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

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[[1]](#footnote-1)•

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Contents

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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.

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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. |
|  |  |  |  |

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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.

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