IEEE 802.15.4k FSK PHY Working Draft version: 2011-12-05

**WARNING: Incomplete Work Product**

**USE AT YOUR OWN RISK**

P™/D  
Draft for

Sponsor

**Committee**of the **IEEE <Society Name> Society**

Approved <XX MONTH 20XX>

**IEEE-SA Standards Board**

Copyright © 201X by the Institute of Electrical and Electronics Engineers, Inc.

Three Park Avenue

New York, New York 10016-5997, USA

All rights reserved.

This document is an unapproved draft of a proposed IEEE Standard. As such, this document is subject to change. USE AT YOUR OWN RISK! Because this is an unapproved draft, this document must not be utilized for any conformance/compliance purposes. Permission is hereby granted for IEEE Standards Committee participants to reproduce this document for purposes of international standardization consideration. Prior to adoption of this document, in whole or in part, by another standards development organization, permission must first be obtained from the IEEE Standards Association Department (stds.ipr@ieee.org). Other entities seeking permission to reproduce this document, in whole or in part, must also obtain permission from the IEEE Standards Association Department.

IEEE Standards Association Department

445 Hoes Lane

Piscataway, NJ 08854, USA

Abstract: <Select this text and type or paste Abstract—contents of the Scope may be used>

Keywords: <Select this text and type or paste keywords>

[[1]](#footnote-1)•

**IEEE Standards** documents are developed within the IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Association (IEEE-SA) Standards Board. The IEEE develops its standards through a consensus development process, approved by the American National Standards Institute, which brings together volunteers representing varied viewpoints and interests to achieve the final product. Volunteers are not necessarily members of the Institute and serve without compensation. While the IEEE administers the process and establishes rules to promote fairness in the consensus development process, the IEEE does not independently evaluate, test, or verify the accuracy of any of the information or the soundness of any judgments contained in its standards.

Use of an IEEE Standard is wholly voluntary. The IEEE disclaims liability for any personal injury, property or other damage, of any nature whatsoever, whether special, indirect, consequential, or compensatory, directly or indirectly resulting from the publication, use of, or reliance upon this, or any other IEEE Standard document.

The IEEE does not warrant or represent the accuracy or content of the material contained herein, and expressly disclaims any express or implied warranty, including any implied warranty of merchantability or fitness for a specific purpose, or that the use of the material contained herein is free from patent infringement. IEEE Standards documents are supplied “**AS IS**.”

The existence of an IEEE Standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE Standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard. Every IEEE Standard is subjected to review at least every five years for revision or reaffirmation, or every ten years for stabilization. When a document is more than five years old and has not been reaffirmed, or more than ten years old and has not been stabilized, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE Standard.

In publishing and making this document available, the IEEE is not suggesting or rendering professional or other services for, or on behalf of, any person or entity. Nor is the IEEE undertaking to perform any duty owed by any other person or entity to another. Any person utilizing this, and any other IEEE Standards document, should rely upon his or her independent judgment in the exercise of reasonable care in any given circumstances or, as appropriate, seek the advice of a competent professional in determining the appropriateness of a given IEEE standard.

Interpretations: Occasionally questions may arise regarding the meaning of portions of standards as they relate to specific applications. When the need for interpretations is brought to the attention of IEEE, the Institute will initiate action to prepare appropriate responses. Since IEEE Standards represent a consensus of concerned interests, it is important to ensure that any interpretation has also received the concurrence of a balance of interests. For this reason, IEEE and the members of its societies and Standards Coordinating Committees are not able to provide an instant response to interpretation requests except in those cases where the matter has previously received formal consideration. A statement, written or oral, that is not processed in accordance with the IEEE-SA Standards Board Operations Manual shall not be considered the official position of IEEE or any of its committees and shall not be considered to be, nor be relied upon as, a formal interpretation of the IEEE. At lectures, symposia, seminars, or educational courses, an individual presenting information on IEEE standards shall make it clear that his or her views should be considered the personal views of that individual rather than the formal position, explanation, or interpretation of the IEEE.

Comments for revision of IEEE Standards are welcome from any interested party, regardless of membership affiliation with IEEE. Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments. Recommendations to change the status of a stabilized standard should include a rationale as to why a revision or withdrawal is required. Comments and recommendations on standards, and requests for interpretations should be addressed to:

Secretary, IEEE-SA Standards Board

445 Hoes Lane

Piscataway, NJ 08854

USA

Authorization to photocopy portions of any individual standard for internal or personal use is granted by The Institute of Electrical and Electronics Engineers, Inc., provided that the appropriate fee is paid to Copyright Clearance Center. To arrange for payment of licensing fee, please contact Copyright Clearance Center, Customer Service, 222 Rosewood Drive, Danvers, MA 01923 USA; +1 978 750 8400. Permission to photocopy portions of any individual standard for educational classroom use can also be obtained through the Copyright Clearance Center.

Introduction

This introduction is not part of IEEE P/D<draft\_number>, Draft<opt\_Trial-Use><Gde./Rec. Prac./Std.> for .

<Select this text and type or paste introduction text>

Notice to users

Laws and regulations

Users of these documents should consult all applicable laws and regulations. Compliance with the provisions of this standard does not imply compliance to any applicable regulatory requirements. Implementers of the standard are responsible for observing or referring to the applicable regulatory requirements. IEEE does not, by the publication of its standards, intend to urge action that is not in compliance with applicable laws, and these documents may not be construed as doing so.

Copyrights

This document is copyrighted by the IEEE. It is made available for a wide variety of both public and private uses. These include both use, by reference, in laws and regulations, and use in private self-regulation, standardization, and the promotion of engineering practices and methods. By making this document available for use and adoption by public authorities and private users, the IEEE does not waive any rights in copyright to this document.

Updating of IEEE documents

Users of IEEE standards should be aware that these documents may be superseded at any time by the issuance of new editions or may be amended from time to time through the issuance of amendments, corrigenda, or errata. An official IEEE document at any point in time consists of the current edition of the document together with any amendments, corrigenda, or errata then in effect. In order to determine whether a given document is the current edition and whether it has been amended through the issuance of amendments, corrigenda, or errata, visit the IEEE Standards Association web site at <http://ieeexplore.ieee.org/xpl/standards.jsp>, or contact the IEEE at the address listed previously.

For more information about the IEEE Standards Association or the IEEE standards development process, visit the IEEE-SA web site at <http://standards.ieee.org>.

Errata

Errata, if any, for this and all other standards can be accessed at the following URL:   
<http://standards.ieee.org/findstds/errata/index.html>. Users are encouraged to check this URL for errata periodically.

Interpretations

Current interpretations can be accessed at the following URL: <http://standards.ieee.org/findstds/interps/index.html>.

Patents

***[If the IEEE has not received letters of assurance prior to the time of publication, the following notice shall appear:]***

Attention is called to the possibility that implementation of this<opt\_trial-use><gde./rec. prac./std.> may require use of subject matter covered by patent rights. By publication of this<opt\_trial-use><gde./rec. prac./std.>, no position is taken with respect to the existence or validity of any patent rights in connection therewith. The IEEE is not responsible for identifying Essential Patent Claims for which a license may be required, for conducting inquiries into the legal validity or scope of Patents Claims or determining whether any licensing terms or conditions provided in connection with submission of a Letter of Assurance, if any, or in any licensing agreements are reasonable or non-discriminatory. Users of this<opt\_trial-use><gde./rec. prac./std.> are expressly advised that determination of the validity of any patent rights, and the risk of infringement of such rights, is entirely their own responsibility. Further information may be obtained from the IEEE Standards Association.

***[The following notice shall appear when the IEEE receives assurance from a known patent holder or patent applicant prior to the time of publication that a license will be made available to all applicants either without compensation or under reasonable rates, terms, and conditions that are demonstrably free of any unfair discrimination.]***

Attention is called to the possibility that implementation of this<opt\_trial-use><gde./rec. prac./std.> may require use of subject matter covered by patent rights. By publication of this<opt\_trial-use><gde./rec. prac./std.>, no position is taken with respect to the existence or validity of any patent rights in connection therewith. A patent holder or patent applicant has filed a statement of assurance that it will grant licenses under these rights without compensation or under reasonable rates, with reasonable terms and conditions that are demonstrably free of any unfair discrimination to applicants desiring to obtain such licenses. Other Essential Patent Claims may exist for which a statement of assurance has not been received. The IEEE is not responsible for identifying Essential Patent Claims for which a license may be required, for conducting inquiries into the legal validity or scope of Patents Claims, or determining whether any licensing terms or conditions provided in connection with submission of a Letter of Assurance, if any, or in any licensing agreements are reasonable or non-discriminatory. Users of this<opt\_trial-use><gde./rec. prac./std.> are expressly advised that determination of the validity of any patent rights, and the risk of infringement of such rights, is entirely their own responsibility. Further information may be obtained from the IEEE Standards Association.

Participants

At the time this draft<opt\_trial-use><gde./rec. prac./std.> was submitted to the IEEE-SA Standards Board for approval, the Working Group had the following membership:

, *Chair*

, *Vice Chair*

Participant1

Participant2

Participant3

Participant4

Participant5

Participant6

Participant7

Participant8

Participant9

The following members of the <individual/entity> balloting committee voted on this<opt\_trial-use><gde./rec. prac./std.>. Balloters may have voted for approval, disapproval, or abstention.

***(to be supplied by IEEE)***

Balloter1

Balloter2

Balloter3

Balloter4

Balloter5

Balloter6

Balloter7

Balloter8

Balloter9

When the IEEE-SA Standards Board approved this<opt\_trial-use><gde./rec. prac./std.> on <XX MONTH 20XX>, it had the following membership:

***(to be supplied by IEEE)***

**<Name>,** *Chair*

**<Name>,** *Vice Chair*

**<Name>,** *Past Chair*

**<Name>,** *Secretary*

SBMember1

SBMember2

SBMember3

SBMember4

SBMember5

SBMember6

SBMember7

SBMember8

SBMember9

\*Member Emeritus

Also included are the following nonvoting IEEE-SA Standards Board liaisons:

<Name>, *NRC Representative*

<Name>, *DOE Representative*

<Name>, *NIST Representative*

<Name>

*IEEE Standards Program Manager, Document Development*

<Name>

*IEEE Standards Program Manager, Technical Program Development*

Contents

<After draft body is complete, select this text and click Insert Special->Add (Table of) Contents>

Draft for

***IMPORTANT NOTICE: This standard is not intended to ensure safety, security, health, or environmental protection. Implementers of the standard are responsible for determining appropriate safety, security, environmental, and health practices or regulatory requirements.***

***This IEEE document is made available for use subject to important notices and legal disclaimers.   
These notices and disclaimers appear in all publications containing this document and may   
be found under the heading “Important Notice” or “Important Notices and Disclaimers   
Concerning IEEE Documents.” They can also be obtained on request from IEEE or viewed at*** [***http://standards.ieee.org/IPR/disclaimers.html***](http://standards.ieee.org/IPR/disclaimers.html)***.***

1. Overview
   1. Scope
   2. Purpose
2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

1. ooo
2. ooo
3. ooo
4. ooo
5. ooo
6. General PHY requirements
   1. FSK PHY specification

***Insert the following item at the end of the second list in 8.1:***

* LECIM FSK PHY: a multi-regional, frequency shift keying PHY operating at over-the-air data rates in support of LECIM applications
  + 1. Operating frequency range

***Insert the following new rows at the end of table 66***

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **PHY**  **(MHz)** | **Frequency band**  **(MHz)** | **Spreading Parameters** | | **Data parameters** | | |
| **Chip rate**  **(kchip/s)** | **Modulation** | **Bit rate**  **(kb/s)** | **Symbol rate**  **(ksymbols/s)** | **Symbols** |
| 863 | 863-870 | --- | GFSK/FSK | 25 | 25 | Binary |
| --- | FSK | 12.5  (coordinator to end device only) | 12.5  (coordinator to end  device only) | Binary |
| 915 | 902-928 | --- | GFSK/FSK | 37.5 | 37.5 | Binary |
| --- | GFSK/FSK | 25 | 25 | Binary |
| --- | FSK | 12.5  (coordinator to end device only) | 12.5  (coordinator to end  device only) | Binary |
| 917 | 917-923.5 | --- | GFSK/FSK | 37.5 | 37.5 | Binary |
| --- | GFSK/FSK | 25 | 25 | Binary |
| --- | FSK | 12.5  (coordinator to end device only) | 12.5  (coordinator to end  device only) | Binary |
| 920 | 920-928 | --- | GFSK/FSK | 37.5 | 37.5 | Binary |
| --- | GFSK/FSK | 25 | 25 | Binary |
| --- | FSK | 12.5  (coordinator to end device only) | 12.5  (coordinator to end  device only) | Binary |
| 2450 | 2400-2483.5 | --- | GFSK/FSK | 37.5 | 37.5 | Binary |
| --- | GFSK/FSK | 25 | 25 | Binary |
| --- | FSK | 12.5  (coordinator to end device only) | 12.5  (coordinator to end  device only) | Binary |

* + 1. Channel Assignments

<REVISIT> LECIM channel assignments match those used for the SUN PHY MR-FSK mode channel assignments. (Can this reference section 16? or do we want a separate channel page for LECIM?)

Table - Total number of channels and first channel center frequencies for LECIM FSK PHYs

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Frequency Band (MHz) | Modulation  (Uplink/Downlink) | *ChanSpacing* (MHz) | *TotalNumChan* | *ChanCenterFreq0* (MHz) |
| 863-870 | GFSK/FSK | 0.1 | 69 | 863.075 |
| 902-928 | 0.2 | 129 | 902.2 |
| 917-923.5 | 32 | 917.1 |
| 920.5- 923.5 | 15 | 920.6 |
| 2400-2483.5 | 416 | 2400.2 |

1. PHY services
   1. Overview
   2. PHY constants

|  |  |  |
| --- | --- | --- |
| **Constant** | **Description** | **Value** |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |

* 1. PHY PIB attributes

|  |  |  |  |
| --- | --- | --- | --- |
| **Attribute** | **Type** | **Valid Range** | **Description** |
| *phyLECIMFSKPreambleLength* | Integer | 1-1000 | The number of 1-octet patterns (see 17.1.1.1) in the preamble.  This value is only valid for the LECIM FSK PHY |
| <REVIEW COMMENT>: There are a number of tradeoffs that have been discussed regarding preamble length.   * Longer preambles consume more power from battery endpoints if they are longer than a coordinator radio needs. Some coordinator radios can preform quite well with only a 1 octet preamble. * Endpoint radios may need 4 or more octets, but the length should not be so long that it violates the MAC operating mode and timing requirements, should the specification be of the form of “ >X but < than the requirements of the MAC operating mode timing requirements”? * Should there be different valid ranges for coordinator to end device communications and end device to coordinators, so that system designers can make different tradeoffs regarding performance and battery life for coordinators versus end devices? (The PAR acknowledges that there may be more capability in a coordinator.) | | | |
| *phyLECIMFSKPSDUMod* | Boolean | TRUE or FALSE | When TRUE, P-GFSK/P-FSK is enabled for the PSDU.  When FALSE, GFSK/FSK modulation is enabled for the PSDU. |
| *phyLECIMFSKSpreading* | Boolean | TRUE or FALSE | When TRUE, spreading is enabled.  When FALSE, spreading is disabled. |
| *phyLECIMFSKSpreadingFactor* | Integer | 1,2,4,8,16 | The spreading factor to be used when *phyLECIMFSKSpreading* is TRUE. |
| *phyLECIMFSKScramblePSDU* | Boolean | TRUE or FALSE | A value of FALSE indicates that data whitening of the PSDU is disabled. A value of TRUE indicates that data whitening of the PSDU is enabled.  This value is only valid for the LECIM FSK PHY. |
| *phyLECIMFECEnabled* | Boolean | TRUE or FALSE | A value of TRUE indicates that FEC is turned on. A value of FALSE indicates that FEC is turned off.  This value is only valid for the LECIM FSK PHY. |
| *phyLECIMFSKInterleavingEnabled* | Boolean | TRUE or FALSE | A value of TRUE indicates that interleaving is turned on. A value of FALSE indicates that interleaving is turned off.  This value is only valid for the LECIM FSK PHY. |
|  |  |  |  |

1. ooo
2. ooo
3. ooo
4. ooo
5. ooo
6. ooo
7. 15.4g PHYs
8. LECIM PHYs
   1. FSK PHY specification

The frequency shift keying PHY is described in the following subclauses.

* + 1. PPDU format for FSK

The FSK PPDU shall support the format shown in Figure 1.

The synchronization header (SHR), PHY header (PHR), and PHY payload components are treated as bit strings of length n, numbered b0 on the left and bn-1 on the right. When transmitted, they are processed b0 first to bn-1 last, without regard to their content or structure.

All reserved fields shall be set to zero upon transmission and shall be ignored upon reception.

|  |  |  |  |
| --- | --- | --- | --- |
|  |  | **Octets** | |
|  |  | N | variable |
| Preamble | SFD | As defined in 17.1.1.3 | PSDU |
| SHR | | PHR | PHY Payload |

Figure - Format of the FSK PPDU

* + - 1. Preamble Field

The Preamble field shall contain *phyLECIMFSKPreambleLength* (as defined in 9.3) multiples of the 8-bit sequence “01010101”.

* + - 1. SFD

The SFD for FSK shall be a 2-octet sequence selected from the list of values shown in Table 2. (language from 15.4g)

<REVIEW COMMENT>: There are concerns that a 2 octet SFD (like 15.4g) may create too much false triggering and perhaps 4 octets is more appropriate. Steve Jillings will do some analysis here.

<REVIEW COMMENT>: Also, should there be multiple SFDs to separate networks or should that be done with a Network ID field?

The SFD is transmitted starting from the leftmost bit (i.e., starting with b0).

Table - SFD Values

|  |  |  |
| --- | --- | --- |
| TBD |  |  |
|  |  |  |

* + - 1. PHR

The format of the PHR is shown in Figure 2. All multi-bit fields are unsigned integers and shall be processed MSB first.

|  |  |  |  |
| --- | --- | --- | --- |
| TBD |  |  |  |
|  |  |  |  |

Figure - PHR

* + - 1. PSDU Field

The PSDU field carries the data of the PPDU.

* + 1. Modulation and coding for FSK

The modulation for the FSK PHY shall be FSK/GFSK and P-FSK/P-GFSK.

Table 3 shows the modulation and channel parameters for the standard-defined PHY operating modes for the 863 MHz, 915 MHz, 917 MHz, 920 MHz, and 2450 MHz bands.

Although there are multiple data rates for each frequency band in Table 3, there is no over-the-air, dynamic data rate changing mechanism defined for this PHY. It is left to the system designed

Table - FSK modulation and channel parameters\*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Frequency band**  **(MHz)** | **Parameter** | **37.5 kbps** | **25 kbps** | **12.5 kbps** |
| 863-870  (Europe) | End device to coordinator | Not supportable due to regulations | GFSK/P-GFSK | Not supported |
| Coordinator to end device | Not supportable due to regulations | FSK/P-FSK | FSK |
| Modulation Index | 0.5 | 1.0 | 4.0 |
| Channel Spacing (kHz) | 100 | 100 | 100 |
| 902-928  (US ISM) | End device to coordinator | GFSK/P-GFSK | GFSK/P-GFSK | Not supported |
| Coordinator to end device | FSK/P-FSK | FSK/P-FSK | FSK |
| Modulation Index | 0.5 | 1.0 | 4.0 |
| Channel Spacing (kHz) | 200 | 200 | 200 |
| 917-923.5  (Korea) | End device to coordinator | GFSK/P-GFSK | GFSK/P-GFSK | Not supported |
| Coordinator to end device | FSK/P-FSK | FSK/P-FSK | FSK |
| Modulation Index | 0.5 | 1.0 | 4.0 |
| Channel Spacing (kHz) | 200 | 200 | 200 |
| 920-928  (Japan) | End device to coordinator | GFSK/P-GFSK | GFSK/P-GFSK | Not supported |
| Coordinator to end device | FSK/P-FSK | FSK/P-FSK | FSK |
| Modulation Index | 0.5 | 1.0 | 4.0 |
| Channel Spacing (kHz) | 200 | 200 | 200 |
| 2400-2483.5  (Worldwide) | End device to coordinator | GFSK/P-GFSK | GFSK/P-GFSK | Not supported |
| Coordinator to end device | FSK/P-FSK | FSK/P-FSK | FSK |
| Modulation Index | 0.5 | 1.0 | 4.0 |
| Channel Spacing (kHz) | 200 | 200 | 200 |

\*Data rates shown are over-the-air data rates (the data rate transmitted over the air regardless whether the FEC is enabled or not).

Table - FSK symbol duration used for MAC and PHY timing parameters

|  |  |
| --- | --- |
| **Frequency Band (MHz)** | **FSK symbol timing used for MAC and PHY timing parameters (µs)** |
| 863-870 (Europe) | 40 |
| 902-928 (US ISM) | 26.67 |
| 917-923.5 (Korea) | 26.67 |
| 920-928 (Japan) | 26.67 |
| 2400-2483.5 (Worldwide) | 26.67 |

The use of P-FSK/P-GFSK modulation for PSDU data is controlled by PIB attribute *phyLECIMFSKPSDUMod,* as defined in 9.3. The modulation for preamble, SFD and PHR shall be FSK/GFSK regardless of *phyLECIMFSKPSDUMod*.

FSK/GFSK encodes one bit by transmitting a frequency modulated signal with duration, i.e., . P-FSK/P-GFSK encodes two bits by transmitting a FSK/GFSK modulated signal with duration in one of two possible positions (also known as time deviation), i.e., and .

* + - 1. Reference modulator diagram

The functional block diagram in Figure 3 is provided as a reference for specifying the FSK PHY data flow processing functions. The subclause number in each block refers to the subclause that describes that function. Each bit shall be processed using the bit order rules defined in 17.1.1.

When FEC is enabled, the PHR and PSDU shall be processed for coding as a single block of data (see 17.1.2.4). When data whitening is enabled, the scrambling shall be only applied over the PSDU (see 17.1.3). When spreading is enabled, the spreading shall be applied over PHR and PSDU (see 17.1.2.6).

All fields in the PPDU shall use the same symbol rate and modulation order, unless otherwise specified elsewhere in this standard.



Figure - FSK reference modulator diagram

* + - 1. Bit-to-symbol mapping

The nominal frequency deviation, ∆f, shall be

The symbol encoding for FSK/GFSK and P-FSK/GFSK modulation is shown in Table 5 and Table 6, where the maximum frequency deviation, fdev is equal to ∆f.

Table – FSK/GFSK symbol encoding

|  |  |  |
| --- | --- | --- |
| Symbol () | Frequency deviation | Time deviation |
| 0 |  | 0 |
| 1 |  | 0 |

Table – P-FSK/P-GFSK symbol encoding

|  |  |  |
| --- | --- | --- |
| Symbol | Frequency deviation | Time deviation |
| 00 |  | 0 |
| 01 |  |  |
| 10 |  | 0 |
| 11 |  |  |

* + - 1. Modulation quality

Modulation quality shall be measured by observing the frequency deviation tolerance and the zero crossing tolerance of the eye diagram caused by a PN9 sequence of length 511 bits.

* + - * 1. Frequency deviation tolerance

**From 15.4g:**

Modulation frequency tolerance is measured as a percentage of the frequency deviation, fdev, dictated by the modulation index. The measured frequency deviation, f, at Ts/2 shall be constrained to the range 70% fdev < |f| < 130% fdev, as shown in Figure 4 Eye diagram for FSK, where Ts is the symbol time.

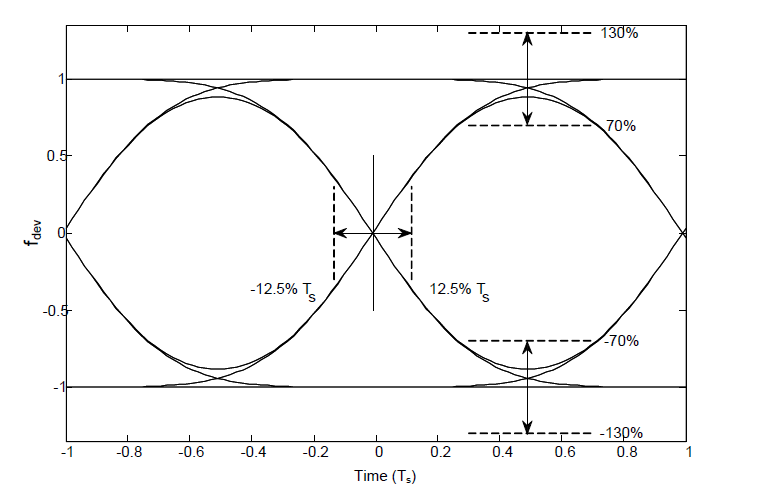
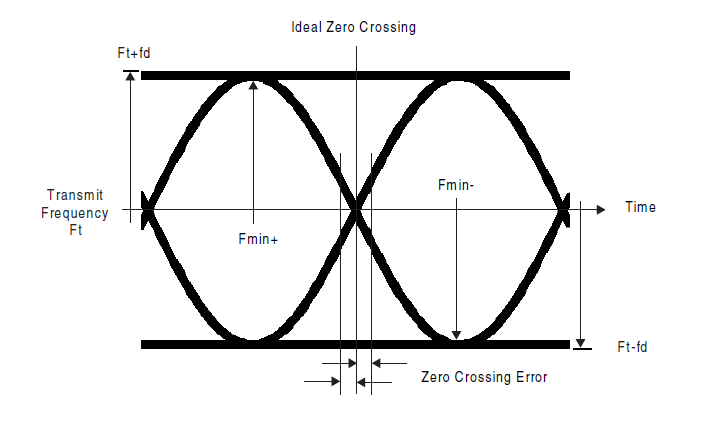


Figure Eye diagram for FSK

**From 15.1:**

The modulation is Gaussian frequency shift keying (GFSK) (see Figure 7) with a bandwidth-bit period product, known as bandwidth time (BT), of 0.5. The modulation index shall be between 0.28 and 0.35. A binary one shall be represented by a positive frequency deviation, and a binary zero shall be represented by a negative frequency deviation. The symbol timing shall be less than ± 20 ppm.



For each transmission, the minimum frequency deviation, Fmin = min{|Fmin+|, Fmin–}, which corresponds to 1010 sequence, shall be no smaller than ± 80% of the frequency deviation fd with respect to the transmit frequency Ft, which corresponds to a 00001111 sequence.

In addition, the minimum frequency deviation shall never be smaller than 115 kHz. The data transmitted have a symbol rate of 1 Msymbol/s.

The zero crossing error is the time difference between the ideal symbol period and the measured crossing time. This shall be less than ± 1/8 of a symbol period.

* + - * 1. Zero crossing tolerance

The excursions for the zero crossings for all trajectories of the eye diagram shall be constrained to within ±12.5% of the symbol time Ts, as shown in Figure 4.

* + - 1. Forward error correction

The FSK PHY shall perform FEC as defined in 16.1.2.4. The use of spreading is controlled by PIB attribute *phyLECIMFECEnabled*, as defined in 9.3. <REVIEW: Refers to 15.4g PHY specification, is that alright?>

* + - 1. Code-symbol interleaving

The FSK PHY shall perform interleaving as defined in 16.1.2.5. The use of spreading is controlled by PIB attribute phyLECIMFSKSpreading, as defined in 9.3. <REVIEW: Refers to 15.4g PHY specification, is that alright?>

* + - 1. Spreading

The use of spreading is controlled by PIB attribute *phyLECIMFSKSpreading*, as defined in 9.3. The spreading factor (SF) can be 1, 2, 4, 8, or 16. The variable spreading factor is indicated by PIB attribute *phyLECIMFSKInterleavingEnabled,* as defined in 9.3*.*

For spreading, a single input bit is mapped into the spreading bits .as shown in Figure 5 and its mapping is represented in Table 7.

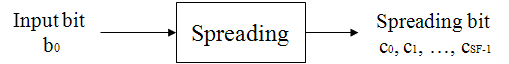


Figure - Spreading function

Table - Input bit to spreading bits mapping

|  |  |  |
| --- | --- | --- |
|  | Input bit  = 0 | Input bit  = 1 |
| SF = 1 | = 0 | = 1 |
| SF = 2 | = 01 | = 10 |
| SF = 4 | = 0101 | = 1010 |
| SF = 8 | = 01010101 | = 10101010 |
| SF = 16 | = 0101010101010101 | = 1010101010101010 |

* + 1. Data whitening for FSK

The FSK PHY shall perform data whitening as defined in 16.1.3. The use of data whitening is controlled by PIB attribute *phyLECIMFSKScramblePSDU*, as defined in 9.3.

* + 1. FSK PHY RF Requirements
       1. Operating Frequency Range

The FSK PHY operates in the bands given in Table 3.

* + - 1. Regulatory compliance

It is the responsibility of the implementer to verify and ensure that the device is in compliance with all regulatory requirements in the geographic region where the device is deployed or sold. Conformance with this standard does not guarantee compliance with the relevant regulatory requirements which may apply.

* + - 1. Radio frequency tolerance

The single-sided clock frequency tolerance *T* at the transmitter, in ppm, shall be as follows:

T = 20 ppm for all sub-GHz bands,

T = 40 ppm for the 2450 MHz band.

* + - 1. Channel switch time

Channel switch time shall be less than or equal to 500 μs. The channel switch time is defined as the time elapsed when changing to a new channel, including any required settling time.

* + - 1. Transmit spectral mask <REVIEW: Would it be better to reference local regulations than to define something here.>

The transmit spectral content is the ratio of the total transmitted out-of-channel power to the total transmitted in-channel power in a given integration bandwidth.

The integration bandwidth shall be equal to 1.5 x *R*, where *R* is the symbol rate, expressed in units of hertz.

Out-of-channel power shall be measured at two offset frequencies relative to the carrier frequency. The offset frequencies M1 and M2 are defined as follows:

*M1* = 1.5 x *R* x (1 + *h*)

*M2* = 3 x *R* x (1 + *h*)

where h is the modulation index for 2-level modulation.

The transmit spectral content at M1 and M2 shall be less than –25 dB and –35 dB, respectively.

The modulated signal shall use a PN data pattern of 511 bits or longer.

The spectrum analyzer settings for this measurement shall be as follows: the resolution bandwidth is 1 kHz, the video bandwidth is 1 kHz or greater, and the detector is RMS.

* + - 1. Receiver sensitivity

The FSK receiver sensitivity shall be better than S, where S, for binary modulation, is defined as follows:

where

S0 is –91 dBm without FEC and –97 dBm with FEC <REVIEW limits, should they be lower?>

R0 is 37.5 kb/s

R is the bit rate in kb/s

See 8.1.7 for additional information on receiver sensitivity.

* + - 1. Receiver interference rejection

The adjacent designated channels are those on either side of the desired designated channel that are closest in frequency to the desired designated channel. The alternate designated channel is more than one removed from the desired designated channel in the operational frequency band.

The adjacent channel rejection shall be measured as follows: the desired signal shall be a compliant FSK PHY signal, as defined in 16.1.2, of pseudo-random data at the center frequency of the desired channel. The desired signal is input to the receiver at a level 3 dB above the receiver sensitivity given in 16.1.4.7.

In either the adjacent or the alternate channel, an unmodulated carrier in the center of that channel is input at the following level relative to the level of the desired signal:

— The adjacent channel rejection shall be greater than or equal to 10 dB.

— The alternate channel rejection shall be greater than or equal to 30 dB.

The test shall be performed for only one interfering signal at a time. The receiver shall meet the error rate criteria defined in 8.1.7 under these conditions.

* + - 1. Tx-to-Rx turnaround time <Review: Is this too stringent for the power supplies of battery devices, i.e does it provide sufficient time for the power supply to recover after transmission?

The FSK PHY shall meet the requirements for TX-to-RX turnaround time as defined in 8.2.1.

* + - 1. Rx-to-Tx turnaround time

The FSK PHY shall meet the requirements for RX-to-TX turnaround time as defined in 8.2.2.

* + - 1. Transmit power

A transmitter shall be capable of transmitting at least –3 dBm. Devices should transmit lower power when possible in order to reduce interference to other devices and systems. <REVIEW power level, should it be higher? Or is it better to avoid a single number here and refer to the 120 dB of path loss from the PAR and local regulations?>

The maximum transmit power is limited by local regulatory bodies.

* + - 1. Receiver maximum input level of desired signal

FSK PHY shall have a receiver maximum input level greater than or equal to –40 dBm using the measurement defined in 8.2.4

* + - 1. Receiver ED

The FSK PHY shall provide the receiver ED measurement as described in 8.2.5.

* + - 1. Link quality indicator

The FSK PHY shall provide the LQI measurement as described in 8.2.6.

* + - 1. Clear channel assessment (CCA)

The FSK PHY shall use the one of the CCA methods as described in 8.2.7.

1. The Institute of Electrical and Electronics Engineers, Inc.

   3 Park Avenue, New York, NY 10016-5997, USA

   Copyright © 20XX by the Institute of Electrical and Electronics Engineers, Inc.

   All rights reserved. Published <XX MONTH 20XX>. Printed in the United States of America.

   IEEE is a registered trademark in the U.S. Patent & Trademark Office, owned by the Institute of Electrical and Electronics   
   Engineers, Incorporated.

   **PDF: ISBN 978-0-XXXX-XXXX-X STDXXXXX**

   **Print: ISBN 978-0-XXXX-XXXX-X STDPDXXXXX**

   *IEEE prohibits discrimination, harassment and bullying. For more information, visit* [*http://www.ieee.org/web/aboutus/whatis/policies/p9-26.html*](http://www.ieee.org/web/aboutus/whatis/policies/p9-26.html)*.*

   *No part of this publication may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.*  [↑](#footnote-ref-1)