-FHSS devices and FHSS devices operating in non-FHSS mode

Wideband Data Transmission (non-FHSS) devices are required to have an RF output with a mean equivalent isotropic radiated power (EIRP) equal to or less than +20 dBm.

In addition, the EIRP power spectral density in a 1 MHz bandwidth cannot exceed +10 dBm/MHz (10 mW/MHz).

The LE 1M PHY and Coded PHY will usually have 99% occupied channel bandwidths slightly greater than 1 MHz as measured according to the procedure defined in EN 300 328. Therefore, according to the power spectral density constraint, they will be limited to a maximum RF output power of slightly more than +10 dBm EIRP.

The LE 2M PHY will usually have a 99% occupied channel bandwidth slightly greater than 2 MHz, and therefore will be limited to a maximum RF output power of slightly more than +13 dBm EIRP.

ETSI EN 300 328 imposes a Medium Utilization (MU) limitation upon non-adaptive Wideband Data Transmission devices operating with an RF output of +10 dBm EIRP or more. This carries with it a maximum Tx-sequence time (the time frame during which one or multiple RF transmissions may be made) of 10 ms, which has to be immediately followed by a Tx-gap time (time frame during which no RF transmissions can be made) that is equally as long as the Tx-sequence and which must take a minimum value of 3.5 ms. This enforced ‘no RF transmissions’ Tx-gap needs to be taken into account in the timing of events if transmitting at +10 dBm or more.

There are two ways to avoid being subject to the MU limitation. The first and simplest option is to reduce the RF output power below +10 dBm such that there is no applicable MU limitation and no resulting duty cycle / Tx-sequence + Tx-gap limitations. The second approach is to have the device comply with adaptivity (non-FHSS) requirements, in which case it must either implement Detect And Avoid (DAA) in full compliance with the technical requirements of EN 300 328, or the device must use Listen Before Talk (LBT) in full compliance with the technical requirements of EN 300 328. Note that adaptivity as defined in the Bluetooth Core Specification’s channel selection algorithms (see Section 7.4.1) satisfies neither DAA nor LBT as defined in EN 300 328, so compliance is left to implementation.

8.2.5.7 Choice of PHY

Choice of PHY (LE 1M, LE 2M, or LE Coded) will affect Occupied Channel Bandwidth, Minimum Hopping Channel Spacing, Duty Cycle, and Medium Utilization. Especially when using the LE Coded PHY, care should be taken to consider the duty cycle. In addition, when using the S=8 forward error correction option in LE Coded PHY, careful attention needs to be paid to the number of bytes used in the PDU section of Link Layer packets to determine that the 'on-air' RF transmission time is within permitted limits. 7.2.3 shows that if PDU lengths are not constrained then the 'on-air' RF transmissions for S=8 Coded PHY Link Layer packets can last for up to 17.04 ms which far exceeds the maximum duration permitted by EN 300 328 TX-sequence time limitations for both non-adaptive Wideband data transmission or non-adaptive frequency hopping spread spectrum device categories as well as for certain ETSI compliant adaptive Wideband data transmission devices.

When using the LE 2M PHY, see Section 8.2.5.9 for considerations.

8.2.5.8 Number of hopping channels

For a non-adaptive FHSS device categorization, ETSI EN 300 328 requires that:

- The Hopping Sequence(s) contains at least N hopping frequencies where N is either 5 or the result of 15 MHz divided by the minimum Hopping Frequency Separation in MHz, whichever is greater.

Similarly, for an Adaptive FHSS device categorization, ETSI EN 300 328 requires that:

- The Hopping Sequence(s) contains at least N hopping frequencies at all times, where N is either 15 or the result of 15 MHz divided by the minimum Hopping Frequency Separation in MHz, whichever is greater.

A cursory glance at EN 300 328 might suggest that Bluetooth LE operating modes that use the general-purpose channels (e.g., extended advertising or LE Connected Asynchronous) could be categorized as non-adaptive or adaptive FHSS and might therefore be able to use up to +20 dBm EIRP (i.e., not be subject to the power spectral density limitation on non-FHSS devices discussed in Section 8.2.5.6), provided it satisfies the minimum required number of hopping frequencies. However the LE channel selection algorithms (see Section 7.4.1) never occupy unused channels, and therefore unused channels do not count toward the minimum number of hopping frequencies (see Section 8.2.4.3 Accumulated Transmit Time, Frequency Occupation, and Hopping Sequence). Nor do the Bluetooth LE algorithms guarantee a minimum number of channels compatible with EN 300 328.

Note that extended advertising on secondary advertising channels is not required by the Bluetooth Core Specification to use the LE channel selection algorithms (see Section 7.6.2.3.1 Channels). Its number and usage of hopping channels is implementation specific. Therefore, it is left to implementation to determine that the minimum number of hopping frequencies is satisfied for the device categorization under ETSI.

Note that this also applies to Peripherals. While the Bluetooth Core Specification provides a way for a Peripheral to request a minimum number of hopping frequencies, the Central makes the final decision about the number of hopping frequencies in the channel map.

There are additional requirements that must be met when transmitting with an RF output of +10 dBm EIRP or more, as described in Section 8.2.5.6.

8.2.5.9 Channel spacing between hopping frequencies

EN 300 328 carries a requirement regarding hopping channel spacing as a function of its 99% occupied channel bandwidth as measured according to the standard:

- For non-adaptive FHSS equipment, the Hopping Frequency Separation is equal to or greater than the Occupied Channel Bandwidth (see EN 300 328 clause 4.3.1.5.3.1), with a minimum separation of 100 kHz.

Note that Hopping Frequency Separation as defined in EN 300 328 is the channel spacing between two adjacent hopping frequencies, not the minimum distance between channel indices used in consecutive (sub)events.

The LE 2M PHY has a 99% occupied channel bandwidth measured according to the procedure required by EN 300 328 of ~2.1 MHz. The channel spacing in Bluetooth LE is 2 MHz and is therefore insufficient for an LE 2M PHY to satisfy the criteria to operate as a non-adaptive FHSS radio. The channel spacing in Bluetooth LE is 2 MHz, and to satisfy the criteria to operate as a non-adaptive FHSS, it is either necessary that the EUT uses the LE 2M PHY for isochronous BIS- or CIS- communication or periodic advertising where the minimum distance between channel indices used in the channel map exceeds the OCB, for example by only using every second channel.

Thus, when using the LE 2M PHY and classification as non-adaptive FHSS equipment, the implementation is responsible for ensuring that the minimum Hopping Frequency Separation is met (while also meeting the requirement on minimum number of hopping channels).

The LE 1M and LE Coded PHYs meet the channel spacing requirements of a non-adaptive FHSS device according to EN 300 328 since the 99% occupied channel bandwidth will be somewhat larger than 1 MHz while the channel spacing in Bluetooth LE is 2 MHz.

8.2.6 European Union regulation, standardization process, and involved parties

Unlike many other jurisdictions, within the European Union, the process of updating or creating new radio regulations and associated harmonized standards involves a complex interaction between three separate bodies. These are the European Commission (EC), the European Conference of Postal and Telecommunications Administrations (CEPT), and the European Telecommunications Standards Institute (ETSI). Both the CEPT’s Short Range Devices Maintenance Group (SRDMG) and Technical Group 11 (TG11) of ETSI’s technical committee on EMC and Radio Spectrum Matters (ERM) have a direct regulatory impact on Bluetooth devices within the European Union.

The EC established the formal process on 9 November 2006 by publishing decision 2006/771/EC “*On Harmonization of the Radio Spectrum for use by Short Range Devices*” [43].

Article 1 of the decision stated that the intention is to:

> “…harmonize the frequency band and the related technical parameters for the availability and efficient use of radio spectrum for short-range devices….”

Point one of Article 2 defines short-range devices as:

> “…radio transmitters which provide either unidirectional or bidirectional communication and which transmit over a short distance at low power….”

Point two of Article 2 defines the following terms:

> “…‘non-interference and non-protected basis’ means that no harmful interference may be caused to any radio communications service and that no claim may be made for protection of these devices against harmful interference originating from radio communications services….”

Article 3 states:

> “Member States shall designate and make available, on a non-exclusive, non-interference and non-protected basis, the frequency bands for the types of short-range devices, subject to the specific conditions and by the implementation deadline, as laid down in the Annex to this Decision….”

Decision 2006/771/EC is still in place and has been subject to amendments over the course of the intervening years, expanding upon the specific conditions and bands covered by the Annex as new bands became available and new technologies were deployed. CEPT's Electronic Communications Committee (ECC) is permanently mandated by the EC to regularly update the technical annex to the Commission Decision. It does this by carrying out coexistence/compatibility studies from which radio regulations are derived. CEPT maintains ERC Recommendation 70-03 on Short Range Devices in Europe, which describes the frequency bands and high-level radio technical operating parameters.

ETSI develops and maintains harmonized standards such as EN 300 328 based upon the ECC reports and resulting regulations and European Commission decisions for the bands and categories of short-range devices covered in ERC Recommendation 70-03. ETSI also liaises with CEPT to provide them with technical information as input to CEPT's compatibility/coexistence studies. An update to EN 300 328 can also be triggered by the European Commission, as was the case with the inclusion of receiver blocking in the harmonized radio standards.

8.2.7 The United Kingdom

The UK formally left the European Union on 31 December 2020 as a consequence of the Brexit referendum in 2016. From 1 January 2021, and following the end of the Brexit transition period, new rules apply that differ depending on whether goods are placed on the market from this date in Great Britain or in Northern Ireland. In UK legislation, the Radio Equipment Regulations 2017 [31] takes the place of the Radio Equipment Directive (2014/53/EU), and with the changes coming from Brexit, the Department for Business, Energy, and Industrial Strategy has published guidance that explains how businesses placing radio equipment on the market in Great Britain [32] and on the market in Northern Ireland [33] can do so. Similarly, the Electromagnetic Compatibility Regulations 2016 replaces the Electromagnetic Compatibility Directive (2014/30/EU).

The processes are similar in many respects, but there are some significant differences. It should furthermore be noted that adjustments may be applied over time. The latest guidance for manufacturers, importers, and suppliers is available from Ofcom, entitled Placing radio equipment on the market.

The following is a summary, updated in December 2022, of the details published by Ofcom.

Approved CE-marked products that were already in circulation in the UK or Northern Ireland before 1 January 2021 remain valid, and the products can continue to be sold in the UK.

Note that "first placed on the market" applies to each new unit, not to a whole product range.

The time of placing on the market can typically be asserted by manufacturers using regular documentation of business transactions, including:

1. Sales contracts for goods that have already been manufactured and meet the legal requirements
2. Invoices
3. Shipping documentation

After 1 January 2021, there are two options for market approval to access the UK:

1. CE marking can continue to be used for the Great Britain (GB) market until 31 December 2024.
2. From 1 January 2025, the UKCA ("UK Conformity Assessed") must be used for the GB market, see also Using the UKCA marking.
    - Northern Ireland remains subject to EU laws after 31 December 2020 via the Northern Ireland Protocol, see [33]. It should also be noted that the amendments to Regulation 14 [34] require the UK(NI) indication for the UK in respect of NI. Products to be placed on the NI, or EU, market will need to use the UK(NI) indication to comply with the 2017 Regulations and Directive 2014/53/EU on Radio Equipment, respectively.

Additionally, conformity assessment activities for CE marking undertaken by 31 December 2024 may be used by manufacturers as the basis for the UKCA marking, until 31 December 2027 [46].

IR 2030 provides the UK Interface Requirements [30] for license-exempt short range devices.

	Normative Part				**Informative Part**
Interface/ Notification number/ Date	**Application**	**Comments to application**	**Maximum transmit power/ Power spectral density/ Field strength**	**Channel access and occupation rules**	**Reference**
IR2030/1/22	Non-specific short-range devices	Equipment may be used airborne	10 mW EIRP	–	EN 300 440
IR2030/7/1	Wideband Data Transmission Systems	Equipment may be used airborne	100 mW EIRP Additionally, emissions limited to 100 mW/100 kHz EIRP when frequency hopping modulation is used, or 10 mW/MHz EIRP when other types of modulation are used	Techniques to access spectrum and mitigate interference that provide at least equivalent performance to the techniques described in relevant designated standards specified in the notice of publication must be used.	EN 300 328
Note that this table is an abbreviated version of the tables in IR 2030 where columns without data (Comments to frequency band, Comments to Maximum transmit power / Power spectral density / Field strength and Channeling) for the applicable interface notifications have been removed					

Table 8.17: IR 2030 License-Exempt Short Range Devices

While initially UKCA marking requirements follow the EU requirements with respect to EU harmonized standards, there is a possibility that this will diverge in the future.

It should additionally be noted that on 1 January 2021, all UK-based EU Notified Bodies became UK Market Conformity Assessment Bodies, allowing UKCA certification work to start immediately. The government has published the UK Market Conformity Assessment Bodies database, which businesses can use to identify the appropriate body to certify their products. Since the EU-UK trade deal excluded a Conformity Assessment Body Mutual Recognition Agreement (MRA), EU-based notified bodies are not recognized as UK Market Conformity Assessment Bodies and cannot be used for UKCA marking, and UK-based Notified Bodies can no longer be used for EU/CE certification work with the exception of work to meet the CE+UKNI requirements for placing products in Northern Ireland.

Ofcom remains a member and active participant in both the CEPT and ETSI, and so it is likely that UK regulations will stay aligned with those of the European Union. There is, however, no longer a requirement for that to be the case.

8.2.7.1 UK cybersecurity

The first point of divergence of UK regulations from those of the European Union is about cybersecurity. The UK government is in the process of introducing legislation to improve basic cybersecurity of a wide variety of connected devices. The new legislation, called the UK Product Security and Telecommunications Infrastructure Bill Part I: Product Security [45], will apply to both wired and wirelessly connected devices and is broader in its coverage than the amendments to RED (see Section 8.2.1.2) that are in process within the European Union. At the time of writing, details of the UK requirements are still scant, but the legislation is written such that they may be amended at a later time.

8.3 US / Canada (FCC / RSS)

In the US, Code of Federal Regulations, Title 47, Part 15 (47 CFR 15) [12] regulates everything from spurious emissions to unlicensed low-power broadcasting.

> §15.247 [11] contains the key applicable requirements to the unlicensed operation of the 2.4 GHz bands.
>
> §15.249 [10] provides an alternative approach to certification; it does not have any modulation requirements, but it sets certain limits on the duty cycle depending on P_{EIRP} of the EUT, in contrast to §15.247.

For simplicity, the technical details of §15.247 are described first and §15.249 second.

The Canadian regulatory authority is Industry Canada (IC). IC issues regulations equivalent to and similar to FCC Part 15 through the publication of RSS-247 [27], RSS-210 [29], and RSS-Gen [28].

US regulations are specified in terms of either RF power or field strength (often measured at 3 m from the EUT), in contrast to power requirements that are defined elsewhere (for example, in Europe and in the Bluetooth Core Specification). The requirements discussed in this section have been converted to dBm EIRP equivalent figures using the formula discussed in Appendix B.

8.3.1 Main process aspects

The Federal Communications Commission (FCC) equipment authorization procedures include both certification and Supplier's Declaration of Conformity (SDoC) [31] as options for demonstrating compliance with the FCC's regulations. Bluetooth equipment is required to obtain certifications for compliance with the FCC regulations from a Telecommunication Certification Body (TCB). TCBs are authorized by the FCC to issue these certifications. When the product is approved, it must be marked with the FCC ID listed on the FCC grant. When the FCC-ID is applied to a radio module, it is the module that is certified. This means that an FCC-ID qualified radio module can be used in any product in the US, which is then assumed to be compliant with the relevant regulations.

IC certification (also called ISED certification) is mandatory for wireless products to enter Canada. It is not sufficient to meet the Canadian approvals requirements with the FCC certification. The FCC test data may, however, be reused to generate the IC test reports. It is therefore convenient to do the FCC and IC testing at the same time. The competent authority that assesses an application for approval of a product on behalf of ISED is the Foreign Certification Body (FCB), which is analogous to the TCB in the US.

In other regulatory jurisdictions around the world, a different approach is followed (for example, see the European Union Section 8.2), and it is the complete product that must be compliant with the regulations. In those other jurisdictions, this means that even if the same radio module is used in different products, each product must still be qualified according to the relevant standards and regulations.

8.3.2 Antenna gain

On 25 August 2022, the FCC urgently notified manufacturers via the TCB council that any applications after five business days of their notice (after 1 September 2022) without the proper antenna information will be dismissed.

The notice stated that this is in response to recent audits of Part 15 applications where the antenna information was omitted or only referred to as “antenna gain information is declared by the manufacturer”, without additional supporting information.

[31] SDoC is a self-declaration process where the manufacturer is responsible for testing their product and ensuring it meets the FCC's technical standards. The manufacturer provides a written statement, known as a Supplier's Declaration of Conformity, to the FCC attesting that the product meets the necessary requirements.

The FCC noted that they require the maximum gain of the antenna for the band of operation as a data sheet or a measurement report. They note that in, for example, field strength measurement on a part 15.249 or 15.231 device, where the antenna gain is inherently accounted for in the results, the gain does not necessarily need to be verified. However, enough information regarding the construction of the antenna is to be provided. Such information may be in the form of photos, length of wire antenna, etc.

The FCC furthermore required that the antenna gain information be made public while any proprietary information about the construction can be stripped from the gain information report and be held confidential.

8.3.3 Applicable FCC / RSS requirements

Section 15.247 [11]/RSS-247 [27] covers two forms of operation: frequency hopping (FHSS) and digital modulation techniques (DTS). Equipment can be a certified FHSS System, DTS System, Hybrid System combination of FHSS and DTS, or a Composite System combination of DTS and FHSS as long as the appropriate requirements for each classification are met.

In 47 CFR § 2.1(c) [12], an FHSS System is defined as:

> “A spread spectrum system in which the carrier is modulated with the coded information in a conventional manner causing a conventional spreading of the RF energy about the frequency carrier. The frequency of the carrier is not fixed but changes at fixed intervals under the direction of a coded sequence. The wide RF bandwidth needed by such a system is not required by spreading of the RF energy about the carrier but rather to accommodate the range of frequencies to which the carrier frequency can hop. The test of a frequency hopping system is that the near-term distribution of hops appears random, the long term distribution appears evenly distributed over the hop set, and sequential hops are randomly distributed in both direction and magnitude of change in the hop set.”

The FHSS operation requires at least 15 hopping channels in operation all the time. Bluetooth BR/EDR satisfies this requirement, while Bluetooth LE operation may not fulfill that all the time; therefore, Bluetooth LE operation is typically categorized as DTS operation.

It should, however, be noted that in [9], the answer to Question 6 *What is the FCC policy on the use of set-up (or “beacon”) channels used in FHSS system devices?* is explicit that FHSS devices may use fewer channels than 15 as setup channels (for example, in some applications involving voice or isochronous communication) and yet those devices can be certified as FHSS devices. The KDB article states, “FCC has interpreted Section 15.247(a)(1) as allowing the use of dedicated set up channels, if the time of occupancy on any such channel does not exceed 0.4 seconds (as required by Sections 15.247(a)(1)(i) and (ii)).” This allows any connected Bluetooth LE operation to be categorized as FHSS if it is beneficial compared to DTS categorization.

A third alternative to DTS and FHSS is FHSS/DTS hybrid operation (see Section 8.3.3.2), which allows hopping on fewer channels and therefore can be a certification alternative for Bluetooth LE in certain cases.

The Composite System certification may be used if the device uses two mutually exclusive operational modes, such as an acquisition mode and a data mode that are distinct. In that case, one mode can show compliance with the DTS requirements, while the other mode shows compliance with the FHSS requirement. A composite system is certified under one FCC ID. This type of certification is unlikely to be of any use for a Bluetooth BR/EDR or Bluetooth LE device.

The commonly used FCC/RSS categorization of Bluetooth technology is:

- BR/EDR: **FHSS**
- Bluetooth Low Energy: **DTS**

Additional relevant part 15 sections for radios operating in 2.4 GHz are:

- 15.35: General rules for certification measurements
- 15.107: Conducted emission limits for unintentional radiators
- 15.109: Radiated emission limits for unintentional radiators
- 15.205: Restricted bands of operation
- 15.207: Conducted emission limits for intentional radiators
- 15.209: Radiated emission limits for intentional radiators

Requirement and Description	Requirement Clause			Applies to	
	47 CFR 15 [12]	**RSS-Gen** [28] **RSS 247** [27]	**Hybrid**	**BR/EDR**	**Bluetooth Low Energy**
FHSS/DTS, common requirements					
Radiated spurious emissions in restricted bands (FHSS and DTS) (see Section 8.3.3.3)	15.205	Gen, 8.10	Yes	X	X
Radiated emissions from both unintentional radiator and intentional radiator (FHSS and DTS) (see Section 8.3.3.4)	15.109 15.209	Gen, 7.0 Rx emissions Gen, 8.9 Tx emissions	Yes	X	X
AC power line conducted emissions (see Section 8.3.3.15)	15.107 15.207	Gen, 8.8	(X)	(X)	(X)
Duty cycle correction factor (DCCF) (see Section 8.3.3.16)	15.35(c)	–	(X)	(X)	(X)
FHSS requirements					
Carrier frequency separation (FHSS) (see Section 8.3.3.5)	15.247(a)(1)	247, 5.1 (b)	Yes	X	–
Number of hopping frequencies (FHSS) (see Section 8.3.3.6)	15.247(a)(1) (i), (ii), and (iii)	247, 5.1 (c) (d) (e)	No	X	–
Average channel occupancy (FHSS) (see Section 8.3.3.7)	15.247(a)(1) (i), (ii), and (iii)	247, 5.1 (c) (d) (e)	Yes	X	–
Maximum peak conducted output power (FHSS) (see Section 8.3.3.8)	15.247(a)(1), (b)(1), and (b)(2)	247, 5.4 (b)	No	X	–
20 dB emission bandwidth (FHSS) (see Section 8.3.3.9)	15.247(a)(1)	247, 5.1 (a)	No	X	–
Out-of-band and conducted spurious emissions (FHSS) (see Section 8.3.3.10)	15.247(d)	247, 5.5	No	X	–
DTS requirements					
Occupied bandwidth (DTS) (see Section 8.3.3.11)	15.247(a)(2)	247, 5.2 (a)	No	–	X
Maximum peak conducted output power (DTS) (see Section 8.3.3.12)	15.247(b)(3)	247, 5.4 (d)	Yes	–	X
Out-of-band and conducted spurious emissions (DTS) (see Section 8.3.3.13)	15.247(d)	247, 5.5	Yes	–	X
Power spectral density (DTS) (see Section 8.3.3.14)	15.247(e)	247, 5.2 (b)	Yes	–	X

X=Applicable, (X) = May apply/ Can apply depending on associate conditions

Table 8.18: FCC, RSS major part 15 requirements for FHSS, DTS, and hybrid certification

8.3.3.1 Required information in FHSS device filings

Besides the tested requirements, the following information, with references to Part 15 text, need to be supplied in an FHSS filing.

1) Section 15.247(a)(1):

i) Pseudorandom frequency hopping sequence

A description of how the hopping sequence is generated is required, to demonstrate that the sequence meets the requirement specified in the definition of an FHSS system (for definition, see Section 8.3.3).

ii) Equal hopping frequency use

A description of how the EUT meets the requirement that hopping channels are used equally on average.

iii) System receiver input bandwidth

A description of how associated receiver(s) complies with the requirement that the input bandwidth (either RF or IF) matches the bandwidth of the transmitted signal.

iv) System receiver hopping capability

A description of how associated receiver(s) shift frequencies in synchronization with the transmitted signals.

2) Section 15.247(g):

For short burst systems, a description of how the EUT operates as an FHSS system (for definition, see Section 8.3.3). The EUT is to comply with the equal frequency use and pseudorandom hopping sequence requirement when transmitting in short bursts, and is to be designed to comply when presented with continuous data.

3) Section 15.247(h):

Describe how the EUT complies with the requirement that it does not deliberately coordinate with other FHSS systems to avoid the simultaneous occupancy of individual hopping frequencies by multiple transmitters.

Note: The descriptions in Sections 7.4.1, 7.4.2, 7.5 and 7.6 may be reviewed when drafting such descriptions.

For additional details on the filing requirements, see KDB558074 [9].

8.3.3.2 FHSS/DTS hybrid operation

FCC part 15.247(f) defines Hybrid operation, which is a combination of FHSS and DTS. Hybrid operation allows a system to use a smaller number of hopping channels than 15. KDB558074 [9] by the FCC OET (2 April 2019), “Guidance for compliance measurements on digital transmission system, frequency hopping spread spectrum system, and hybrid system devices operating under section 15.247 of the FCC rules”, clarifies that the requirement set for Hybrid operation is a combination of the FHSS and DTS with the following adjustments:

1. It must comply with power spectral density (DTS) (see Section 8.3.3.14) requirements of 8 dBm in any 3 kHz band when the frequency hopping function is turned off.
2. It must have an average channel occupancy less than 0.4 s * number of channels used when hopping (that is, comply with the Average channel occupancy (FHSS) requirement, see Section 8.3.3.7).

3. There is no requirement to comply with the 500 kHz minimum 6 dB bandwidth normally associated with a DTS device.
4. It has no minimum number of hopping channels, but hop sequence is required to appear as pseudorandom per Section 15.247(a)(1).
5. The hopping function has to be a true frequency hopping system, according to the specific requirements in Section 15.247(a)(1), which are:
   a) Minimum channel separation
   b) Pseudorandom hop sequence
   c) Equal use of each frequency
   d) Receiver matching bandwidth and synchronization
6. The non-coordination requirement of Section 15.247(h) does not apply.
7. Generally, the test procedures for FHSS and DTS in Clauses 7.8 and 11 of ANSI C63.10 [26], respectively, are used:
   a) Carrier frequency separation (FHSS): ANSI C63.10 [26] Clause 7.8.2
   b) Average channel occupancy (FHSS): ANSI C63.10 [26] Clause 7.8.4
   c) Maximum peak conducted output power (DTS): ANSI C63.10 [26] Clause 11.9
   d) Power spectral density (DTS): ANSI C63.10 [26] Clause 11.10

8.3.3.3 Radiated spurious emissions in restricted bands (FHSS and DTS)

Definitions:

> *Restricted bands:* A frequency band in which intentional radiators are permitted to radiate only spurious emissions but not fundamental signals. The complete list of restricted bands is outlined in FCC 15.205.
>
> *Spurious emissions:* Emissions on a frequency or frequencies, which are outside the necessary bandwidth and the level of which may be reduced without affecting the corresponding transmission of information. Spurious emissions include harmonic emissions, parasitic emissions, intermodulation products, and frequency conversion products.

Test Standard and Clause: ANSI C63.10 [26] Clauses 6.5 and 6.6

EUT Operational Mode: Mode with the highest output power and the mode with the highest output power spectral density for each modulation family

EUT Channels Measured: Low, Mid, High

When testing for this, it is particularly important to take note that:

1. 2310–2390 MHz is a restricted band
2. 2390–2400 MHz is not restricted
3. 2483.5–2500 MHz is a restricted band

Additionally, note that the 2nd, 3rd, and 5th harmonics occur in restricted bands.

Frequency range (MHz)	Field Strength, µV/m at 3 m (dBm equivalent)	Resolution Bandwidth (kHz)
25.5–25.67	100 (-55.2)	120
37.5–38.25	100 (-55.2)	120
73–74.6	100 (-55.2)	120
74.8–75.2	100 (-55.2)	120
108–121.94	150 (-51.7)	120
123–138	150 (-51.7)	120
149.9–150.05	150 (-51.7)	120
156.52475–156.52525	150 (-51.7)	120
156.7–156.9	150 (-51.7)	120

Frequency range (MHz)	Field Strength, µV/m at 3 m (dBm equivalent)	Resolution Bandwidth (kHz)
162.0125–167.17	150 (-51.7)	120
167.72–173.2	150 (-51.7)	120
240–285	200 (-49.2)	120
322–335.4	200 (-49.2)	120
399.9–410	200 (-49.2)	120
608–614	200 (-49.2)	120
960–1240	500 (-41.2)	120, 1000 from 1 GHz
1300–1427	500 (-41.2)	1000
1435–1626.5	500 (-41.2)	1000
1645.5–1646.5	500 (-41.2)	1000
1660–1710	500 (-41.2)	1000
1718.8–1722.2	500 (-41.2)	1000
2200–2300	500 (-41.2)	1000
2310–2390	500 (-41.2)	1000
2483.5–2500	500 (-41.2)	1000
2690–2900	500 (-41.2)	1000
3260–3267	500 (-41.2)	1000
3332–3339	500 (-41.2)	1000
3345.8–3358	500 (-41.2)	1000
3600–4400	500 (-41.2)	1000
4500–5150 [32]	500 (-41.2)	1000
5350–5460	500 (-41.2)	1000
7250–7750 [33]	500 (-41.2)	1000
8025–500	500 (-41.2)	1000
9000–9200	500 (-41.2)	1000
9300–9500	500 (-41.2)	1000
10600–12700 [34]	500 (-41.2)	1000
13250–13400	500 (-41.2)	1000
14470–14500	500 (-41.2)	1000
15350–16200	500 (-41.2)	1000
17700–21400	500 (-41.2)	1000
22010–23120	500 (-41.2)	1000
23600–24000	500 (-41.2)	1000
31200–31800	500 (-41.2)	1000
36430–36500	500 (-41.2)	1000

Table 8.19: Radiated spurious emissions in restricted bands (FHSS and DTS)

8.3.3.4 Radiated emissions from both unintentional radiator and intentional radiator (FHSS and DTS)

Definition: The radio frequency signals generated within the receiver, including the period during which the equipment is scanning or switching channels

[32] 2nd harmonic domain
[33] 3rd harmonic domain
[34] 5th harmonic domain

Test Standard and Clause: ANSI C63.10 [26], Clauses 6.5 and 6.6

EUT Operational Mode: Perform with EUT at its maximum duty cycle. All modulation schemes, data rates, and power settings to observe the worst-case configuration in each nominal bandwidth.

EUT Channels Measured: Low, Mid, High

Measurement BW: 1 MHz

Detector: Quasi-peak up to 1 GHz, Peak above 1 GHz

Frequency range (MHz)	Field Strength, µV/m at 3 m (dBm equivalent)	Resolution Bandwidth (kHz)
30–88	100 (-55.23)	120
88–216	150 (-51.71)	120
216–960	200 (-49.21)	120
960–25000	500 (-41.25)	120 1000 from 1 GHz

Table 8.20: Radiated Emissions Limits according to 15.109 and 15.209

8.3.3.5 Carrier frequency separation (FHSS)

Definition: The frequency separation between two adjacent hopping frequencies

Test Standard and Clause: ANSI C63.10 [26], Clause 7.8.2

EUT Operational Mode: Perform with EUT at its maximum duty cycle. All modulation schemes, data rates, and power settings to observe the worst-case configuration in each nominal bandwidth.

EUT Channels Measured: All from low to highest

Resolution BW: 100 kHz

Requirement: Frequency hopping systems are to have hopping channel carrier frequencies separated by a minimum of 25 kHz or the -20 dB bandwidth of the hopping channel, whichever is greater. Alternatively, frequency hopping systems operating in the band 2400 MHz to 2483.5 MHz may have hopping channel carrier frequencies that are separated by 25 kHz or two-thirds of the -20 dB bandwidth of the hopping channel, whichever is greater, provided that the systems operate with an output power no greater than 125 mW (21 dBm).

8.3.3.6 Number of hopping frequencies (FHSS)

Definition: The total number of hopping frequencies (the center frequencies defined within the hopping sequence of FHSS equipment), which are randomly sequenced in order to spread the transmission

Test Standard and Clause: ANSI C63.10 [26], Clause 7.8.3

EUT Operational Mode: Perform with EUT at its maximum duty cycle. All modulation schemes, data rates, and power settings to observe the worst-case configuration in each nominal bandwidth.

EUT Channels Measured: All from lowest to highest

Span: Depending on the number of channels the device supports, it may be necessary to divide the frequency range of operation across multiple spans, to allow the individual channels to be clearly seen.

Resolution BW: To clearly identify the individual channels, set the Resolution BW to less than 30% of the channel spacing or the 20 dB bandwidth, whichever is smaller.

Video BW: ≥ Resolution BW

Detector: Peak

Requirement: Frequency hopping systems operating in this band use at least 15 hopping channels. See Section 8.3.3.1 for details on how to describe the randomness of the hopper.

8.3.3.7 Average channel occupancy (FHSS)

Definition: The total transmitter 'on' time on a particular hopping frequency, during an observation period.

Test Standard and Clause: ANSI C63.10 [26], Clause 7.8.4

EUT Operational Mode: Perform with EUT at its maximum duty cycle. All modulation schemes, data rates, and power settings to observe the worst-case configuration in each nominal bandwidth.

EUT Channels Measured: Mid

Resolution BW: 200 kHz

Detector: Peak

Requirement: The average time of occupancy on any channel is not greater than 0.4 seconds within a period of 0.4 seconds, multiplied by the number of hopping channels employed.

8.3.3.8 Maximum peak conducted output power (FHSS)

Definition: The maximum power level measured with a peak detector using a filter with width and shape that is sufficient to accept the signal bandwidth.

Test Standard and Clause: ANSI C63.10 [26], Clause 7.8.5

EUT Operational Mode: Perform with EUT at its maximum duty cycle. All modulation schemes, data rates, and power settings to observe the worst-case configuration in each nominal bandwidth.

EUT Channels Measured: Low, Mid, High – hopping disabled

Resolution BW: 1 MHz and 2 MHz (Data rate dependent)

Video BW: 3 MHz and 5 MHz (Data rate dependent)

Detector: Peak

Voltage Extreme Environment Test Range: Mains power = 85% and 115% of Nominal (FCC only requirement); Battery power = new battery

Requirement: For a hopper employing ≥75 channels maximum peak conducted output power does not exceed 1 W (30 dBm); for all other frequency hopping systems in the band, the maximum peak conducted output power does not exceed 0.125 W (20.97 dBm). The EIRP power does not exceed 4 W (36.02 dBm).

8.3.3.9 20 dB emission bandwidth (FHSS)

Definition: The frequency range between two points, one above and one below the carrier frequency, at which the spectral density of the emission is attenuated 20 dB below the maximum in-band spectral density of the modulated signal

Test Standard and Clause: ANSI C63.10 [26], Clause 6.9

EUT Operational Mode: Perform with hopping disabled, EUT at its maximum duty cycle. All modulation schemes, data rates, and power settings to observe the worst-case configuration in each nominal bandwidth.

EUT Channels Measured: Low, Mid, High

Resolution BW: 1% to 5% Occupied Bandwidth (OBW)

Detector: Peak

Requirement: This verifies the 20 dB requirement defined within Section 8.3.3.5.

8.3.3.10 Out-of-band and conducted spurious emissions (FHSS)

Definition:

> *Out-of-band emission:* Emission on a frequency or frequencies immediately outside the necessary bandwidth resulting from the modulation process but excluding spurious emissions.
>
> *Spurious emission:* Emission on a frequency or frequencies that are outside the necessary bandwidth and the level of which may be reduced without affecting the corresponding transmission of information. Spurious emissions include harmonic emissions, parasitic emissions, intermodulation products, and frequency conversion products, but exclude out-of-band emissions.

Test Standard and Clause: ANSI C63.10 [26], Clause 7.8.8

EUT Operational Mode: Perform with EUT at its maximum duty cycle. All modulation schemes, data rates, and power settings to observe the worst-case configuration in each nominal bandwidth.

EUT Channels Measured: Low, Mid, High

Resolution BW: 100 kHz

Detector: Peak

Measurement Range: 30 MHz to 26.5 GHz

Requirement: In any 100 kHz bandwidth outside the frequency band in which the spread spectrum or digitally modulated device is operating, the RF power that is produced is at least 20 dB below that in the 100 kHz bandwidth within the band that contains the highest level of the desired power, based on either an RF conducted or a radiated measurement, provided that the transmitter demonstrates compliance with the peak conducted power limits. If the transmitter complies with the conducted power limits based on the use of root-mean-square averaging over a time interval, then the attenuation required is 30 dB instead of 20 dB.

Attenuation below the general field strength limits specified in FCC 47 CFR 15.209(a) / RSS-Gen is not required.

8.3.3.11 Occupied bandwidth (DTS)

Definition: The frequency range between two points, one above and one below the carrier frequency, at which the spectral density of the emission is attenuated 6 dB below the maximum in-band spectral density of the modulated signal.

Test Standard and Clause:

1. FCC: ANSI C63.10 [26], Clause 11.8
2. ISED: ANSI C63.10 [26], Clause 6.9

EUT Operational Mode: Perform with EUT at its maximum duty cycle. All modulation schemes, data rates, and power settings to observe the worst-case configuration in each nominal bandwidth.

EUT Channels Measured: Low, Mid, High

Resolution BW: 1% to 5% OBW

Detector: Peak

Requirement: The minimum 6 dB bandwidth is at least 500 kHz.

8.3.3.12 Maximum peak conducted output power (DTS)

Definition: The maximum power level measured with a peak detector using a filter with width and shape that is sufficient to accept the signal bandwidth. The maximum conducted output power is defined as the total transmit power delivered to all antennas and antenna elements averaged across all symbols in the signaling alphabet when the transmitter is operating at its maximum power control level.

Test Standard and Clause: ANSI C63.10 [26], Clause 11.9.1

EUT Channels Measured: Low, Mid, High

Resolution BW: 1 MHz LE 1M, 2 MHz LE 2M

Detector: Peak

Voltage Extreme Environment Test Range: Mains power = 85% and 115% of Nominal (FCC only requirement); Battery power = new battery

Requirement: The maximum peak conducted output power does not exceed 1 W (30 dBm).

8.3.3.13 Out-of-band and conducted spurious emissions (DTS)

Definition:

> *Out-of-band emission:* Emission on a frequency or frequencies immediately outside the necessary bandwidth that results from the modulation process but excluding spurious emissions.
>
> *Spurious emission:* Emission on a frequency or frequencies that are outside the necessary bandwidth and the level of which may be reduced without affecting the corresponding transmission of information. Spurious emissions include harmonic emissions, parasitic emissions, intermodulation products, and frequency conversion products, but exclude out-of-band emissions.

Test Standard and Clause: ANSI C63.10 [26], Clause 11.11 for emissions in non-restricted frequency bands. ANSI C63.10 [26], Clause 11.12 for emissions in restricted frequency bands.

Resolution BW: 100 kHz

Detector: Peak

EUT Channels Measured: Low, Mid, High

EUT Operational Mode: Perform with EUT at its maximum duty cycle. All modulation schemes, data rates, and power settings to observe the worst-case configuration in each nominal bandwidth.

Requirement:

In any 100 kHz bandwidth outside the frequency band in which the spread spectrum or digitally modulated device is operating, the RF power that is produced is at least 20 dB below that in the 100 kHz bandwidth within the band that contains the highest level of the desired power, based on either an RF conducted or a radiated measurement, provided that the transmitter demonstrates compliance with the peak conducted power limits. If the transmitter complies with the conducted power limits based on the use of root-mean-square averaging over a time interval, then the attenuation required is 30 dB instead of 20 dB.

Attenuation below the general field strength limits specified in FCC 47 CFR 15.209(a) / RSS-Gen is not required.

8.3.3.14 Power spectral density (DTS)

Definition: The power per unit bandwidth

Test Standard and Clause: ANSI C63.10 [26], Clause 11.10

EUT Operational Mode: Perform with EUT at its maximum duty cycle. All modulation schemes, data rates, and power settings to observe the worst-case configuration in each nominal bandwidth.

EUT Channels Measured: Low, Mid, High

Resolution BW: Set to 3 kHz ≤ RBW ≤ 100 kHz

Video BW: ≥ [3 × RBW]

Detector: Peak

Requirement: The transmitter PSD conducted from the transmitter to the antenna is not greater than 8 dBm in any 3 kHz band during any time interval of continuous transmission.

8.3.3.15 AC power line conducted emissions

Definition: The RF voltage that is conducted onto the AC power line on any frequency in the band 150 kHz to 30 MHz from a low power RF device that is designed to be connected to AC power.

Test Standard and Clause: ANSI C63.4 [25]

Frequency Range (MHz)	Quasi-Peak Limit (dBµV)	Average Limit (dBµV)
0.15–0.5	66-56[35]	55-46[35]
0.5–5	56	46
5–30	60	50

Table 8.21: AC Power Line Limits

8.3.3.16 Duty cycle correction (DCCF)

Definition: The factor to be subtracted from the peak pulse amplitude (in dB) to find the average emission. Section 15.35(c) specifies that the DCCF represents the worst-case (greatest duty cycle) over any 100 ms transmission period. In cases where the pulse train is truly random or pseudorandom, some regulatory agencies may accept a declaration by the manufacturer of the worst-case value.

Test Standard and Clause: ANSI C63.10 [26], Clauses 7.5 and 11.6

KDB558074 [9] clarifies that the use of a duty cycle correction factor (DCCF) is permitted for calculating average radiated field strength emission levels for an FHSS (Section 9b) or DTS (11, answer 3) device in 15.247. This DCCF can be applied when the unwanted emission limit is subject to an average field strength limit (for example, within a Government Restricted band when testing to Clause 11.12 of ANSI C63.10 [26]) and the conditions specified in Section 15.35(c) can be satisfied.

The average radiated field strength is calculated by subtracting the DCCF from the maximum radiated field strength level as determined through measurement. The maximum radiated field strength level represents the worst-case (maximum amplitude) RMS measurement of the emission(s) during continuous transmission (for example, not including any time intervals during which the transmitter is off or is transmitting at a reduced power level). It is also acceptable to apply the DCCF to a measurement performed with a peak detector instead of the specified RMS power averaging detector. The test report provided with the certification application must provide clear and complete documentation of the justification for use of the procedure as well as the calculations and assumptions that are used. Subclause 7.5 of ANSI C63.10 [26] provides additional measurement guidance applicable to determination of the DCCF.

[35] Decreases with the logarithm of the frequency.

8.3.4 FCC/RSS, FHSS, and DTS tests and EUT conditions table

Requirement	ANSI Test Clause [26]	Channels tested	Modulations	EUT Operation mode
Radiated spurious emissions in restricted bands (FHSS and DTS) (see Section 8.3.3.3)	6.5 and 6.6	Low/Mid/High	All	Fixed frequency transmitting modulated carrier
Out-of-band and conducted spurious emissions (FHSS) (see Section 8.3.3.4)	6.5 and 6.6	Low/Mid/High	All	Fixed frequency receiving modulated carrier
Carrier frequency separation (FHSS) (see Section 8.3.3.5)	7.8.2	All	All	Normal operation with a companion device
Number of hopping frequencies (FHSS) (see Section 8.3.3.6)	7.8.3	All	All	Normal operation with a companion device
Average channel occupancy (FHSS) (see Section 8.3.3.7)	7.8.4	Mid	All	Normal operation with a companion device
Maximum peak conducted output power (FHSS) (see Section 8.3.3.8)	7.8.5	Low/Mid/High	All	Fixed frequency transmitting modulated carrier
20 dB emission bandwidth (FHSS) (see Section 8.3.3.9)	6.9	Low/Mid/High	All	Fixed frequency transmitting modulated carrier
Out-of-band and conducted spurious emissions (FHSS) (see Section 8.3.3.13)	7.8.8	Low/Mid/High	All	Fixed frequency transmitting modulated carrier
Occupied bandwidth (DTS) (see Section 8.3.3.11)	11.8 (FCC), 6.9 (ISED)	Low/Mid/High	All	Fixed frequency transmitting modulated carrier
Maximum peak conducted output power (DTS) (see Section 8.3.3.12)	11.9.1	Low/Mid/High	All	Fixed frequency transmitting modulated carrier
Out-of-band and conducted spurious emissions (DTS) (see Section 8.3.3.13)	11.11	Low/Mid/High	All	Fixed frequency transmitting modulated carrier
Power spectral density (DTS) (see Section 8.3.3.14)	11.10	Low/Mid/High	All	Fixed frequency transmitting modulated carrier

Table 8.22: FCC/ RSS test requirements for FHSS and DTS

8.3.5 FCC 15.249 requirements for certification of “other than FHSS or DTS”

Instead of certifying to 15.247 [11], one can utilize 15.249 [10] as the alternative and certify as other than FHSS, other than DTS, or other than a combination of FHSS and DTS. In summary, 15.249 [10] defines that:

1. Allowed field strength from intentional radiators within the 2.4 GHz frequency band, specified at 3 m distance, is 50 mV/m (on the fundamental signal) and 500 μV/m for harmonics (in 15.249(a)).
2. Besides the harmonics, the FCC radiated emission limits for restricted bands (defined in §15.205) and general radiated emission limits (defined in §15.209) apply (in 15.249 (d)).
3. The field strength limits are based on average limits. However, the peak field strength of any emission does not exceed the maximum permitted average limits specified above by more than 20 dB under any condition of modulation (in 15.249 (e)).

This translates to the following limits in expressed in dBm:

Radiated emission	Power levels	Power dBm equivalent (field strength requirement)
Fundamental	Average	-1.25 (50 mV/m)
	Peak	18.75
Harmonic	Average	-41.25 (500 µV/m)
	Peak	-21.95

Table 8.23: 15.249 radiated emission

Section 15.249 does not have any modulation requirements, but it sets certain limits on duty cycle depending on P_{EIRP} of the EUT, which results in the following possible power versus duty cycle combinations:

EIRP (dBm)	Duty Cycle
0	86%
10	27%
18.75 [36]	10%

Table 8.24: Section 15.249 Power versus possible Duty Cycle

8.3.5.1 FCC 15.249 test requirements

ANSI C63.10 [26] Clause 7.5 clarifies that for emission limits expressed as average values on an operation that is treated as a pulsed operation, averaging occurs with a duty correction factor. This test procedure clarifies that for emission limits expressed as average values on an operation that is treated as a pulsed operation, averaging occurs:

1. Over one complete pulse train, including blanking intervals when the pulse train is < 0.1 s, or
2. Over 0.1 s when the pulse train exceeds 0.1 s

The duty cycle correction factor (in dB) associated with the pulse modulation is calculated as:

$$DCCF(dB) = 20\log_{10}(DC).$$

The average field strength is found by measuring the peak pulse amplitude (in log equivalent unit) and adding the duty cycle correction factor:

$$P_{avg} = P_{peak} + DCCF$$

An EUT that transmits up to 18.75 dBm Peak will comply with P_{avg} = -1.25 dBm up to a duty cycle of 10%.

Duty Cycle (%)	1	5	10
DCCF (dB)	-40	-26.02	-20
AVG reading (dBm)	-21.25	-7.27	-1.25

Table 8.25: Duty Cycle relative to Average Power, with 18.75 dBm P_{peak}

An EUT that transmits up to 10 dBm Peak will comply with P_{avg} = -1.25 dBm up to a duty cycle of 27%.

Duty Cycle (%)	1	5	10	20	27	28
DCCF (dB)	-40	-26.02	-20	-13.98	-11.37	-11.06
AVG reading (dBm)	-30	-16.02	-10	-3.98	-1.37	-1.06

[36] Max possible P_{EIRP}

Table 8.26: Duty Cycle relative to Average Power, with P_{peak} = 10 dBm

With the same reasoning, an EUT that transmits up to 0 dBm Peak will comply with P_{avg} = -1.25 dBm up to a duty cycle of 86%.

8.4 China

Access to the Chinese market requires proof of meeting Chinese radio, public safety, and energy standards. The Bureau of Radio Regulation (BRR) is the department of the Ministry of Information Industry Technology (MIIT) that has responsibility for the regulation of radio spectrum use in China.

- SRRC certification, managed by State Radio Regulation of China (a bureau under MIIT), is mandatory for equipment with a radio transmitting function.
  - SRRC certificates are valid for five years, after which time they need to be renewed. The subsequent renewal period is valid for three years, after which the product must be resubmitted as a new product for testing. Renewal is generally a paperwork transaction with no need to send a product sample.
- China Compulsory Certification (CCC) demonstrates that the product meets safety and EMC standards, provided the product is listed in the CCC catalog.
- Network Access License (NAL) certification is required for devices that access a public telecom network, such as cell phones, modems, telecom communication terminals, and ethernet switches. A device has to pass SRRC before NAL certification is possible. It is typically not a concern for Bluetooth devices.

8.4.1 SRRC radio requirements

The legacy SRRC test requirements that are applicable to Bluetooth devices are derived from the EN 300 328 v1.7.1 [7] transmitter requirements (the receiver requirements are ignored) together with the national standard GB/T 12572-2008 [3].

The regulatory foundation for these SRRC requirements is Xin Bu Wu [2002] #353 [23]. It does not distinguish between Bluetooth BR/EDR and Bluetooth Low Energy, and both are certifiable as frequency hoppers.

In October 2021, new requirements applicable to 2.4 GHz (as well as 5.1 GHz and 5.8 GHz) Gong Xin Bu Wu [2021] #129 [22] were published by MIIT. The regulation has been in force since 1 January 2022 and was published with a 2-year transition period that ends 15 October 2023. The new 2.4 GHz requirements largely match those of EN 300 328 v2.2.2 [4] in the case of the adaptivity and Tx-requirements. Although the adaptivity requirements match those from EN 300 328, it should be noted that they apply irrespective of output power; in other words, even in the case of power <10 dBm. Finally, the new requirements are stricter for emission requirements in specific restricted bands than they are in EN 300 328 [4]. New CCSA test methods are yet to be published, but test results based on EN 300 328 v2.2.2 [4] with the stricter spurious emissions requirements are expected to be satisfactory.

A device certified to current requirements can be sold until its 5-year validity expires. Following that, the device will need to comply with updated requirements.

With the transition from legacy to updated requirements, note that each section either describes the legacy requirements applicable until 15 October 2023 or the updated requirements that can be applied during the transition period but which will be mandatory from 15 October 2023.

The main certification process steps are:

- Manufacturer applies for type approval to SRRC.
- Samples are sent for testing to an accredited local test lab in China (in-country testing is required).
- A type approval certificate will be issued after successful tests and SRRC review of the test report.

8.4.2 Technical SRRC application form details

The legacy requirements applicable until 15 October 2023 define the details to include with the application form for Radio Transmission Equipment Type Approval:

- Technical specification and operational description
- Modulation mode
- Frequency Range
- Occupied Bandwidth
- Transmitting Power
- Antenna Gain
- RF transmit cable loss (if cable is used to connect final RF output to antenna)

The assessment of the application is based on the antenna gain according to Xin Bu Wu [2002] #353 [23]. With array antenna gain (antenna gain + BF gain) ≥ 10 dBi, the EUT can apply as 27 dBm (500 mW) equipment; otherwise, with antenna gain < 10 dBi, the EUT can apply as 20 dBm (100 mW) equipment.

8.4.3 EUT operations requirements

A method of operating and controlling the radio is required, including all necessary software and communications accessories (for example, cables and computers). It must be possible to test the EUT in the following modes of operation:

1. Continuous transmit
2. Hopping on all available channels
3. All available data rates
4. All modulations available
5. Continuous wave, non-modulated operation (for output power and frequency stability testing)

Corresponding application details based on the new MIIT publication (Gong Xin Bu Wu [2021] #129) [22] have not yet been published.

8.4.4 Legacy SRRC requirement breakdown

The list of tested parameters for SRRC type approval for the legacy requirements applicable until 15 October 2023 are outlined below. The primary guideline for the tests is EN 300 328 1.7.1 [8]. Additional information can be found in GB/T 12572-2008 [3].

In the Test Setup column, the following abbreviations are used to describe how the measurements are performed: RBW = Resolution bandwidth, VBW = Video bandwidth.

Requirement	Limit	Test Setup	EUT Channels Measured	EUT Op Mode
Output Power	Antenna gain: <10 dBi, EIRP ≤ 100 mW (20 dBm) ≥10 dBi, EIRP ≤ 500 mW (27 dBm)	RBW: 1 MHz VBW: Auto or 1 MHz Detector: RMS Trace mode: AVG Sweep time: Auto or 200 ms	Low, High	All modulation schemes and data rates. Hopping.
Power Spectral Density	Antenna gain (FHSS): <10 dBi, EIRP ≤ 20 dBm/MHz ≥10 dBi, EIRP ≤ 27 dBm/MHz	RBW: 1 MHz VBW: Auto or 1 MHz Detector: RMS Trace mode: Max Hold Span: 2*BW	Low, High	All modulation schemes and data rates. Fixed frequency.

Requirement	Limit	Test Setup	EUT Channels Measured	EUT Op Mode
	Antenna gain (DSSS or others): <10 dBi, EIRP ≤ 10 dBm/MHz ≥10 dBi, EIRP ≤ 17 dBm/MHz	Sweep time: Auto or 200 ms		
Out-of-band transmit power [37]	≤ -80 dBm/Hz	RBW: 100 kHz VBW: 1 MHz Sweep: Auto	Low, High	All modulation schemes and data rates. Fixed Frequency.
Frequency Range	2400 MHz to 2483.5 MHz Range where the PSD has dropped to -80 dBm/Hz EIRP from lowest channel and the highest channel, respectively	RBW: 100 kHz VBW: 300 kHz Detector: RMS Sweep time: Auto or 200 ms	Low, High	All modulation schemes and data rates. Fixed frequency.
Occupied Bandwidth (99% power)	Compared with declared values	See 5.2 of [3]	Low, High	All modulation schemes and data rates. Hopping.
Carrier Frequency Tolerance	± 20 ppm	See 4.2 of [3] RBW: 5 kHz VBW: 50 kHz	Low, High	Fixed Channel, CW
Transmit Spurious Emissions	30 MHz –1000 MHz: ≤ -36 dBm/100 kHz 2400 MHz –2483.5 MHz: ≤ -33 dBm/100 kHz 3400 MHz –3530 MHz: ≤ -40 dBm/MHz 5725 MHz –5850 MHz: ≤ -40 dBm/MHz Others at 1000 MHz –12750 MHz: ≤ -30 dBm/MHz (at 2.5x BW away)	See 6.2, 7 of [3] 30 MHz –1000 MHz:100 k/300 k 1000 MHz –12750 MHz:1 M/3 M 2400 MHz –2483.5 MHz: 100 k/300 k 3400 MHz –3530 MHz:1 M/3 M 5725 MHz –5850 MHz:1 M/3 M All frequencies: Sweep: Auto Detector: RMS	Low, High	All modulation schemes and data rates. Fixed Frequency.

Table 8.27: China MIIT 2002 No.353 Requirements, Limits, Test Setup, EUT Channels Measured

8.4.5 New SRRC requirements

Updated regulations in MIIT notice 2021 No.129 [22] replace previous regulations from 2002. With the updates, the China regulatory framework aligns itself more closely with EN 300 328 v2.2.2 for 2.4 GHz and EN 301 893 v2.1.1 for 5 GHz. While the new regulatory framework takes effect from 1 January 2022, it becomes mandatory from 15 October 2023.

The significant changes are:

- Addition of the beamforming gain for multiple antenna devices in RF requirements.
- Addition of spurious emission requirement restrictions to protect services in adjacent bands. Note that these are stricter requirements than those in EN 300 328.
- Addition of interference avoidance requirements mandating adaptivity through LBT or DAA and EU (Equivalent Utilization) limitation as the alternative when one cannot comply with any of the adaptivity requirements, where:

$$EU = \left(\frac{P_{eirp}(mW)}{P_{limit}(mW)}\right) \times DC \text{ where EU is } < 10\%$$

[37] Emissions within the 2.5 times channel bandwidth from the center frequency.

Note that the adaptivity requirement applies regardless of the output power of the device, which is different from EN 300 328, which requires adaptivity when power is ≥10 dBm.

Requirement	Limit		Reference [22]
Output Power (EIRP)	≤ 20 dBm for synthetic antenna gain < 10 dBi ≤ 27 dBm for synthetic antenna gain ≥ 10 dBi $P_{eirp} = \sum_{k=1}^{n}(A_k + G_k) + G_{bf}$ $Peirp$ is the equivalent isotropically radiated power, n is the maximum number of antennas for the equipment, Ak is port power, Gk is antenna gain, and Gbf is beam-forming gain.		Appendix 1/I.(II)
Frequency Tolerance	± 20 ppm		Appendix 1/I.(IV)
Out-of-band transmit power	≤ -80 dBm/Hz Max EIRP at upper and lower limits of the operating frequency		Appendix 1/I.(V)
Spurious emissions (RMS)	30 MHz – 1000 MHz ≤ -36 dBm (RBW:100 kHz) 1000 MHz – 12750 MHz ≤ -30 dBm (RBW:1 MHz) The spurious domain is beyond 2.5 times the channel bandwidth of the corresponding carrier		Appendix 1/I.(VI)
Spurious emissions for special frequency bands (RMS)	48.5 MHz – 72.5 MHz	≤ -54 dBm (RBW:100 kHz)	Appendix 1/I.(VII)
	76 MHz – 118 MHz	≤ -54 dBm (RBW:100 kHz)	
	167 MHz – 223 MHz	≤ -54 dBm (RBW:100 kHz)	
	470 MHz – 702 MHz	≤ -54 dBm (RBW:100 kHz)	
	2300 MHz – 2380 MHz	≤ -40 dBm (RBW:1 MHz)[38]	
	2380 MHz – 2390 MHz	≤ -40 dBm (RBW:100 kHz)[31]	
	2390 MHz – 2400 MHz	≤ -30 dBm (RBW:100 kHz)[31]	
	2400 MHz – 2483.5 MHz	≤ -33 dBm (RBW:100 kHz)	
	2483.5 MHz – 2500 MHz	≤ -40 dBm (RBW:1 MHz)[31]	
	5150 MHz – 5350 MHz	≤ -40 dBm (RBW:1 MHz)	
	5725 MHz – 5850 MHz	≤ -40 dBm (RBW:1 MHz)	
Power Spectral Density			
FHSS	≤ 20 dBm/100 kHz		Appendix 1/I.(III).2
DSSS or other modulation method	≤ 10 dBm/MHz for synthetic antenna gain < 10 dBi ≤ 17 dBm/MHz for synthetic antenna gain ≥ 10 dBi $PSD_{eirp} = \sum_{k=1}^{n}(A_k + G_k) + G_{bf}$ PSD_{eirp} is the equivalent isotropically radiated power spectral density, n is the maximum number of antennas for the equipment, Dk is port power spectral density, Gk is antenna gain, and Gbf is beam-forming gain.		Appendix 1/I.(III).1

Table 8.28: China MIIT 2021 No.129 breakdown, Common Tx parameters

38 Note these are stricter requirements than in MIIT 2002 No 353

8.4.5.1 Adaptivity in new SRRC requirements

In contrast with EN 300 328, the adaptivity requirement applies regardless of the power of the device. A device must implement one interference-mitigation technique from the following list, as defined by the MIIT notification:

- Non-adaptive operation, [22] in Appendix 2/IV
- FHSS using DAA, [22] Appendix 2/II.(I)
- Non FHSS using DAA, [22] in Appendix 2/II.(II)
- FHSS using LBT, [22] Appendix 2/I.(I)
- Frame Based non-FHSS using LBT, [22] Appendix 2/I.(II)
- Load Based non-FHSS using LBT, [22] Appendix 2/I.(III)

Requirement	**Limit**	**Reference** [22]
Common Adaptivity parameters		
Detection threshold	TL ≤ −70 dBm/MHz + 10 × $lg\frac{100\ mW}{P_{out}}$ P_{out} is EIRP in mW	Appendix 2/I.I.(I).5 Appendix 2/I.I.(II).6 Appendix 2/I.I.(III).4 Appendix 2/I.II.(I).4 Appendix 2/I.II.(II).3
Unwanted continuous wave	On 2395 MHz or 2488.5 MHz, -35 dBm, continuous wave	Appendix 2/I.I.(I).6 Appendix 2/I.I.(II).7 Appendix 2/I.I.(III).5 Appendix 2/I.II.(I).5 Appendix 2/I.II.(II).4
Non-adaptive operation	Applies to devices that do not comply with any of the adaptivity mechanisms defined below	Appendix 2/IV
Equivalent Utilization rate	EU ≤ 10% where $EU = \left(\frac{P_{eirp}(mW)}{P_{limit}(mW)}\right) \times DC$ (Note: analogous to MU in EN 300 328) P_{limit} is the P_{eirp} limit in Appendix 1/I, which is 100 mW for synthetic antenna gain < 10 dBi, 500 mW for synthetic antenna gain ≥ 10 dBi.	Appendix 2/IV
Adaptive FHSS using DAA		
Channel availability	When detected as unavailable, channel unavailable ≥ 1 s, or 5*N hopping channels*channel occupation time, whichever is larger	Appendix 2/II.(I).1
Channel holding time	Max 40 ms in principle If > 40 ms, idle time should be ≥ 5% of dwell time and no less than 100 μs	Appendix 2/II.(I).2
Short Control Transmission signaling	Transmissions allowed on unavailable channels as long as duty cycle ≤ 10%	Appendix 2/II.(I).3
Adaptive non FHSS using DAA		
Channel availability	When detected as unavailable, channel unavailable time should be ≥ 1 s	Appendix 2/II.(II).1
Channel holding time	Max 40 ms Idle time should be ≥ 5% of dwell time and ≥ 100 μs	Appendix 2/II.(II).2
Adaptive FHSS using LBT		
Clear channel assessment	Before transmitting, should be ≥ 0.2% of channel holding time and ≥ 16 μs	Appendix 2/I.(I).1
Occupied channel access	After discovering that a channel is occupied: 1. Hop to another available channel, before the dwell time expires 2. Reconduct channel reassessment	Appendix 2/I.(I).2

Requirement	Limit	Reference [22]
	3. Perform Short Control Signaling on the occupied channel as long as duty cycle ≤ 10%	
Channel holding time	Max 60 ms before CCA is required	Appendix 2/I.(I).3
Channel idle time	≥ 5% of channel holding time and ≥ 100 μs	Appendix 2/I.(I).4
Adaptive Frame Based non-FHSS using LBT		
Clear channel assessment	Before transmitting, ≥ 16 μs	Appendix 2/I.(II).1
Occupied channel access	After discovering that a channel is occupied: 1. Discontinue transmission of the next fixed frame at that channel frequency 2. Can perform Short Control Signaling on the occupied channel as long as duty cycle ≤ 10%	Appendix 2/I.(II).2 and 3
Channel holding time	1 ms ≤ time ≤ 10 ms	Appendix 2/I.(II).4
Channel idle time	≥ 5% of channel holding time	Appendix 2/I.(II).5
Adaptive Load Based non-FHSS using LBT		
Clear channel assessment	Before transmitting, ≥16 μs	Appendix 2/I.(III).1
Occupied channel access	After discovering that a channel is occupied: 1. Discontinue transmission 2. Reconduct channel reassessment until channel is not occupied 3. Can perform Short Control Signaling on the occupied channel as long as duty cycle ≤ 10%	Appendix 2/I.(III).2.(1) and (2)
Channel holding time	≤ 13 ms	Appendix 2/I.(III).3

Table 8.29: China MIIT 2021 No.129 breakdown, adaptivity parameters

8.5 Japan

The legal framework in Japan is the Japanese Radio Law (JRL), 1951 plus amendments. The conditions for placing an unlicensed product operating in the 2.4 GHz band are defined in Article 49.20 [17] together with more generic articles such as Article 5 (frequency tolerance), Article 6 (occupied bandwidth), and Article 14 (antenna power tolerances).

The legal framework defines the following modulation methods:

1. OFDM or spread spectrum system
2. Other modulation methods than (1)

In the spread spectrum method, the following is included:

a) Direct spreading (DSSS)
b) Frequency hopping (FHSS)
c) A combination of a) and b)
d) A combination of OFDM and frequency hopping

The power requirement for the two modulation methods makes it advantageous to certify as *OFDM or spread spectrum system* compared to *Other modulation methods than (1)*.

ARIB STD-T66 [1] is used to distinguish technical requirements for Bluetooth technology and other radio technologies from RFID equipment in the 2.471 MHz – 2.497 MHz band (covered in ARIB STD-33).

Frequency hopping is defined as when *the transmitted signal is a sequence of pulses at different frequencies over a large bandwidth.* This sequence is called a *frequency hopping pattern.*

8.5.1 Requirement breakdown

The requirements, broken down per modulation method, can be summarized in Table 8.30, with the JRL reference to the left and the STD reference to the right.

Requirement (Ordinance reference)	**Limits applicable to spread spectrum methods defined by JRL**				**STD Reference and Comments**
Modulation (49.20.B)	**DSSS**	**FHSS**	**FHSS (partial)**	**Other than SS**	FHSS and DSSS, defined in T66 3.2
Frequency allocation (49.20)	[2400, 2483.5]	[2400, 2483.5]	[< 2427, >2470.75]	[2400, 2483.5]	
Antenna power (49.20.1) (2)[39] (see Section 8.5.1.7)	10 mW/MHz OCBW ≤ 26 MHz 5 mW/MHz OCBW [> 26, < 38] MHz	3 mW/MHz	10 mW/MHz	10 mW	STD T66 3.2.(2) The regulation defines: 1: the maximum conducted output power (referred to in the regulation as 'antenna power' or 空中線電力) and 2: the maximum antenna gain separately
Antenna power tolerance (Article14) (see Section 8.5.1.7)	Upper limit: 20% Lower limit: 80%				STD T66 3.2.(3) This is allowable deviation between declared power and measured power on the low-, mid-, and high channels.
Antenna gain EIRP (49.20 1) f	Omnidirectional antenna 12.14 dBm/MHz	Omnidirectional antenna 6.91 dBm/MHz	Omnidirectional antenna 12.14 dBm/MHz	Omnidirectional antenna 12.14 dBm	STD T66 Annex 2, Table 4.1

[39] Note that this is mean power; tested with the intent that if the end user replaces the antenna, then radiated maximum power limits will not be exceeded.

<table>
<tr><th>Requirement (Ordinance reference)</th><th colspan="4">Limits applicable to spread spectrum methods defined by JRL</th><th>STD Reference and Comments</th></tr>
<tr><td></td><td>Directional antenna:
22.14 dBm/MHz</td><td>Directional antenna:
16.91 dBm/MHz</td><td>Directional antenna:
22.14 dBm/MHz</td><td></td><td></td></tr>
<tr><td>Absolute Antenna Gain
[49.20 1) f]
(see Section 8.5.1.9)</td><td colspan="4">≤ 12.14 dB, when an EIRP is less than a limit, the shortage is compensated for by the gain of the transmitting antenna.
When the effective radiated power is lower than or equal to the value obtained by applying an antenna power with the mean power of 10 mW within a bandwidth of 1 MHz to the transmitting antenna with its absolute gain being 2.14 dB, the shortage is compensated for by the gain of the transmitting antenna.</td><td>STD T66 3.6.(2).a</td></tr>
<tr><td>Half Power Beam Angle
(see Section 8.5.1.10)</td><td colspan="4">HPBA = angle between two points at which radiated power becomes 1/2 = 360 / A
A = EIRP / (2.14 dBi + Output Power (10 mW/MHz, 3 mW/MHz)).</td><td>STD T66 3.6.(2).b
When A < 1, HPBA will be 360° or less</td></tr>
<tr><td>Frequency Tolerance
(Article 5)
(see Section 8.5.1.4)</td><td colspan="4">± 50 ppm</td><td>STD T66 3.2.(4)
This is the difference in declared center frequency and the measured center frequency of the channel.</td></tr>
<tr><td>Permissible occupied bandwidth
(Article 6, Attached Table No. 2)
(see Section 8.5.1.5)</td><td colspan="4">≤ 83.5 MHz (99%)
Necessary bandwidth ≤ 26 MHz, if not FHSS, DS and FH hybrid or FH and OFDM hybrid</td><td>STD T66 3.2.(7)</td></tr>
<tr><td>Diffusion BW
[49-20 1) h]
(see Section 8.5.1.5)</td><td colspan="4">≥ 500 kHz
Defined as the bandwidth where 90% of the average radiated power in the occupied bandwidth (in MHz)
Applicable to FHSS and DSSS</td><td>STD T66 3.2.(8)
Referred to as Spread BW in the STD</td></tr>
<tr><td>Diffusion ratio
(49-20)
(see Section 8.5.1.5)</td><td colspan="4">(Diffusion BW / modulation rate of EUT) ≥ 5

Applicable to FHSS and DSSS</td><td>STD T66 3.2.(9)
Referred to as Process gain in the STD, may also be referred to as Spread Spectrum factor by some labs</td></tr>
<tr><td>Number of carriers
(49-20), OFDM only
(see Section 8.5.1.13)</td><td colspan="4">One or more carriers per 1 MHz bandwidth</td><td>STD T66 3.2.(10)</td></tr>
<tr><td>Frequency retention time
(49-20), FHSS only
(see Section 8.5.1.12)</td><td colspan="4">Frequency retention time ≤ 0.4 s
Calculated as [diffusion rate/channels used] x duty cycle x 0.4 s
Diffusion Rate = Spread BW / Data Rate</td><td>STD T66 3.2.(10)
(Requirement is ≤ 0.05 seconds for radio control transmitter of a model airplane used outdoors)</td></tr>
<tr><td rowspan="5">Spurious Emission intensity
(Article 7)
(see Section 8.5.1.6)</td><td colspan="4">Permissible mean power emission in the 1 MHz bandwidth</td><td>STD T66 3.2.(6)</td></tr>
<tr><td>30 MHz to 2387 MHz</td><td colspan="3">2.5 µW/MHz</td><td rowspan="4">–</td></tr>
<tr><td>2387 MHz to 2400 MHz</td><td colspan="3">25 µW/MHz</td></tr>
<tr><td>2483.5 MHz to 2496.5 MHz</td><td colspan="3">25 µW/MHz</td></tr>
<tr><td>2496.5 MHz to 12500 MHz</td><td colspan="3">2.5 µW/MHz</td></tr>
<tr><td>Secondary (Receiver) Radiated Emission Strength
(Article 24)
(see Section 8.5.1.8)</td><td colspan="4">< 1GHz ; 4nW
≥ 1GHz ; 20nW</td><td>STD T66 3.3 (1)
The standard says “Neither adjacent channel selectivity, intermodulation characteristic, nor spurious response are regulated.”</td></tr>
<tr><td>Interference protection</td><td colspan="4">>> NOTE >> General requirements, not tested</td><td>–</td></tr>
</table>

Requirement (Ordinance reference)	Limits applicable to spread spectrum methods defined by JRL	STD Reference and Comments
(see Section 8.5.1.11)		

Table 8.30: JRL requirement breakdown and respective STD T66 references

Any modulation with a Spread Spectrum Factor = (Spreading Bandwidth / symbol rate) ≥ 5 is considered Spread Spectrum modulation. Bluetooth BR/EDR and Bluetooth Low Energy both fulfill that requirement.

The power restrictions on spread spectrum modulation are specified as average power, distributed over the band by which the device operates in relationship to the symbol rate.

Which means that: $Antenna\ Power\ = \frac{AVG\ Power}{Spread\ Factor}$

Where

AVG Power = measured average power averaged over a set of bursts. It is important to note that this is the *average* power, not the peak power.

Spread Factor = measured Spread BW divided by symbol rate.

For FHSS modulation using the 2.4 GHz whole band, maximum declared antenna power must be no more than 3 mW/MHz. [40]

Regulation adds a power tolerance range of [-80%, +20%], which effectively makes the measured maximum antenna power allowed 3.6 mW/MHz (if declared antenna power is no more than 3 mW/MHz).

Which means that, $Max\ average\ measured\ power\ = \frac{Antenna\ Power \times 1.2 \times Spread\ BW}{Symbol\ Rate}$

For DSSS modulation, the maximum declared antenna power must be no more than 10 mW/MHz.

For other modulations, the maximum declared antenna power must be no more than 10 mW measured over 1 MHz.

One additional aspect to consider in JRL is the frequency retention time requirement. That in relationship to the spread bandwidth and the symbol rate leads to the maximum allowable duty cycle a device may have through the following function:

$$\left(\frac{Spread\ BW}{Symbol\ Rate}\right) \times Channels\ Used\ \times Duty\ Cycle\ \times 0.4s$$

For additional details on the maximum allowable duty cycle on the different types of modulation, see Section 8.5.1.3.

8.5.1.1 Applicable JRL test methods

The applicable test methods for ARIB STD-T66 [1] requirements are published in Appendix No. 43 [15], together with Appendix Number 1 [16], spurious emission or unnecessary emission intensity.

Appendix 43 [15] includes test methods for devices with an antenna connector (Sections 1 to 13 of Appendix Number 43) and test methods on devices with an integrated antenna (Sections 14 to 24 of Appendix Number 43). If there are samples with antenna connectors, then there is no restriction in the appendix that prevents some tests from being performed radiated.

[40] JRL provides a second antenna power limit of 10 mW/MHz for an FHSS implementation that excludes operation entirely in the sub-spectrum 2427 MHz – 2470.75 MHz.

JRL requirement	STD T66-requirement	EUT with antenna connector	EUT with integrated antenna	Notes
Frequency tolerance (see Section 8.5.1.4)	3.2.(4)	Section 3	Section 15	–
Occupied bandwidth Spread bandwidth (see Section 8.5.1.5)	3.2.(7), 3.2.(8)	Section 4	Section 16	–
Spurious emission intensity (see Section 8.5.1.6)	3.2.(6)	Section 5	Section 17	–
Antenna power tolerance (see Section 8.5.1.7)	3.2.(2), 3.2.(3)	Section 6	Section 18	–
Receive mode spurious emission (see Section 8.5.1.8)	3.3.(1)	Section 7	Section 19	–
Carrier sense function (applies to OFDM > 26 MHz and ≤ 38 MHz)	–	Section 8	Section 20	Not applicable to Bluetooth.
Carrier sense function	–	Section 9	Section 21	Not applicable to Bluetooth. Applies only to model aircraft used outdoors, excluding those using a frequency hopping system.
Absolute antenna gain (see Section 8.5.1.9)	3.6.(2).a	Section 10	N/A	This test is not applicable for transmission antennas of testing equipment with an absolute gain of < 2.14 dBi.
Transmission Radiation Angle Width (see Section 8.5.1.10)	3.6.(2).b	Section 11	Section 22	This test is not applicable for transmission antennas of testing equipment with an absolute gain of < 2.14 dBi.
Interference prevention function (see Section 8.5.1.11)	3.4.1.(1)	Section 12	Section 23	Basic test to verify that the device uses a 48-bit long MAC address.
Frequency retention time (see Section 8.5.1.12)	3.2.(10)	Section 13	Section 24	–

Table 8.31: Test methods, conducted/radiated, applicable to Bluetooth implementations

8.5.1.2 Max power in relationship to antenna power

Maximum output power is shown in Table 8.32 for declared output power and in Table 8.33 for tested output power.

Note: Occupied bandwidth and spread bandwidth are subject to measurement and therefore they may vary from the numbers used to illustrate what is possible for the various modes of operation.

	Occupied BW, MHz (99% PWR)	Spreading BW, MHz (90% PWR)	Spread Factor (Spreading BW/Symbol Rate)	Max Average, Possible Power, mW	Max Average, Possible Power, dBm
BR/EDR 79 channels, FHSS	79	71.1	71.1	100	20.0
BR/EDR 20 channels AFH, FHSS	20	18	18	54	17.3
LE 1M, FHSS	74	66.6	66.6	100	20.0
LE 2M, FHSS	74	66.6	33.3	99.9	20.0
LE 1M 15 channels AFH, FHSS	30	27	27	81	19.1
LE 2M 15 channels AFH, FHSS	30	27	13.5	40.5	16.1

Table 8.32: Max Average Power (Declared Antenna Power = 3 mW/MHz)

	Occupied BW, MHz (99% PWR)	Spreading BW, MHz (90% PWR)	Spread Factor (Spreading BW/Symbol Rate)	Max Average, Possible Power, mW	Max Average, Possible Power, dBm
BR/EDR 79 channels, FHSS	79	71.1	71.1	100	20.0
BR/EDR 20 channels AFH, FHSS	20	18	18	64.8	18.1
LE 1M, FHSS	74	66.6	66.6	100	20.0
LE 2M, FHSS	74	66.6	33.3	100	20.0
LE 1M 15 channels AFH, FHSS	30	27	27	97.2	19.9
LE 2M 15 channels AFH, FHSS	30	27	13.5	48.6	16.9

Table 8.33: Max Tested Power (Antenna Power = 3.6 mW/MHz)

8.5.1.3 Frequency retention time and duty cycle in relation to type of modulation

The relation between type of modulation and maximum possible duty cycle is shown in Table 8.34.

Note: Spread bandwidth is subject to measurement and therefore it may vary somewhat from the numbers used to illustrate what is possible for the various modes of operation over the LE PHY.

Modulation Types	LE 1M	LE 2M	LE 500k[41]	LE 125k[42]
Channels Used	37	37	37	37
Data Rata (Mb/s) (PHY symbol rate × coding)	1	2	0.5	0.125
Symbols per Bit	1	1	2	8
Bits per Symbol	1	1	0.5	0.125
Symbol Rate = $\frac{\text{Data Rate}}{\text{Bits per symbol}}$ MSym/s (Frequency equal to transmission rate of the modulation signal)	1	2	1	1
Assuming example values of measured Spread BW				
Spread BW (MHz) 90% PWR	79.5	75.5	79.5	79.5
Diffusion rate[43]=Spread BW/Frequency equal to transmission rate of the modulations signal	79.5	37.75	79.5	79.5
Results				
Frequency Retention Measurement period (s) (Diffusion Rate x 0.4 s)	31.8	15.1	31.8	31.8
Max Accumulated Retention Time (s) (Sum with Tx up to 0.4 s, on each channel)	14.8	14.8	14.8	14.8
Max Duty Cycle (Max Accumulated Time/ Measurement Period)	46.5%	98%	46.5%	46.5%

Table 8.34: Frequency retention time and max possible duty cycle on LE

Similarly, the possible duty cycle for the various modes of operation over the Bluetooth BR/EDR PHY is shown in Table 8.35.

Note: Spread bandwidth is subject to measurement and therefore it may vary somewhat from the numbers used to illustrate what is possible.

[41] LE Coded PHY with coding parameter S=2
[42] LE Coded PHY with coding parameter S=8
[43] This can also be referred to as spread factor, spread ratio, or process gain.

Modulation Types	**BR**	**EDR2**	**EDR3**
Channels Used	79	79	79
Data Rata (Mb/s) (PHY symbol rate × coding)	1	2	3
Symbols per Bit	1	1/2	1/3
Bits per Symbol	1	2	3
Symbol Rate = $\frac{\text{Data Rate}}{\text{Bits per symbol}}$ MSym/s (Frequency equal to transmission rate of the modulation signal)	1	1	1
Assuming example values of measured Spread BW			
Spread BW (MHz) 90% PWR	79.5	79.5	79.5
Diffusion rate=Spread BW / Frequency equal to transmission rate of the modulations signal [17]	79.5	79.5	79.5
Results			
Frequency Retention Measurement period (s) Diffusion Rate x 0.4 s	31.8	31.8	31.8
Max Acc Retention Time (s) Sum with Tx up to 0.4 s, on each channel	31.6	31.6	31.6
Max Duty Cycle (Max Acc Time/ Measurement Period)	99.4%	99.4%	99.4%

Table 8.35: Frequency retention time and max possible duty cycle on BR/EDR

8.5.1.4 Frequency tolerance

Definition: Stability measure of the frequency difference between the declared frequency and the measured frequency.

Requirement: STD-T66 3.2.(7) [1]. The frequency tolerance test case is directly measured using the frequency accuracy function of the Bluetooth tester or spectrum analyzer. The frequency error formula is:

$(f\text{-}fc)/fc^{*}\ 1 \times 10^{6}$ ppm with the limit < $\pm$50 ppm

Test Clause: Section 3 [15] on EUT with antenna connector. Section 15 [15] on EUT with integrated antenna.

Resolution BW: 3% or less of the channel bandwidth

Video BW: Same as resolution BW

Detector: Peak

EUT Operational Mode: Fixed frequency, CW

EUT channel measured: Low, Mid, High

8.5.1.5 Occupied bandwidth and spread bandwidth

Definition:

Occupied bandwidth: The permissible occupied bandwidth, which is the sum of the occupied bandwidths of the individual carriers in the band.

Spread bandwidth: Bandwidth with upper limit and lower limit such that each of the mean powers radiated above the upper frequency limit and below the lower frequency limit is equal to 5% of the total mean radiated power.

Process gain: Spread bandwidth / modulation rate of the EUT

Requirement:

Occupied Bandwidth STD-T66 3.2.(7) [1]

1. Frequency Hopping Mode: 83.5 MHz
2. If not FHSS: 26 MHz

Spread Bandwidth: 500 kHz or more, STD T66 3.2.(8) [1]

Process gain[44]: ≥ 5, STD T66 3.2.(8) [1]

Test Clause: Section 4 [15] on EUT with antenna connector. Section 16 [15] on EUT with integrated antenna.

Resolution BW: 1% to 5% OBW

Video BW: 3x Resolution BW

Detector: Peak

EUT Operational Mode: Perform with EUT on one tested channel at a time. All modulation schemes, maximum duty cycle, data rates, and power settings to observe the worst-case configuration in each nominal bandwidth.

EUT channel measured: Low, Mid, High

8.5.1.6 Spurious emission intensity

Definition: Permissible mean power emission in the 1 MHz bandwidth.

Requirement:

Frequency Range (MHz)	Emissions µW/MHz (dBm/MHz equivalent)	Test Equipment Setting
30–2387	2.5 (-26)	Peak detect, Max hold < 1000 MHz: RBW/VBW: 100/300 kHz > 1000 MHz: RBW/VBW: 1/3 MHz
2387–2400	25 (-16)	RBW/ VBW: 1/3 MHz
2483.5–2496.5	25 (-16)	RBW/ VBW: 1/3 MHz
2496.5–12500	2.5 (-26)	RBW/ VBW: 1/3 MHz

Table 8.36: Spurious emission intensity according to STD T66 3.2.(6)

Test Clause: Section 5 [15] on EUT with antenna connector. Section 17 [15] on EUT with integrated antenna.

Resolution BW: 1 MHz

Video BW: 3x Resolution BW

EUT Operational Mode: Perform with EUT on one tested channel at a time. All modulation schemes, maximum duty cycle, data rates, and power settings to observe the worst-case configuration in each nominal bandwidth.

EUT channel measured: Low, Mid, High

8.5.1.7 Antenna power and antenna power tolerance

Definition:

Antenna Power: The average power, distributed over the band by which the device operates in relation to the symbol rate.

Antenna Power Tolerance: The tolerance between declared maximum antenna power and measured maximum and minimum antenna power.

[44] This may also be referred to as Diffusion Ratio or Spread Factor at times.

Requirement:

Antenna Power: STD T66 3.2.(2) [1]

1. Frequency Hopping Spread Spectrum 3 mW/MHz (for equipment used in the range of 2427 MHz – 2470.75 MHz)[45]
2. Direct Sequence Spread Spectrum 10 mW/MHz
3. OFDM with OBW ≤ 26 MHz
4. Other than for spread spectrum systems 10 mW/MHz

Antenna Power Tolerance: +20%, -80%, STD T66 3.2.(3) [1]

Test Clause: Section 6 [15] on EUT with antenna connector. Section 18 [15] on EUT with integrated antenna.

Resolution BW: 1 MHz

Video BW: 1 MHz

Detector: Peak, Max Hold

EUT Operational Mode: Perform with EUT on one tested channel at a time. All modulation schemes, maximum duty cycle, data rates, and power settings to observe the worst-case configuration in each nominal bandwidth.

8.5.1.8 Receive mode spurious emission

Definition: Emissions at any frequency when the equipment is in receive mode [46]

Requirement: STD T66 3.3.(1) [1]

Frequency range (MHz)	Limit (dBm equivalent)	Resolution Bandwidth (kHz)
30–1000	4 nW (-54 dBm)	100
> 1000	20 nW (-47 dBm)	1000

Table 8.37: Receiver Spurious Emissions according to STD T66 3.3 (1)

Test Clause: Section 7 [15] on EUT with antenna connector. Section 19 [15] on EUT with integrated antenna.

EUT Operational Mode: Tested on all modulation schemes.

1. Measurements may be performed when normal hopping is disabled, with EUT on one tested channel at a time.
2. Otherwise, the measurement is performed during normal operation (hopping).

EUT channel measured: Low, Mid, and High

8.5.1.9 Absolute antenna gain

Definition: The transmission gain of an antenna in dBi

Applicability: This is not applicable if the EIRP power of EUT is lower than 12.14 dBm/MHz.

Requirement: STD T66 3.6.(2).a [1]

[45] JRL provides a second antenna power limit of 10 mW/MHz for an FHSS implementation that excludes operation entirely in the sub-spectrum 2427–2470.75 MHz. This is not a requirement relevant to Bluetooth.

[46] The standard says *"Neither adjacent channel selectivity, intermodulation characteristic, nor spurious response are regulated.*

Item	Limits
EIRP Power Density	≤ 6.91 dBm/MHz (FHSS form 2400 MHz – 2483.5 MHz) ≤ 12.14 dBm/MHz (OFDM, DS from 2400 MHz – 483.5 MHz) ≤ 12.14 dBm (Other from 2400 MHz – 2483.5 MHz)

Table 8.38: Transmission Antenna Gain according to STD T66 3.6.(2).a

Test Clause: Section 10 [15] on EUT with antenna connector

EUT Operational Mode: Tested with normal hopping disabled, with EUT on one tested channel at a time

EUT channel measured: Low, Mid, and High

Resolution BW: 1 MHz

Video BW: 1 MHz

Detector: Positive Peak, Continuous sweep

8.5.1.10 Transmission radiation angle width (3 dB beamwidth)

Definition: The angle of the half-power beam width

Applicability: This test is not applicable for transmission antennas of testing equipment with absolute gain of less than 2.14 dBi.

Requirement: STD T66 3.6.(2).b [1]

Item	Limits
3 dB antenna beamwidth	360/A (If A < 1; then A = 1) A = {EIRP Power [mW] / 16.36 for DS, OFDM}, or A = {EIRP Power [mW] / 4.9 for FHSS}

Table 8.39: Half Power Beam Angle according to STD T66 3.6.(2).b

Test Clause: Section 11 [15] on EUT with antenna connector. Section 22 [15] on EUT with integrated antenna.

Resolution BW: 1 MHz

Video BW: 1 MHz

Detector: Positive peak

EUT Operational Mode: Tested with normal hopping disabled, with EUT on one tested channel at a time

EUT channel measured: Low, Mid, High

8.5.1.11 Interference prevention function

Definition: Identification code transmission/reception

Requirement: STD T66 3.6.(2).b [1], basic test to verify that the device uses an identification code ≥ 48-bits.

Test Clause: Section 12 [15] on EUT with antenna connector. Section 23 [15] on EUT with integrated antenna.

EUT Operational Mode: Normal operation with companion device

8.5.1.12 Frequency retention time

Definition: Average channel occupancy that is the total of the transmitter 'on' times, during an observation period, on a particular hopping frequency.

In JRL, it is defined as $\left(\frac{Spread\ BW}{Symbol\ Rate}\right) \times Channels\ Used\ \times Duty\ Cycle\ \times 0.4\ s$

Requirement: STD T66 3.2.(10) [1], ≤ 0.4 s

See also Section 8.5.1.3 for details about the measurement period for each of the utilized modulation options.

Test Clause: Section 13 [15] on EUT with antenna connector. Section 24 [15] on EUT with integrated antenna.

Resolution BW: 1 MHz

Video BW: 1 MHz

Detector: Positive peak, single sweep

EUT Operational Mode: Tested on all modulation schemes and data rates with a companion device and with EUT on one tested channel at a time

EUT channel measured: All channels

8.5.1.13 Tests not applicable to Bluetooth technology

The following tests in Appendix 43 do not apply to Bluetooth technology:

Carrier sense function, OFDM > 26 MHz and ≤ 38 MHz

With antenna connector: Section 8

With Integrated Antenna: Section 20 [15]

Carrier sense function, modulation other than FHSS for model aircraft outdoors

With antenna connector: Section 9

With Integrated Antenna: Section 21 [15]

8.5.1.14 Test and EUT conditions table

STD T66-requirement clause #	Appendix 43 Conducted/Radiated Test Clauses	Channels Tested	Modulations	EUT Operational mode
Frequency tolerance #3.2.(4) (see Section 8.5.1.4)	Sect.3/Sect.15	Low, Mid, High	CW only	EUT on fixed frequency.
Occupied bandwidth and spread bandwidth #3.2.(7), #3.2.(8) (see Section 8.5.1.5)	Sect.4/Sect.16	Low, Mid, High	All modulations	EUT on fixed frequency transmitting modulated carrier. Representative maximum duty cycle, data rates, and maximum power settings.
Spurious emission intensity #3.2.(6) (see Section 8.5.1.6)	Sect.5/Sect.17	Low, Mid, High	All modulations	EUT on fixed frequency transmitting modulated carrier. Representative maximum duty cycle, data rates, and maximum power settings.

STD T66-requirement clause #	Appendix 43 Conducted/Radiated Test Clauses	Channels Tested	Modulations	EUT Operational mode
Antenna power and Antenna power tolerance #3.2.(2), #3.2.(3) (see Section 8.5.1.7)	Sect.6/Sect.18	All	All modulations	Frequency hopping. All modulation schemes, maximum duty cycle, data rates, and power settings to observe the worst-case configuration.
Receive mode spurious emission #3.3.(1) (see Section 8.5.1.8)	Sect.7/Sect.19	Low, Mid, High	All modulations	Test may be performed when normal hopping is disabled, with EUT on one tested channel at a time. Otherwise, the measurement is performed during normal operation (hopping).
Absolute Antenna Gain #3.6.(2).a (see Section 8.5.1.9)	Sect.10/n/a	Low, Mid, High	CW only	Tested with normal hopping disabled, EUT on one tested channel at a time. Test not applicable to EUTs with absolute gain antennas < 2.14 dBi.
Transmission Radiation Angle Width (3 dB Beamwidth) #3.6.(2).b (see Section 8.5.1.10)	Sect.11/Sect.22	Low, Mid, High	CW only	Tested with normal hopping disabled, with EUT on one tested channel at a time. Test not applicable to EUTs with absolute gain antennas < 2.14 dBi.
Interference prevention function #3.4.1.(1) (see Section 8.5.1.11)	Sect.12/Sect.23	–	All modulations	Normal operation with companion device. Basic test to verify that the device uses a MAC address that is at least 48 bits long.
Frequency retention time (#4.3.1.8) (see Section 8.5.1.12)	Sect.13/Sect.24	All channels	All modulations	Normal operation with companion device with most demanding data rate. Tests EUT on one tested channel at a time.

Table 8.40: STD T66 requirements, Appendix 43 tests clauses and EUT conditions

8.6 Korea

All electrical/electronic/radio products entering Korea are subject to KC (Korea Certification). A radio transmitter in an ISM band must go through conformity certification according to the Korean Radio Waves Act. Bluetooth products are required to have KC-certification for RF and EMC and may, depending on the type of product, also be subject to additional certification not related to RF, such as KC Safety. KC-RF and KC-EMC certification is under the jurisdiction of the Ministry of Science and ICT (MSIT).

The National Radio and Research Agency (RRA) is the entity under MSIT that reviews certification applications, designates testing laboratories, and grants certifications to applicants whose RF devices are compliant with the applicable standards and regulations.

To achieve KC Safety EMC + RF Certification, a product must follow these steps (see also: https://ccac.rra.go.kr/en/view/sub201010.jsp)

1. Application for KC certification
2. Product testing in Korea (required for KC RF, while KC EMC testing may be done by a lab abroad provided it is accredited for such testing)
3. Assessment and certificate issued by RRA
4. Labeling according to KC labeling requirements, see: http://www.kats.go.kr/kcmark

The technical requirements applicable to KC-RF certification of devices operating in the 2.4 GHz band can be found in Chapter 7 of notice MSIT 2022-20 [20]. Receiver emission requirements are defined in Radio Equipment Rules Article 12(1). The applicable test methods are defined in Annex P *Test method for equipment working on the 2.4 GHz band and using frequency hopping spectral method* within KS X 3123 *Wireless equipment conformity evaluation test method* [21].

In Korea, the limiting factor for FHSS operation is average power distributed over the band used by the hopper ≤ 3 mW/MHz, while the maximum output power levels are not explicitly defined.

Note: A device with output power < 10 mW may also be certified as using modulation other than spread spectrum, although certification as a FHSS device is the preferred type of certification for types of modulation.

8.6.1 Requirement breakdown

Requirement	**Limit**	**Test Clause, KS X 3123 [21]**
Common requirements (clause 2) in [20]		
Frequency tolerance (see Section 8.6.2)	≤ 50 ppm	P.2.1.2.1 or P.2.1.2.2
Antenna absolute gain	± 6 dBi	P.2.1
Out of band transmitter emissions [20] (see Section 8.6.5.1)	≤ -30 dBm/100 kHz	P.2.4.2.1
Spurious domain transmitter emissions (excluding OOB) (see Section 8.6.5.2)	–	P.2.4.2.2
Receiver Emissions Radio Equipment Rules Article 12(1) (see Section 8.6.6)	≤ -54 dBm	P.2.5
FHSS (clause 3) in [20]		
Antenna power (mW/MHz) (see Section 8.6.3)	≤ 3 mW/MHz, average power divided by the band used in hopping	P.2.2
Occupied bandwidth (see Section 8.6.4)	≤ 5 MHz hopping channel occupied bandwidth	P.2.3
Dwell time (see Section 8.6.8)	≤ 0.4 s on one hopping channel	P.2.7

Requirement	**Limit**	**Test Clause, KS X 3123** [21]
Number of hopping channels (see Section 8.6.7)	≥ 15 with the exception of the channels for connection	P.2.6
Hopping channel separation	Channel hops should not overlap each other	No explicit test
Hopping distribution	Pseudorandom and should be uniformly hopping over the entire band, except for when a carrier-detect function finds that some channels are unavailable	No explicit test
Other than spread spectrum (clause 4) in [20]		
Power (ERP)	≤ 10 mW	D.5.3[47]
Occupied Bandwidth (OBW)	< 26 MHz	D.3.3[47]
DSSS/Chirp Spread Spectrum (including in combination with FHSS or OFDM) (clause 2)		
Power (ERP)	≤ 10 mW	D.5.3[47]
Power spectral density (mW/MHz) versus OBW (MHz)	≤ 10: 0.5 ≤ OBW ≤ 26 ≤ 5: 26 < OBW ≤ 40 ≤ 2.5: 40 < OBW ≤ 80 ≤ 0.1: 40 < OBW ≤ 60	D.3.3[47]

Table 8.41: KC-RF requirement breakdown and the respective KS X 3123 test clause

8.6.2 Frequency tolerance

Requirement: Within ± 50 ppm

Test Clause:

P.2.1.2.1 (EUT on fixed frequency, CW) in [21], or

P.2.1.2.2 (EUT in normal hopping mode) in [21]

Measurement settings

1. P.2.1.2.1 [21] Resolution BW: ≤ 5 kHz, Video BW > 3x Resolution BW, Peak detect
2. P.2.1.2.2 [21] Resolution BW: 1% to 3% of the channel bandwidth or less, Video BW: > 3x Resolution BW, Peak detect

EUT channel measured: Low, Mid, High

8.6.3 Antenna power

Definition: Power supplied to the antenna connector

Test Clause:

P.2.2.2.1 in [21], conducted using a spectrum analyzer, or

P.2.2.2.2 in [21], conducted using a power meter.

EUT Operational Mode: The two different test methods allow for testing either with hopping off or in regular operation with a companion device.

All modulation schemes and data rates, maximum duty cycle, and maximum power settings to observe the worst-case configuration in each nominal bandwidth.

EUT channel measured: Low, Mid, and High

[47] Not explicitly covered in this document.

8.6.3.1 P.2.2.2.1 measured using a spectrum analyzer

Measure average power over the burst and divide by the band used in hopping.

Resolution BW: Channel bandwidth

Video BW: > 3x Resolution BW

Detector: RMS

Sweep time: Burst duration

8.6.3.2 P.2.2.2.2 measured using a power meter

1. Measure average power (AVG) in the burst.
2. Calculate BRST AV = AVG * (Burst Period / Burst Width).
3. Divide BRST AV by the band used in hopping.

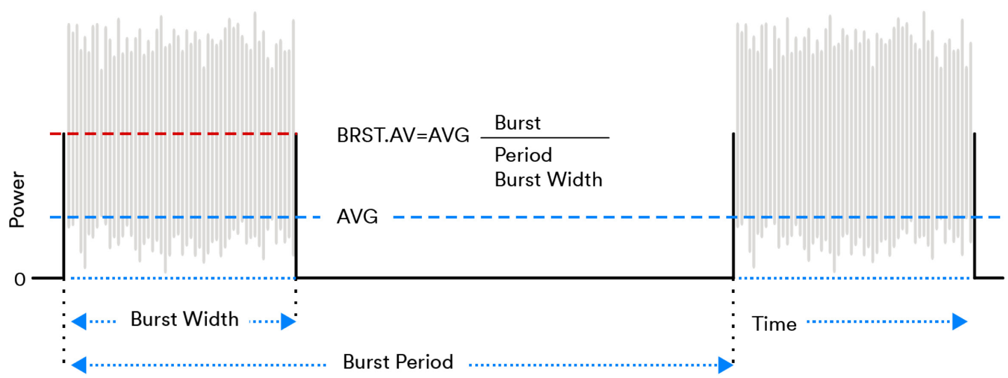


Figure 8.2: KS X 3123 P.2.2.2.2, Average power measurement within the burst duration

8.6.4 Occupied bandwidth

Test Clause: P.2.3 in [21]

Resolution BW: 1% to 3% of OBW

Video BW: 3 x Resolution BW

Detector: Peak, Max Hold

EUT Operational Mode: This may be tested with hopping off or in regular operation with a companion device. Perform with EUT on one tested channel at a time. All modulation schemes, maximum duty cycle, data rates, and power settings to observe the worst-case configuration in each nominal bandwidth.

EUT channel measured: Low, Mid, and High

8.6.5 Allowable emission levels

EUT Operational Mode: This may be tested with hopping off or in regular operation with a companion device. All modulation schemes, maximum duty cycle, data rates, and power settings to observe the worst-case configuration in each nominal bandwidth.

EUT channel measured: Low, Mid, High

8.6.5.1 Out of band transmitter emissions

Test Clause: P.2.4.2.1 in [21]

The spectrum analyzer used as follows:

1. Set up to sweep from the end of the hopping frequency band to ±250% of the required frequency bandwidth with a 100 kHz resolution.
2. The marker is moved to a maximum measurement value and the measurement value is recorded.
3. If the peak value exceeds the limit, the specification analyzer may be set to measure the peak value.

Resolution BW: 100 kHz, or less; if so, convert to a value over 100 kHz

Video BW: >3x Resolution BW

Detector: Peak. If the peak value exceeds the limit, then set detector to RMS.

EUT Operational Mode: This may be tested with hopping off or in regular operation with a companion device. Perform with EUT on one tested channel at a time. All modulation schemes, maximum duty cycle, data rates, and power settings to observe the worst-case configuration in each nominal bandwidth.

EUT Channels Measured: Low, Mid, High

8.6.5.2 Spurious domain transmitter emissions (excluding OOB)

Test Clause: P.2.4.2.2 in [21]

Resolution BW: 100 kHz

Video BW: > 3x Resolution BW

Detector: Peak, Max Hold. If the peak value exceeds the limit, then set detector to RMS.

EUT Operational Mode: This may be tested with hopping off or in regular operation with a companion device. Perform with EUT on one tested channel at a time. All modulation schemes, maximum duty cycle, data rates, and power settings to observe the worst-case configuration in each nominal bandwidth.

EUT channel measured: Low, Mid, High

8.6.6 Receiver emissions

Test Clause: P.2.5 in [21]

Resolution BW/Video BW:

Measurement frequency	RBW (kHz)	VBW (kHz)
< 1000 MHz	100	> 300
≥ 1000 MHz	1000	> 3000

Table 8.42: KS X 3123 P.2.5 Receiver emissions test, resolution bandwidth and video bandwidth

Detector: Peak, Max Hold. Sweep over 30 MHz to 12.75 GHz.

EUT Operational Mode: EUT in standby state, ready to receive. This may be tested with hopping off or in regular operation mode.

EUT channel measured: Low, Mid, High

8.6.7 Number of hopping channels

Test Clause: P.2.6 in [21]

Resolution BW: 100 kHz

Video BW: > 3x Resolution BW

Detector: Peak, Continuous sweep, Max hold Sweep over 2400 MHz to 2500 MHz

EUT Operational Mode: This may be tested with hopping off or in regular operation with a companion device. All modulation schemes and data rates.

8.6.8 Dwell time

Test Clause: P.2.7 in [21]

Resolution BW: > channel bandwidth

Video BW: 3x Resolution BW

Detector: Peak, Max Hold. Sweep over at least two burst cycles.

EUT Operational Mode: This may be tested with hopping off or in regular operation with a companion device. All modulation schemes and data rates with maximum duty cycle.

EUT channel measured: Low, Mid, High

8.6.9 KC-RF test and EUT conditions table (summary)

Requirement	Test Clause, KS X 3123 [21]	Channels tested	Modulations	EUT Operational mode
Frequency tolerance (see Section 8.6.2)	1. EUT on fixed frequency, CW or 2. EUT in normal hopping mode	Low, Mid, High	CW or modulated carrier	Fixed frequency, CW, or normal hopping
Antenna Power (mW/ MHz) (see Section 8.6.3)	1. With spectrum meter, or 2. With spectrum analyzer	Low, Mid, and High	All modulations	All data rates, maximum duty cycle, and maximum power. Fixed frequency with modulated carrier or in normal operation with companion device.
Occupied bandwidth (see Section 8.6.4)	P.2.3	Low, Mid, High	All modulations	All data rates, maximum duty cycle, and maximum power. Fixed frequency with modulated carrier or in normal operation with companion device.
Out of band transmitter emissions (see Section 8.6.5.1)	P.2.4.2.1	Low, High	All modulations	All data rates, maximum duty cycle, and maximum power. Fixed frequency with modulated carrier or in normal operation with companion device.
Spurious domain transmitter emissions (excluding OOB) (see Section 8.6.5.2)	P.2.4.2.2	Low, Mid, High	All modulations	All data rates, maximum duty cycle, and maximum power. Fixed frequency with modulated carrier or in normal operation with companion device.
Receiver Emissions (see Section 8.6.6)	P.2.5	–	–	EUT in standby state, ready to receive. This may be tested with hopping off or in regular operation mode.
Number of hopping channels (see Section 8.6.7)	P.2.6	All channels	All modulations	All data rates, maximum duty cycle, and maximum power. Fixed frequency with modulated carrier or in normal operation with companion device.
Dwell time (see Section 8.6.8)	P.2.7	Low, Mid, High	All modulations	All data rates, maximum duty cycle, and maximum power. Fixed frequency with modulated carrier or in normal operation with companion device.

Table 8.43: KC-RF requirements, KS X 3123 test clauses and EUT operational modes

9 LE Audio Device Testing

This section provides further guidance for testing the specific device configurations of LE Audio devices, the limits generated by the regulatory requirements referenced in Table 9.1, and the configuration's adherence to the generated limits.

The Basic Audio Profile (BAP) of LE Audio supports many configuration options. This section shows the types of considerations, using selected unicast and broadcast audio configurations as examples. If other configurations are used, equivalent duty cycle calculations must be made.

A Public Auracast™ Transmitter is required to broadcast a Standard Quality Public Audio Broadcast stream. The UA_16_2_1 configuration in BAP is an example of a Standard Quality Public Audio Broadcast stream. Similarly, the BC_48_2_2 configuration corresponds to a Public Auracast™ Transmitter High Quality Public Audio Broadcast. Duty cycle calculations for these configurations are shown in Section 9.2 and Section 9.3, respectively.

For other possible configurations that can be chosen for both Standard and High Quality, the equations supplied in this section can be used for duty cycle calculations.

If multiple isochronous streams are supported, the duty cycles must be summed for the maximum number of streams to determine the worst-case duty cycle limit.

In addition, if extended advertising of the available streams and periodic advertising of stream configuration information are used (as is required for a Public Auracast™ Transmitter), they must also be added to determine the worst-case duty cycle limit. With respect to EU requirements discussed in Sections 8.2.4.3 and 8.2.5.8, particular attention is called to the fact that extended advertising, periodic advertising, and isochronous communication may use the general-purpose channels in different ways (see Sections 7.6.2.3.1, 7.6.3.2, 7.6.5.2.2 and 7.6.5.3.2).

9.1 Duty cycle dependent requirements

Certain region-specific regulatory requirements result in effective duty cycle limitations.

Table 9.1 shows identified duty cycle dependent regulatory requirements for each region.

Region	Requirement	Duty cycle limit
US / Canada (FCC / RSS) (see Section 8.3)	Average channel occupancy (FHSS) (see Section 8.3.3.7)	Table 9.2
Europe (see Section 8.2)	Adaptive FHSS using DAA (see Section 8.2.4.6.2)	Table 9.2
	Accumulated Transmit Time, Frequency Occupation and Hopping Sequence (see Section 8.2.4.3)	Table 9.2
Japan (see Section 8.5)	Frequency Retention Time (see Section 8.5.1.3)	Table 9.2

Table 9.1: Duty cycle dependent tests per region

The Average Channel Occupancy (FHSS), Accumulated Transmit Time, Frequency Occupation and Hopping Sequence, and Frequency Retention Time tests require an EUT to demonstrate a maximum accumulated transmission time on any given channel.

The test observation window length is a function of the number of channels used in the Average Channel Occupancy (FHSS) and Accumulated Transmit Time, and Frequency Occupation and Hopping Sequence tests.

The test observation window length in the Frequency Retention Time test is a function of the number of channels, the spreading bandwidth (the bandwidth of the lowest to highest channel centers), and symbol rate used on the PHY (which corresponds to the 'transmission rate of the modulation signal' in the Japanese regulations); see also Section 8.5.1.3.

Table 9.2 shows the summary of the different test observation window lengths for each of the Bluetooth PHYs and the number of channels used, and the corresponding duty cycle limit that would apply to the Bluetooth PHY when testing to the applicable regulatory requirement in a general sense (that is, the maximum duty cycle that could be used with a particular PHY and number of channels before breaching the test limit). For Europe, the limits listed in the table assume that the device fits the definition of Adaptive FHSS using DAA.

The maximum duty cycles actually used by some example configurations consisting of two LE Audio streams are shown in Sections 9.2 and 9.3.

Test	PHY	Number of channels	Observation window length (s)	Duty cycle limit (%)
Average channel occupancy (FHSS) (see Section 8.3.3.7)	BR/EDR (All)	79	31.6	100
	LE (All)	37	14.8	100
Accumulated Transmit Time, Frequency Occupation and Hopping Sequence (see Section 8.2.4.3)	BR/EDR (All)	79	6	100
	LE (All)	37	6	100
Frequency retention time (see Section 8.5.1.12)	BR/EDR 1 Mb/s	79	31.8	99.3
	BR/EDR 2 Mb/s	79	30.2	100
	BR/EDR 3 Mb/s	79	30.2	100
	LE 1 M (1 Mb/s) LE Coded S=2 (500 kb/s) LE Coded S=8 (125 kb/s)	37	31.8	46.5
	LE 2 M (2 Mb/s)	37	15.1	98

Table 9.2: Duty cycle dependent tests: limits

The following table explains the format and meaning of the Host and Controller parameters used in Sections 9.2 and 9.3.

Host/Controller	Parameter	Description
Host	CIS	Number of isochronous streams being transmitted by the device
Host	BR	Bitrate in kbps of the isochronous channel
Host	SDU	Size in octets of the audio payload transmitted on the isochronous channel
Host	SDU_{INT}	SDU interval in ms
Host	RTN_{HOST}	Host Retransmission Number (RTN) request, the maximum number of times the first PDU should be retransmitted
Controller	ISO_{INT}	Isochronous interval in ms
Controller	NSE	Number of isochronous subevents per isochronous interval per CIS
Controller	BN	Burst Number, the number of new payloads sent from the Host in each isochronous interval
Controller	FT	Flush Timeout (unicast only), used with BN to control which data is transmitted in a CIS event
Controller	RTN_{AVG}	Controller average Retransmission Number, the maximum number of times each PDU should be retransmitted on average (corresponds to the maximum duty cycle possible when all PDUs are retransmitted RTN_{AVG} times)
Controller	PTO	Pre-transmission Offset (broadcast only), associated broadcast data with future transmission events (BIS events)
Controller	IRC	Immediate Repetition Count (broadcast only), used with PTO to determine which data is associated with the current BIS event

Table 9.3: Host and Controller parameters

9.2 BAP unicast audio streaming configurations

Table 9.4 shows an example unicast configuration that uses the LC3 codec and the LE 2M PHY and that is identified by the Set Name from Table 5.2.in BAP (prefixed by UA for *Unicast Audio*).

Configuration	Host Parameters					Controller Parameters					Max duty cycle %
	CIS	BR	SDU	SDU_{INT}	RTN_{HOST}	ISO_{INT}	NSE	BN	FT	RTN_{AVG}	
UA_16_2_1	2	32	40	10	2	10	3	1	2	2	13.2

Table 9.4: LE Audio configurations

9.3 Broadcast audio streaming configurations

Table 9.5 shows the LE Audio configurations for Broadcast use cases.

All broadcast configurations shown use the LC3 codec and the LE 2M PHY, identified by the Set Name and Recommendation number in Table 6.5 of the BAP specification.

Configuration	Host Parameters					Controller Parameters						Max duty cycle %
	BIS	BR	SDU	SDU_{INT}	RTN_{HOS}	ISO_{INT}	NSE	BN	IRC	PTO	RTN_{AV}	
BC_48_2_2 (Rec.1)	2	80	100	10	4	30	9	3	2	1	2	27.6
BC_48_2_2 (Rec.2)	2	80	100	10	4	10	5	1	1	1	4	46
BC_48_2_2 (Rec.3)	2	80	100	10	4	20	8	2	2	1	3	36.8

Table 9.5: LE Audio Broadcast configurations

9.4 Testing configurations for LE Audio

Although the tests in Table 9.1 are referred to as duty-cycle dependent, the duty cycle itself is not the figure of merit; rather, it is the EUT's *accumulated transmission time* on a channel that is observed. The accumulated transmission time is summed during a test and compared to a limit, which determines whether the EUT passes the test. The per-channel accumulated transmission time is a function of the duty cycle, the number of hopping channels in use, and the EUT's frequency hopping implementation. For a given number of channels and duty cycle, the randomness of the frequency hopping implementation determines the number of times the EUT will hop to a particular channel, and the duty cycle will determine whether the EUT transmits on the channel currently occupied.

Radio test modes do not exercise the frequency hopping implementation of the EUT; instead, they use either a predefined sequential hopping sequence (hopping from a lower channel to the next higher channel, or vice versa) or remain on a single channel. Their usage to determine regulatory compliance to the tests in Table 9.1 will not generate results that are representative of normal operation. When testing this, the EUT should be in a connection with a companion device or in its broadcast mode, both of which exercise the EUT's frequency hopping implementation.

Regulatory testing typically requires the worst-case duty cycle configuration to be tested and observed by a tester. For unicast, this will only occur when the connection between the EUT and companion device suffers high enough packet loss to cause all configured retransmission opportunities to be used. It is impractical to attempt to test devices reliably and repeatably in a high packet loss environment, therefore the EUT vendor should select the worst-case duty cycle configuration supported in Section 9.2 and Section 9.3 and test that configuration by executing the test for the broadcast configuration in Table 9.11: Broadcast ISO parameters for LE Audio configs that achieves the same duty cycle, because broadcast retransmissions are unconditional. When using broadcast configurations, there is no requirement to use a companion device; the tester can observe transmissions from the EUT directly.

RTN_{HOST} in Equation 2 represents the maximum number of retransmissions of the first PDU, with maximum duty cycle occurring when all configured retransmission opportunities are used (that is, when there are *NSE* PDU transmissions per isochronous event).

This is shown as RTN_{AVG} and expressed in Equation 1 as:

$$RTN_{AVG} = \frac{NSE}{BN} - 1$$

Equation 1

For example, the worst-case duty cycle for the UA_16_2_1 configuration in Table 9.4: LE Audio configurations would occur when:

$$RTN_{HOST} = \frac{3}{1} - 1 = 2$$

Equation 2

That is, in the three subevents (NSE=3) each packet ends up being transmitted three times (one transmission and two retransmissions).

Maximum duty cycle in Sections 9.5.1 through 9.5.3 refers to the entire system and is expressed as a percentage and calculated as:

$$SystemDutyCycle = \frac{Tx\_time_{PDU} \times NSE \times Num\_BIS}{ISO\_interval} \times 100$$

$$\text{Where } Tx\_time_{PDU} = Tx\_time_{Overhead} + Tx\_time_{Payload}$$

Equation 3

And where the following applies:

PHY	Tx_timePayload (µs)	Tx_timeOverhead (µs)
LE 2M	4 * SDU	60

Table 9.6: Bluetooth LE PHY transmission times

The expected results in Section 9.5 derive the accumulated transmission time on any given channel during regulatory testing, which is expressed as:

$$PerChannelTransmitTime = \frac{SystemDutyCycle}{NumberOfChannels} \times ObservationWindowLength$$

Equation 4

9.5 Duty cycle dependent tests and expected results

This section lists the approximate expected results for each of the duty cycle dependent regulatory tests when testing LE Audio devices. The expected results are an idealized set of figures that assume idealized behavior from the EUT such as a perfectly random hopping sequence. In practice, real-world results will likely differ depending on implementation differences but are generally expected to a represent a reasonable approximation.

9.5.1 Average channel occupancy (FHSS) expected results

Table 9.7 shows the expected results for the Average channel occupancy (FHSS) test in Section 8.3.3.7.

Configuration	Test duty cycle %	Average channel occupancy (FHSS) limit, s	Expected Average channel occupancy (FHSS), s
UA_16_2_1	13.2	0.4	0.0533

BC_48_2_2 (Rec.1)	27.6	0.4	0.1095
BC_48_2_2 (Rec.2)	46	0.4	0.1835
BC_48_2_2 (Rec.3)	36.8	0.4	0.148

Table 9.7: Duty cycle test: Average channel occupancy (FHSS) expected accumulated transmit time results

9.5.2 Adaptive FHSS using DAA expected results

Table 9.8 shows the expected *limits* for the Adaptive FHSS using DAA test in Section 8.2.4.6.2 for examples using LE 2M PHY with the only traffic at the air interface comprising the broadcast isochronous streams configured. The reaction time limit is calculated assuming 37 LE 2M channels free from interference at the start of the test. The expected silent period limit is calculated for the EUT assuming five channels are unavailable in response to interference, resulting in 32 remaining channels using LE 2M.

It is not feasible to predict actual reaction time or silent period results because the adaptive frequency hopping (AFH) channel classifier is sensitive to environmental conditions (that is, in addition to the interferer introduced during the test, there might be other unexpected effects and/or interference sources present during the test that might affect the overall test result, for example by reducing the number of used channels before or during the test). The reaction time limit and expected silent period limits are shown here to aid in collection of test results.

Note: Extended and periodic advertising might take place in parallel with the isochronous stream transmission (e.g. for public Auracast), and BIG Control PDUs might be included in the isochronous stream transmission. If they do contribute meaningfully to the overall duty cycle of the system then they need to be factored into the reaction time and silent time limits.

Note: Real-world testing might see slightly more or less channels unavailable depending on how well shielded the test environment is from external interference sources, which would influence the reaction time and silent period limits.

The reaction time and silent period time are derived in Section 8.2.4.14.

Configuration	Test duty cycle, %	Expected Adaptive FHSS using DAA reaction time limit, s	Expected Adaptive FHSS using DAA silent period limit, s
UA_16_2_1	13.2	11.2	6.4
BC_48_2_2 (Rec.1)	27.6	5.4	6.4
BC_48_2_2 (Rec.2)	46	3.2	6.4
BC_48_2_2 (Rec.3)	36.8	4.0	6.4

Table 9.8: Example duty cycle and test limits for Adaptive FHSS using DAA for selected LE Audio device configurations assuming 2M PHY, 37 channels in use at the start and interference added on 5 channels

9.5.3 Accumulated transmit time, frequency occupation and hopping sequence expected results

Table 9.9 shows the expected results for the Accumulated Transmit Time, Frequency Occupation, and Hopping Sequence (Section 8.2.4.3) test for accumulated transmit time.

Configuration	Test duty cycle %	Accumulated Transmit Time, s Limit	Expected Accumulated Transmit Time, s
UA_16_2_1	13.2	0.4	0.00216
BC_48_2_2 (Rec.1)	27.6	0.4	0.0444
BC_48_2_2 (Rec.2)	46	0.4	0.744
BC_48_2_2 (Rec.3)	36.8	0.4	0.06

Table 9.9: Duty cycle test: Accumulated Transmit Time, Frequency Occupation and Hopping Sequence expected accumulated transmit time results for LE Audio devices

9.5.4 Frequency retention time expected results

Table 9.10 shows the expected results for the Frequency retention time (see Section 8.5.1.12) test.

Configuration	Test duty cycle %	Frequency retention time limit (s)	Expected Frequency retention time (s)
UA_16_2_1	13.2	0.4	0.0544
BC_48_2_2 (Rec.1)	27.6	0.4	0.112
BC_48_2_2 (Rec.2)	46	0.4	0.187
BC_48_2_2 (Rec.3)	36.8	0.4	0.151

Table 9.10: Duty cycle test: Frequency retention time expected accumulated transmit time results for LE Audio devices

9.6 Procedures for testing LE Audio devices

The general sequence of the duty cycle dependent regulatory test procedure for LE Audio configurations is shown in Figure 9.1.

Example sequences of commands in

Figure 9.2 through Figure 9.6 sent to the EUT are shown in the message sequence charts (MSCs), and using example parameters in the MSCs, substituting for the specific parameters in Table 9.11 when sending values for the HCI_LE_Create_BIG_Test command.

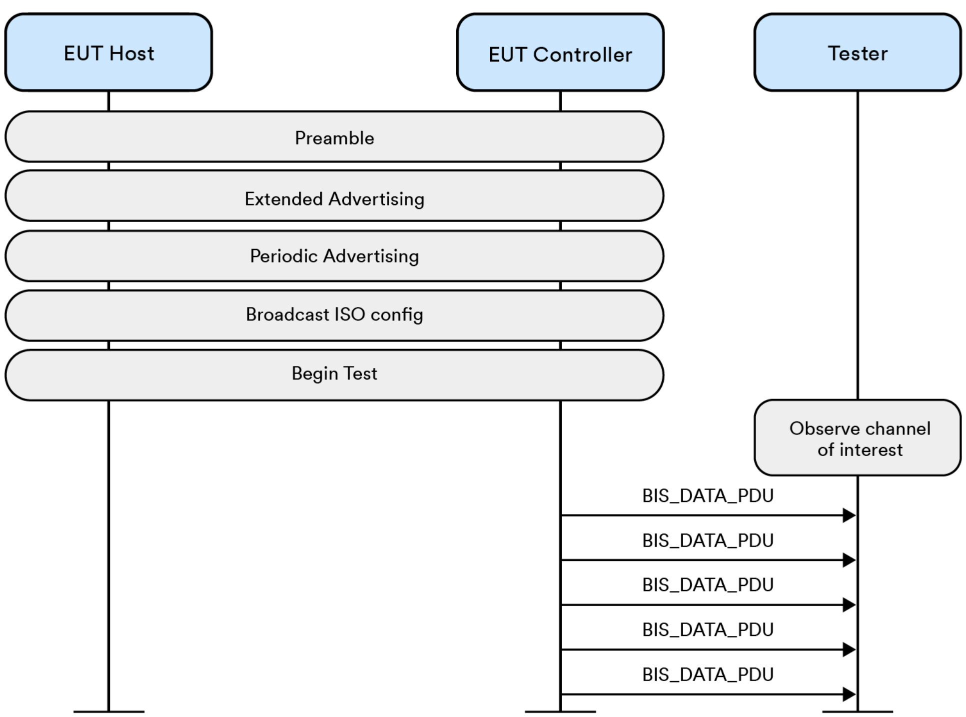


Figure 9.1: LE Audio duty cycle test general format MSC: general format

Figure 9.2 through Figure 9.6 show examples of each individual component of the duty cycle dependent test setup.

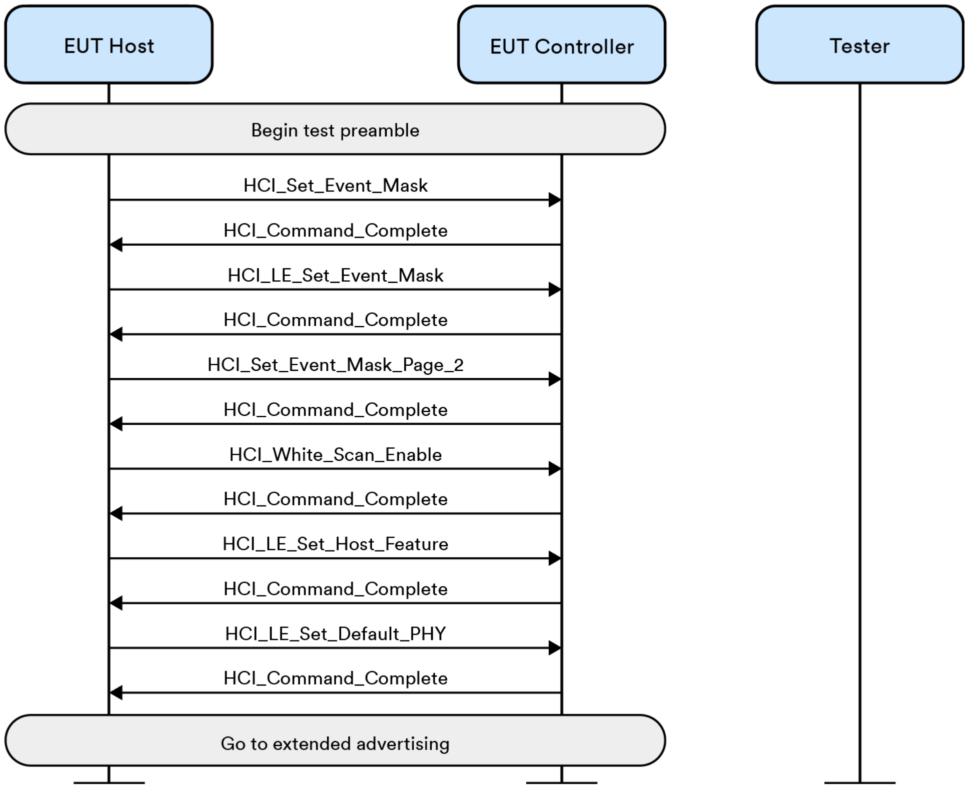


Figure 9.2: LE Audio duty cycle test general format MSC: preamble

Figure 9.3 shows the extended advertising being configured.

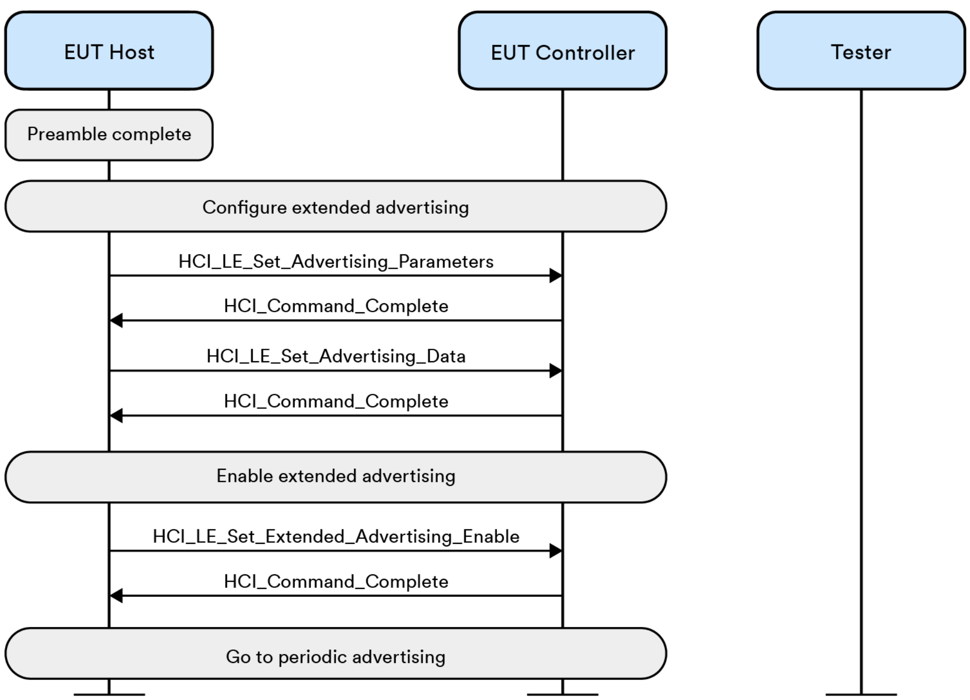


Figure 9.3: LE Audio duty cycle test general format MSC: extended advertising

Figure 9.4 shows the periodic advertising being configured.

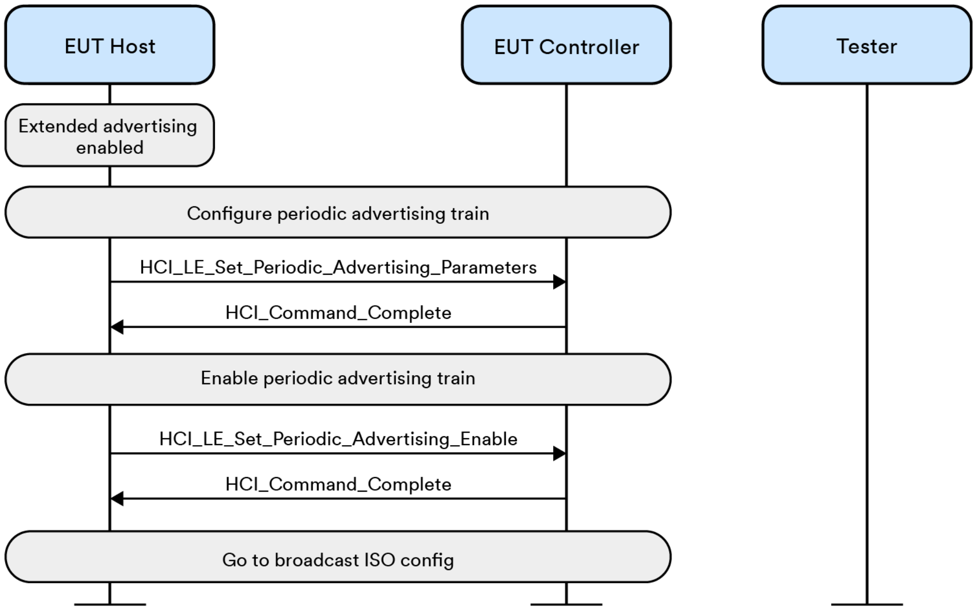


Figure 9.4: LE Audio duty cycle test general format MSC: periodic advertising

Figure 9.5 shows the broadcast isochronous streams being configured, and Table 9.11 shows the HCI_LE_Create_BIG_Test command required parameters for each configuration (not all parameters for the HCI command are shown; only the Host and Controller parameters required to achieve the duty cycle of interest are shown).

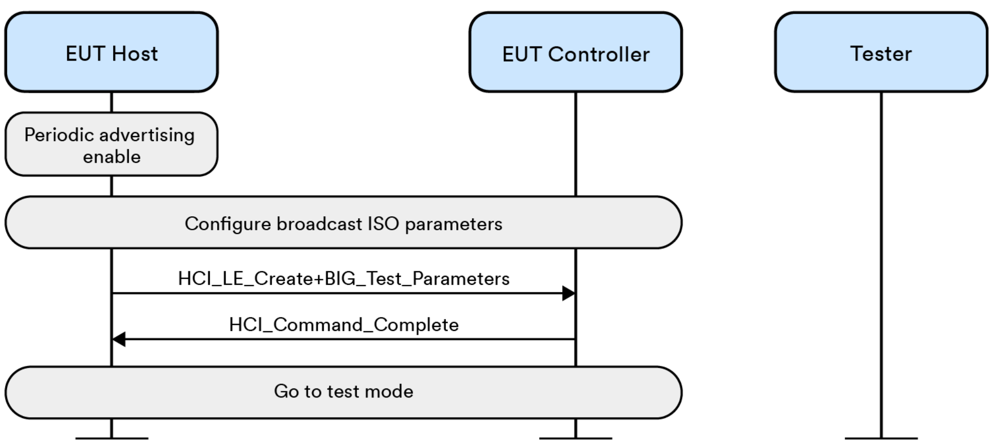


Figure 9.5: LE Audio duty cycle test general format MSC: broadcast ISO configuration

Configuration	Test duty cycle %	HCI_LE_Create_BIG_Test parameters (see Table 9.3: Host and Controller parameters)							
		BIS	SDU	SDU_{INT}	ISO_{INT}	NSE	BN	IRC	PTO
UA_16_2_1	13.2	2	40	10	10	3	2	1	0
BC_48_2_2 (Rec.1)	27.6	2	100	10	30	9	3	2	1
BC_48_2_2 (Rec.2)	46	2	100	10	10	5	1	1	1
BC_48_2_2 (Rec.3)	36.8	2	100	10	20	8	2	2	1

Table 9.11: Broadcast ISO parameters for LE Audio configs

Figure 9.6 shows the broadcast isochronous streams being enabled.

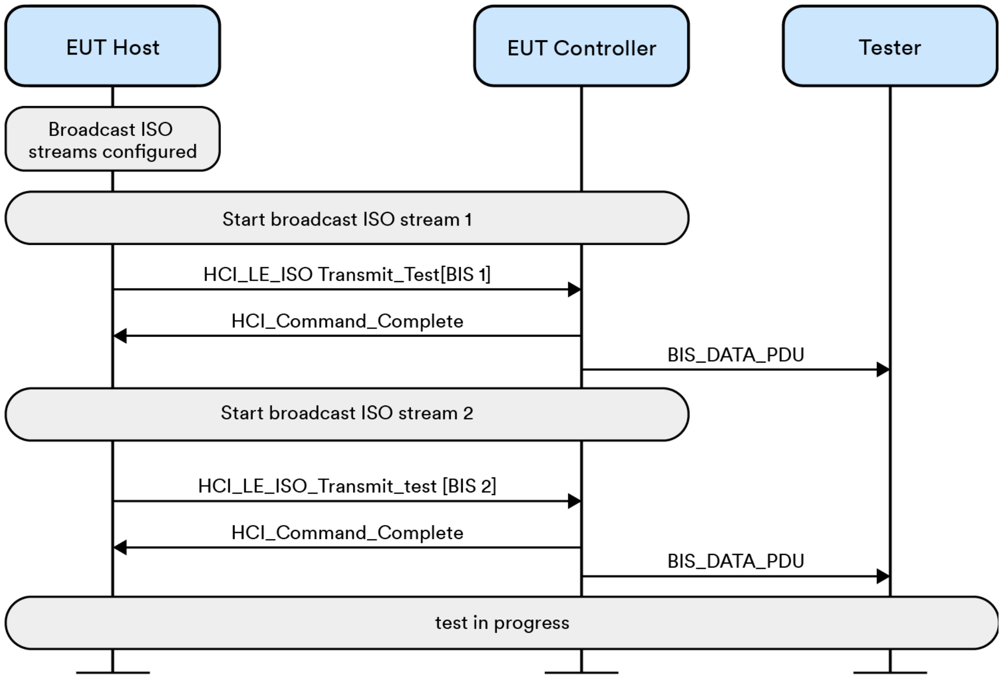


Figure 9.6: LE Audio duty cycle test general format MSC: ISO test mode

Appendix A References

Ref./Document title	Reference
[1] ARIB STD-T66 v 3.7 (2 October 2014), Second Generation Small Power Data Communication System/ Wireless Lan Systems standard, Association of Radio Industries and Businesses (ARIB)	ARIB, URL: https://www.arib.or.jp/english/std_tr/telecommunications/std-t66.html
[2] Bluetooth Core Specification, Version 5.4	Bluetooth SIG, URL: https://www.bluetooth.com/specifications/specs/
[3] GB/T 12572-2008, Universal requirements and measurement methods of parameters for radio transmitting equipment	CCSA, URL: https://www.ccsa.org.cn/bzcx
[4] EN 300 328, V2.2.2 (2019-07), Electromagnetic compatibility and Radio spectrum Matters (ERM); Wideband transmission systems; Data transmission equipment operating in the 2,4 GHz band; Harmonized Standard for access to radio spectrum	ETSI, URL: https://www.etsi.org/deliver/etsi_en/300300_300399/300328/02.02.02_60/en_300328v020202p.pdf
[5] EG 203 336, V1.2.1 (2020-05), ETSI Guideline (EG); Guide for the selection of technical parameters for the production of Harmonized Standards covering article 3.1(b) and article 3.2 of Directive 2014/53/EU	ETSI, URL: https://www.etsi.org/deliver/etsi_eg/203300_203399/203336/01.02.01_60/eg_203336v010201p.pdf
[6] EN 300 440, V2.2.1 (2018-07), Short Range Devices (SRD); Radio equipment to be used in the 1 GHz to 40 GHz frequency range; Harmonized Standard for access to radio spectrum	ETSI, URL: https://www.etsi.org/deliver/etsi_en/300300_300399/300328/02.02.02_60/en_300328v020202p.pdf
[7] TR 103 665, V1.1.1 (2021-05), System Reference document (SRdoc); Data Transmission Systems using Wide Band technologies in the 2.4 GHz band	ETSI, URL: https://www.etsi.org/deliver/etsi_tr/103600_103699/103665/01.01.01_60/tr_103665v010101p.pdf
[8] EN 300 328, V1.7.1 (2006-10), Wideband transmission systems; Data transmission equipment operating in the 2,4 GHz band; Harmonized Standard for access to radio spectrum	ETSI, URL: https://www.etsi.org/deliver/etsi_en/300300_300399/300328/01.07.01_60/en_300328v010701p.pdf
[9] Publication 558074, OET (2 April 2019), Guidance for compliance measurements on digital transmission system, frequency hopping spread spectrum system, and hybrid system devices operating under section 15.247 of the FCC rules	FCC, URL: https://apps.fcc.gov/kdb/GetAttachment.html?id=tylb5MMggvhIIVMK75RrRQ%3D%3D&desc=558074%20D01%2015.247%20Meas%20Guidance%20v05r02&tracking_number=21124

Ref./Document title	Reference
[10] §15.249 Operation within the bands 902-928 MHz, 2400-2483.5 MHz, 5725-5875 MHZ, and 24.0-24.25 GHz.	FCC, FCC 15.249, URL: https://www.ecfr.gov/current/title-47/chapter-I/subchapter-A/part-15#15.249
[11] § 15.247 Operation within the bands 902-928 MHz, 2400-2483.5 MHz, and 5725-5850 MHz	FCC, FCC 15.247, URL: https://www.ecfr.gov/current/title-47/chapter-I/subchapter-A/part-15#15.247
[12] FCC 47 CFR Part 15 - Radio Frequency Devices	FCC, URL: https://www.ecfr.gov/current/title-47/chapter-I/subchapter-A/part-15
[13] IEEE 802.11-2001, IEEE Standard for Local and Metropolitan Area Networks: Overview and Architecture	IEEE, URL: http://standards.ieee.org/findstds/standard/802-2001.html
[14] IEEE Registration Authority	IEEE Registration Authority, URL: https://standards.ieee.org/faqs/regauth/
[15] MIC Notice 88, appendix No. 43, Applicable test methods for 2.4 GHz band advanced low power data communication system	JRL, URL: https://www.tele.soumu.go.jp/resource/j/equ/tech/betu/43.pdf
[16] MIC Notice 88, appendix No. 1, Applicable test methods for 2.4 GHz band advanced low power data communication system	JRL, URL: https://www.tele.soumu.go.jp/resource/j/equ/tech/betu/01.pdf
[17] JRL Article 49.20, Radio equipment that uses emissions of a frequency from 2400 MHz to 2483.5 MHz	JRL, URL:https://www.tele.soumu.go.jp/resource/e/equ/tech/
[18] Radio Law (Law No. 131 of 1950)	JRL, URL: https://www.tele.soumu.go.jp/resource/e/equ/tech/orre.pdf
[19] Korean Radio Waves Act, Act No. 16019, Dec 24, 2018	KCC, URL: https://elaw. klri.re.kr/kor_service/lawView.do?lang=ENG&hseq=50184
[20] MSIT Notice 2022-20, Technical standard for wireless equipment for stations that can be opened without notification	KCC, URL: https://www.law.go.kr/행정규칙/신고하지아니하고개설할수있는무선국용무선설비의기술기준/(2022-20,20220510)
[21] KS X 3123:2022, Wireless equipment conformity evaluation test method	KCC, URL: https://www.rra.go.kr/ko/reference/kcsList.do

Ref./Document title	Reference
[22] Gong Xin Bu Wu [2021]#129, Interpretation of the Ministry of Industry and Information Technology's "Notice on Strengthening and Regulating the Radio Management of the 2400MHz, 5100MHz and 5800MHz Frequency Bands	MIIT, URL: https://www.miit.gov.cn/zwgk/zcwj/wjfb/tz/art/2021/art_e4ae71252eab42928daf0ea620976e4e.html
[23] Xin Bu Wu [2002]#353 Notice on Adjusting 2.4 GHz Frequency Band Transmitting Power Limit and Related Issues (China Spread Spectrum Requirements)	MIIT, URL: http://www.miit.gov.cn/n1146285/n1146352/n3054355/n3057735/n3057748/c5711103/content.html
[24] Official Journal of the European Union, Directive 2014/53/EU of the European Parliament and of the Council of 16 April 2014 on the harmonization of the laws of the Member States relating to the making available on the market of radio equipment and repealing Directive 1999/5/EC Text with EEA relevance	European Parliament and of the Council, URL: http://eur-lex.europa.eu/ eli/dir/2014/53/oj
[25] ANSI C63.4-2014, American National Standard for Methods of Measurement of Radio Noise Emissions from Low-Voltage Electrical and Electronic Equipment in the Range of 9 kHz to 40 GHz	RSS, URL: https://standards.ieee.org/standard/C63_4-2014.html
[26] ANSI C63.10-2020, American National Standard of Procedures for Compliance Testing of Unlicensed Wireless Devices	RSS, URL: https://standards.ieee.org/standard/C63_10-2020.html
[27] RSS-247, Issue 2, February 2017, Digital Transmission Systems (DTSs), Frequency Hopping Systems (FHSs) and License-Exempt Local Area Network (LE-LAN) Devices	RSS, URL: https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf10971.html
[28] RSS-Gen, Issue 5, November 2018, License-Exempt Radio Apparatus: Category I Equipment	RSS, URL: https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf08449.html
[29] RSS-210, Issue 10, December 2019, License-Exempt Radio Apparatus: Category I Equipment	RSS, URL: https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf01320.html
[30] IR 2030 – UK interface requirements 2030	UK, URL: https://www.ofcom.org.uk/__data/assets/pdf_file/0028/84970/ir-2030.pdf
[31] Radio Equipment Regulations 2017 No 1206	UK, URL: https://www.legislation.gov.uk/uksi/2017/1206

Ref./Document title	Reference
[32] Statutory guidance: Radio Equipment Regulations 2017: Great Britain	UK, URL: https://www.gov.uk/government/publications/radio-equipment-regulations-2017/radio-equipment-regulations-2017-great-britain
[33] Statutory guidance: Radio Equipment Regulations 2017: Northern Ireland	UK, URL: https://www.gov.uk/government/publications/radio-equipment-regulations-2017/radio-equipment-regulations-2017-northern-ireland
[34] Statutory guidance: Radio Equipment Regulations 2017: Regulation 14	UK, URL: https://www.gov.uk/government/publications/radio-equipment-regulations-2017/radio-equipment-regulations-2017-regulation-14
[35] Radio Frequency Physical Layer (RFPHY) Test Suite	Bluetooth SIG URL: https://www.bluetooth.com/specifications/qualification-test-requirements/
[36] Paper - Bluetooth Core Specification Version 5.0 Feature Enhancements	Bluetooth SIG URL: https://www.bluetooth.com/bluetooth-resources/bluetooth-5-go-faster-go-further/
[37] Paper - Bluetooth Core Specification Version 5.1 Feature Overview	Bluetooth SIG URL: https://www.bluetooth.com/bluetooth-resources/bluetooth-core-specification-v5-1-feature-overview/
[38] Paper - Bluetooth Core Specification Version 5.2 Feature Overview	Bluetooth SIG URL: https://www.bluetooth.com/bluetooth-resources/bluetooth-core-specification-version-5-2-feature-overview/
[39] Paper - Bluetooth Core Specification Version 5.3 Feature Enhancements	Bluetooth SIG URL: https://www.bluetooth.com/bluetooth-resources/bluetooth-core-specification-version-5-3-feature-enhancements/
[40] Directive 2014/53/EU of the European Parliament and of the Council of 16 April 2014 on the harmonization of the laws of the Member States relating to the making available on the market of radio equipment and repealing Directive 1999/5/EC"	European Parliament and Council, Document 32014L0053 URL: http://data.europa.eu/eli/dir/2014/53/oj
[41] Commission Delegated Regulation (EU) 2022/30 of 29 October 2021 supplementing Directive 2014/53/EU of the European Parliament and of the Council with regard to the application of the essential requirements referred to in Article 3(3), points (d), (e) and (f), of that Directive (Text with EEA relevance)	European Commission URL: https://eur-lex.europa.eu/eli/reg_del/2022/30/oj

Ref./Document title	Reference
[42] EU Blue Guide	European Commission, URL: https://eur-lex.europa.eu/legal-content/EN/TXT/?toc=OJ:C:2022:247:TOC&uri=uriserv:OJ.C_.2022.247.01.0001.01.ENG
[43] 2006/771/EC: Commission Decision of 9 November 2006 on harmonization of the radio spectrum for use by short-range devices	European Commission, Document 32006D0771(01) URL: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32006D0771%2801%29
[44] § 15.209 Radiated emission limits; general requirements.	FCC, FCC 15.209, URL: https://www.ecfr.gov/current/title-47/chapter-I/subchapter-A/part-15#15.209
[45] Product Security and Telecommunications Infrastructure Act 2022	UK Parliament, UK Public General Acts 2022 c. 46 URL: https://bills.parliament.uk/bills/3069
[46] The Product Safety and Metrology (Amendment and Transitional Provisions) Regulations 2022	UK Draft Statutory Instruments (link fetched 2022-12-20) URL: https://www.legislation.gov.uk/ukdsi/2022/9780348241150
[47] Introducing Bluetooth® LE Audio (by Nick Hunn, 2022)	Bluetooth SIG URL: https://www.bluetooth.com/bluetooth-resources/le-audio-book/
[48] Specifications and Test Documents List	Bluetooth SIG URL: https://www.bluetooth.com/specifications/specs/
[49] Brand Guide for Bluetooth Trademarks	Bluetooth SIG URL: https://www.bluetooth.com/develop-with-bluetooth/marketing-branding/

Appendix B Unit conversions

Units used may differ from one regulatory domain to another.

Radiated power can be expressed in ERP (Effective Radiated Power), EIRP (Effective Isotropic Radiated Power), or Field Strength.

- ERP describes the power emitted by the transmitter and the ability of a dipole antenna to direct the power in a given direction.
- EIRP describes the radiated power from an ideal isotropic antenna, with a 0 dBi gain, where the transmitted power is distributed equally in all directions around the antenna.
- The dipole antenna has a power gain of 1.64 or 10 log 1.64 = 2.15 dB above the isotropic antenna.
- Field Strength E (V/m) describes radiated power at given distance (d) in meters (m) from the antenna.

To convert between EIRP and ERP, the following applies:

EIRP (W) = 1.64 * ERP, when EIRP and ERP are expressed in Watts

EIRP (dBm) = ERP + 2.15, when EIRP and ERP are expressed through logarithmic units, dBm, where dBm is decibels (dB) with reference to one milliwatt (mW)

The relation between Field Strength E and power P in Watt is E = $\frac{\sqrt{30*P*G}}{d}$,

where power gain is G (linear relative to isotropic antenna), and d (m) equals the distance from the antenna.

In logarithmic units, the relationship is E (dBμV/m) = EIRP (dBm) +104.8 -20log(d).

To convert to the EIRP power equivalent (dBm) from field strength E (V/m) at a given distance, the conversion formula is:

$$\text{EIRP (dBm)} = 10\log_{10}(1000 \times \frac{E^2\ r^2}{30})$$

where E is the field strength in V/m, and r is the distance (radius) in m.

To convert from field strength to ERP, first convert field strength to EIRP and then consider the EUT's antenna gain to obtain the corresponding ERP figure.

Appendix C Glossary

Term	Definition
8DPSK	8-Differential Phase Shift Keying digital modulation scheme
µs	microsecond
µV	microvolt
µW	microwatt
AC	Alternating Current
ACL	Asynchronous Connection-oriented logical transport, used for reliable or time-bounded, bi-directional, point-to-point traffic
ADVB	Operational mode using the LE Advertising Broadcast logical transport, used for unreliable, unidirectional broadcast communication
Advertising Channel	Bluetooth LE Channel with index 37, 38, or 39
ANSI	American National Standards Institute (US)
API	Application Programming Interface
ARIB	Association of Radio Industries and Businesses (Japan)
Auxiliary Advertising Segment	The set of packets consisting of the first auxiliary packet transmitted in an extended advertising event and each of its subordinate packets transmitted in the same extended advertising event.
AVG	Average
BAP	Basic Audio Profile
BC	Broadcast audio
BER	Bit Error Rate
BIG	Broadcast Isochronous Group, a group of time-related Broadcast Isochronous Streams
BIS	Broadcast Isochronous Stream
BR/EDR	Basic Rate/Enhanced Data Rate
Broadcaster	One of the four GAP roles
Broadcast Isochronous	Logical transport for unidirectional, time-bounded, connectionless broadcast communication
BRR	Bureau of Radio Regulation (China)
BW	Bandwidth
CAP	Common Audio Profile
CCA	Clear Channel Assessment
CCC	China Compulsory Certification
CCSA	China Communications Standards Association
Central	One of the four GAP roles and a Link Layer role
CEPT	European Conference of Postal and Telecommunications Administrations
CFR	Code of Federal Regulations (US)
CIG	Connected Isochronous Group, a group of time-related Connected Isochronous Streams
CIS	Connected Isochronous Stream

Term	Definition
Connected Asynchronous	Logical transport for connection-oriented communication
COT	Channel Occupation Time
CRC	Cyclic Redundancy Check, a field used in the detection of transmission errors. This field and its use are defined in the Link Layer specification.
CSA	Channel Selection Algorithm
CTE	Constant Tone Extension
CW	Continuous Waveform
DAA	Detect And Avoid
dB	decibel
dBi	decibel isotropic
dBm	decibel-milliwatt
DC	Duty Cycle
DCCF	Duty Cycle Correction Factor
DQPSK	Differential Quadrature Phase Shift Keying digital modulation scheme
DS	Direct Sequence
DSSS	Direct Sequence Spread Spectrum
DTS	Digital Transmission Systems using digital modulation techniques
dwell time	The time between frequency changes for FHSS equipment. EN 300 328 [4] notes that this time may comprise transmit, receive, and idle phases of the equipment.
EC	European Commission
EEA	European Economic Area
EIRP	Equivalent Isotropically Radiated Power or Effective Isotropic Radiated Power
EMC	Electromagnetic Compatibility
EN	Harmonized European Standard (EU)
ERM	Electromagnetic compatibility and Radio spectrum Matters (EU)
ERP	Effective Radiated Power
ETSI	European Telecommunications Standards Institute
EU	Abbreviation with dual meanings: European Union, or Equivalent Utilization (China)
EUT	Equipment Under Test, also known as Unit Under Test
Extended advertising	Advertising comprising extended advertising events using PDUs transmitted on both the primary channels and general-purpose channels
FCB	Foreign Certification Body (Canada) Organization accredited by ISED to approve product compliance to Radio Standards Specifications (RSS). Analogous role to TCB in the US.
FCC	Federal Communications Commission (US)
FEC	Forward Error Correction coding
FER	Frame Error Rate
FHSS	Frequency Hopping Spread Spectrum
GAF	Generic Audio Framework
GAP	Generic Access Profile

Term	Definition
GATT	Generic Attribute Profile
GB/T	Guojia Biaozhun/ Tuijian (China) Translates as National Standard/ Recommended. The remainder of the standard designation is constructed from a numerical code that follows GB/T.
General-purpose channel	Channel with index in the range 0 to 36 inclusive
GFSK	Gaussian Frequency Shift Keying digital modulation scheme
GHz	gigahertz
HCI	Host Controller Interface, a component of the Core Specification
HFS	Hopping Frequency Separation
IC	Industry Canada
IEEE	Institute of Electrical and Electronics Engineers
IF	Intermediate Frequency
ISED	Innovation, Science and Economic Development Canadian government department responsible for industry regulation, including RF.
ISM	Industrial, Scientific, Medical; used as a synonym for the 2.4 GHz band
ISO	Isochronous
JRL	Japanese Radio Law (Japan)
kb	kilobit
KC	Korea Certification (Korea)
kHz	kilohertz
KS X	Korean Standards. “X” references a broadcasting and communications standard. The remainder of the standard designation is constructed from a numerical code.
LBT	Listen Before Talk
LE	Low Energy
LE 1M	The LE PHY with no coding and a symbol rate of 1 Msym/s
LE 2M	The LE PHY with no coding and a symbol rate of 2 Msym/s
LE ACL	The Connected Asynchronous logical transport of Bluetooth Low Energy.
LE BIS	The Broadcast Isochronous logical transport of Bluetooth Low Energy.
LE-C	The Bluetooth LE link for control data.
LE CIS	The Connected Isochronous logical transport of Bluetooth Low Energy.
LE Coded PHY	The LE PHY with FEC coding and pattern mapping applied by the Link Layer and a symbol rate of 1 Msym/s.
LE-U	The Bluetooth LE link for user data.
Legacy advertising	Advertising comprising advertising events using PDUs transmitted on the primary channels
LL	Link Layer
log	Logarithm - in this document, only log10 (the logarithm with 10 as the base) is used
LSB	Least Significant Bit
m	Meter
Max	Maximum

Term	Definition
Mb	Megabit
Mb/s	Megabits per second
MHz	Megahertz
MIC	Abbreviation with dual meanings: Message Integrity Check (used when describing Bluetooth PDU format) Ministry of Internal Affairs and Communication (Japan)
MIIT	Ministry of Industry and Information Technology (China)
MRA	Mutual Recognition Agreement
ms	Millisecond
MSB	Most Significant Bit
MSC	Message Sequence Chart
MSIT	Ministry of Science and ICT (Korea)
Msym/s	Megasymbols per second
MU	Medium Utilization
mV	Millivolt
mW	Milliwatt
n/a	Not applicable
NAL	Network Access License (China)
NI	Northern Ireland
nW	Nanowatt
Observer	One of the four GAP roles
OBW	Occupied Bandwidth
OCBW	Occupied Channel Bandwidth
OFDM	Orthogonal Frequency Division Multiplexing
OJEU	Official Journal of the European Union (EU)
OOB	Out Of Band
OSI	Open Systems Interconnection model
P	Power
PADVB	The Periodic Advertising Broadcast logical transport of Bluetooth Low Energy.
PDU	Protocol Data Unit
PER	Packet Error Rate
Periodic Broadcast Advertising	Logical transport for periodic advertising
Peripheral	One of the four GAP roles and a Link Layer role
PHY	Physical Layer
ppm	parts per million
Protocol Data Rate	The transmission rate of bits relating to PDUs, including their application data payload, but excluding FEC data, which is included in packets when the LE Coded PHY is in use.
PSD	Power Spectral Density
PSK	Phase Shift Keying digital modulation scheme
RBW	Resolution Bandwidth

Term	Definition
RED	Radio Equipment Directive (EU)
RF	Radio Frequency
RMS	Root Mean Square
RRA	National Radio and Research Agency (Korea)
RSS	Radio Standard Specification (Canada)
RSSI	Received Signal Strength Indication
RTN	Retransmission Number
Rx	Receive
S	Second Parameter indicating coding level for LE Coded PHYs
SDoC	Supplier's Declaration of Conformity
SDU	Service Data Unit, the part of the payload that contains the actual data that is transmitted
SIG	Special Interest Group
Sink	The side in the Bluetooth audio path that received the audio signal
Source	The side in the Bluetooth audio path that transmits the audio signal
SRD	Short Range radio Device
SRRC	State Radio Regulation of China (China)
Symbol Rate	The rate at which analogue symbols are transmitted at the Physical Layer
TCB	Telecommunication Certification Body (US)
TDD	Time Division Duplex
Tx	Transmit
U	The number of RF channels in use (from EN 300 328)
UA	Unicast Audio
UK	United Kingdom
UKCA	UK Conformity Assessed
US	United States of America
UUT	Unit Under Test
V/m	Volt per meter, standard unit for electric field strength
VBW	Video Bandwidth
W	Watt

Additional definitions and abbreviations can be found in [2].

Appendix D Major feature additions to Bluetooth LE and Specification End-of-Life

The following table summarizes major features from the perspective of regulatory aspects added to Bluetooth Low Energy technology since its introduction in the Bluetooth Core Specification v4.0 that have contributed to the progression of the Bluetooth LE system since 2010.

Please note that the list of changes and specifications is a simplified version of the comprehensive list of changes that can be found in the [Vol 0] Part C, Revision History and Acknowledgments of [2].

Year Added	Specification(s)	Major Feature	Description
2023	Core 5.4	Periodic Advertising with Responses (PAwR)	Provides the ability for devices receiving periodic advertising data to respond to the transmitter. Also adds a group concept to periodic advertising, which enables devices to only listen to specific transmissions, thus enhancing the number of addressable devices in periodic advertising.
2023	Core 5.4	Advertising Coding Selection	Allows S=2 or S=8 configuration in using LE Coded PHY for extended advertising. The benefit is the possibility of shorter transmission timing than prior cores that defaulted to S=8.
2021	Core 5.3	LE Channel Classification	The feature allows the LE Peripheral to report its current channel classification to the LE Central.
2021	Core 5.3	LE Enhanced Connection Update	The feature shortens the time to change connection interval, which is advantageous for applications with dynamic bandwidth requirements that need both low power and low latency data transfers.
2021	Core 5.3	AdvDataInfo in Periodic Advertising	Enables the use of the AdvDataInfo (ADI) field in Periodic Advertising PDUs for filtering of duplicate periodic advertising reports sent to the Host. The addition supports various Generic Audio and Mesh use cases.
2020/ 2022	LC3, BAP, CAP plus 16 other supportive services and profiles	LE Audio	Added a flexible audio middleware to the Bluetooth LE system, enabling the creation of higher quality, lower power audio products capable of supporting unicast and broadcast audio use cases.
2019	Core 5.2	LE Isochronous Channels	Added connection-oriented and connectionless isochronous data transports to the Bluetooth LE system, enabling the transmission of time-bound data such as audio.
2019	Core 5.1	LE Direction Finding	Added the ability for a receiver to determine the direction of a signal from a transmitter to the Bluetooth LE system, enabling the creation of higher accuracy position location systems.
2017	Mesh Profile	LE Mesh Networking	Added a many-to-many device communications topology to the Bluetooth LE system, enabling the creation of large-scale device networks.
2016	Core 5.0	LE 2M PHY	Added a PHY that provides a 2 Mb/s data rate to the Bluetooth LE system, doubling the bit rate provided by the original LE 1M PHY.
2016	Core 5.0	LE Coded PHY (Long Range)	Added a PHY that incorporates forward error correction (FEC) to the Bluetooth LE system. Provides bit rates of 500 kb/s or 125 kb/s depending on the level of FEC coding applied.
2016	Core 5.0	LE Channel Selection Algorithm # 2	Improved channel hopping algorithm to mitigate interference and multi-path fading effects.

Year Added	Specification(s)	Major Feature	Description
2016	Core 5.0	LE Extended Advertising	Significantly increased the size of data packets that could be sent via the advertising broadcast and periodic advertising broadcast data transports and added the ability to transmit those packets via the 37 general-purpose channels.
2016	Core 5.0	LE Periodic Advertising	Added the periodic advertising broadcast data transport to the Bluetooth LE system.
2015	CSA5	Higher Output Power	Enabled higher Output Power on LE (100 mW), going from 10 mW.
2014	Core 4.2	LE Secure Connections	Added a FIPS-complaint algorithm called Elliptic Curve Diffie Hellman (ECDH) for security key generation to the Bluetooth LE system.
2014	Core 4.2	LE Data Packet Length Extension	Significantly increased the size of data packets (up to 251 octets versus 27 when disabled) that could be sent via the Bluetooth LE connection-oriented data transports.
2010	Core 4.0	Bluetooth Low Energy (LE)	Introduced the Bluetooth LE system.

D.1 Specification End-of-Life

The Bluetooth SIG encourages the use of the newer versions of their adopted specifications, through the specification end-of-life phase where specifications first enter the deprecated state and then later the withdrawn state; these stages happen at preannounced times.

Bluetooth v4.0 was deprecated in January 2019 and became withdrawn in February 2022.

Bluetooth v4.1 was deprecated in January 2019 and became withdrawn in February 2023.

Bluetooth v4.2 has a preannounced deprecation date in February 2026 and will become withdrawn in February 2031.

All versions prior to v4.0 (e.g., v3.0, v2.1, 2.0) reached their end-of-life at previous dates.