Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: [Radio Specification Analysis of Draft FSK PHY]
Date Submitted: [11 March 2012]
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Re: []

Abstract: []

Purpose: [To assist with the definition of the 15.4k FSK PHY]

FSK PHY Radio Specification and Regulatory Compliance

- Review of the draft LECIM FSK PHY radio specifications and regulatory compliance

- Section 19.2 FSK PHY RF Requirements
  - Refer 15-12-0089-01-004k
- Sub-GHz FSK PHYs
  - PHY recommendations for the sub-GHz PHYs will be presented in this presentation

- 2.4 GHz FSK PHY
  - Question for group:
  - Is mandating a narrowband 200 kHz channel spacing at 2450 MHz the best use of available spectrum given that 83 MHz is available?

- LECIM FSK modulation and channel parameters
  - Recommendation for Sub-GHz PHYs

FREQ BAND (MHz)	PARAMETER	37.5 kb/s	25 kb/s	12.5 kb/s
470 – 510 MHz (China)	End device to coordinator	GFSK / P-GFSK	GFSK / P-GFSK	GFSK / P-GFSK
	Coordinator to end device	GFSK / P-GFSK	GFSK / P-GFSK	GFSK / P-GFSK
	Modulation index	0.5	1.0	2.0
	Channel spacing (kHz)	100 / 200	100 / 200	100 / 200
779 – 787 MHz (China)	End device to coordinator	GFSK / P-GFSK	GFSK / P-GFSK	GFSK / P-GFSK
	Coordinator to end device	GFSK / P-GFSK	FSK / P-GFSK	FSK / P-GFSK
	Modulation index	0.5	1.0	2.0
	Channel spacing (kHz)	100 / 200	100 / 200	100 / 200
863 – 870 MHz (Europe)	End device to coordinator	NOT SUPPORTED DUE TO REGULATORY CONSTRAINTS	GFSK / P-GFSK	GFSK / P-GFSK
	Coordinator to end device		GFSK / P-GFSK	GFSK / P-GFSK
	Modulation index		1.0	2.0
	Channel spacing (kHz)		100	100
902 – 928 MHz (N.A.)	End device to coordinator	GFSK / P-GFSK	GFSK / P-GFSK	GFSK / P-GFSK
	Coordinator to end device	FSK / P-GFSK	GFSK / P-GFSK	GFSK / GP-FSK
	Modulation index	0.5	1.0	2.0
	Channel spacing (kHz)	100 / 200	100 / 200	100 / 200

- LECIM FSK modulation and channel parameters
  - Recommendation for Sub-GHz PHYs

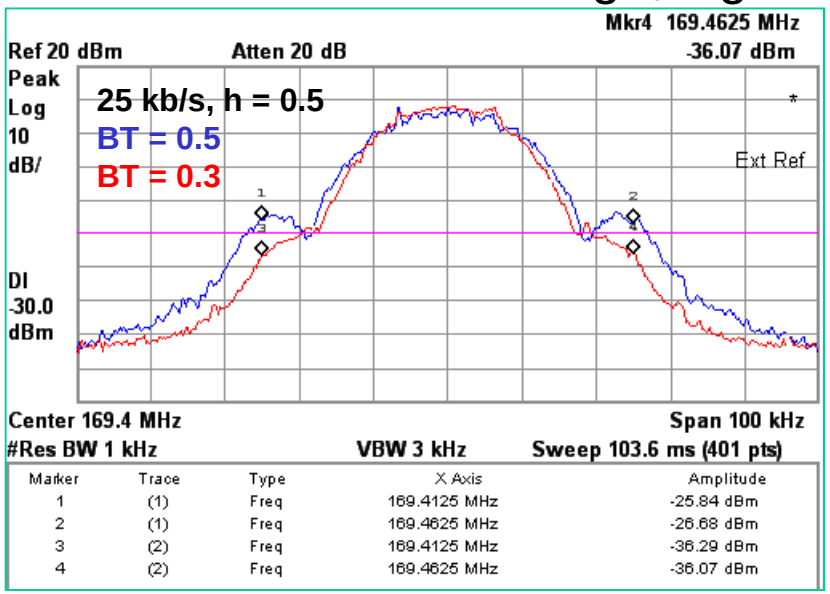
FREQ BAND (MHz)	PARAMETER	37.5 kb/s	25 kb/s	12.5 kb/s
917 – 923.5 (Korea)	End device to coordinator	GFSK / P-GFSK	GFSK / P-GFSK	GFSK / P-GFSK
	Coordinator to end device	GFSK / P-GFSK	GFSK / P-GFSK	GFSK / P-GFSK
	Modulation index	0.5	1.0	2.0
	Channel spacing (kHz)	200	200	200
920 – 928 MHz (Japan)	End device to coordinator	GFSK / P-GFSK	GFSK / P-GFSK	GFSK / P-GFSK
	Coordinator to end device	GFSK / P-GFSK	GFSK / P-GFSK	GFSK / P-GFSK
	Modulation index	0.5	1.0	2.0
	Channel spacing (kHz)	200	200	200

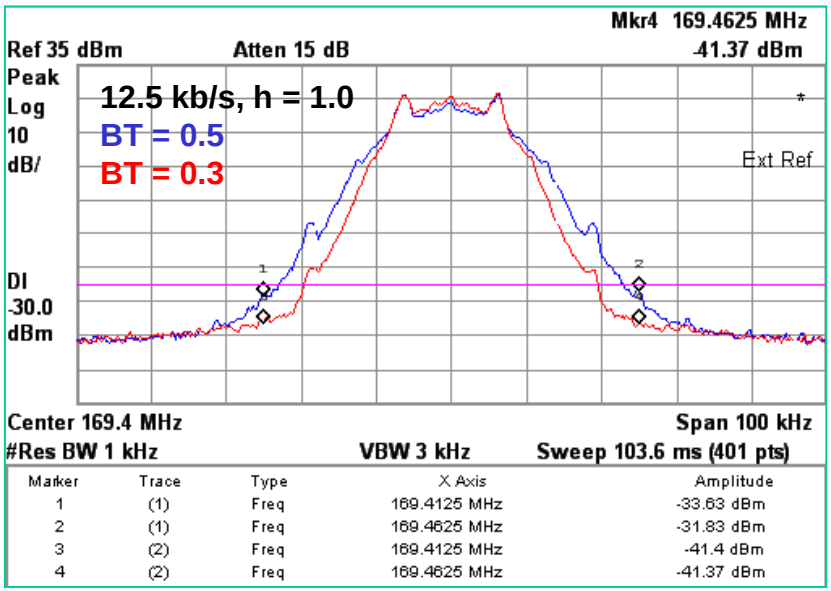
  - NOTES
    - 863 – 870 MHz PHY intended to comply with FHSS implementation requirements which mandates 100 kHz channel spacing (min. 47 hopping channels)
    - Although asymmetric data flow can be supported, it is not mandatory. Thus ALL available PHYs should be available to both end device and coordinator
    - Currently the LECIM FSK PHY does not support adaptive data rate mechanisms. Should such a mechanism be considered?

- New Sub-GHz PHY Bands
- European 169 MHz Band Proposal
  - 169.400 – 169.475 MHz (75 kHz)
  - 50 kHz maximum channel spacing
  - 500 mW ERP (+27 dBm) maximum permissible output power
- LECIM FSK modulation and channel parameters
  - 15-12-0094-00-004k
  - 25 kb/s PHY Mode GFSK modulation BT = 0.3
  - 12.5 kb/s PHY mode GFSK modulation BT = 0.5

FREQ BAND (MHz)	PARAMETER	25 kb/s	12.5 kb/s
169.400 – 169.475 (Europe)	End device to coordinator	GFSK / P-GFSK	GFSK / P-GFSK
	Coordinator to end device	GFSK / P-GFSK	GFSK / P-GFSK
	Modulation index	0.5	1.0
	Channel spacing (kHz)	50	50

- European 169 MHz Band Proposal
- Transmit spectral mask analysis
  - ETSI EN 300 220-1 Section 7.7 (Modulation BW) applies
  - At band / channel edge, signal must be at least -30 dBm / 1 kHz RBW



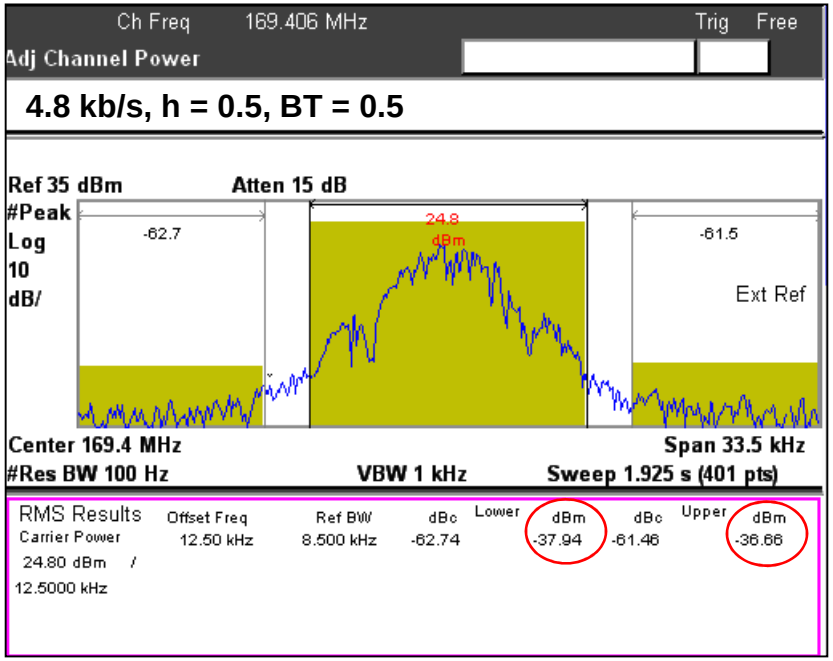


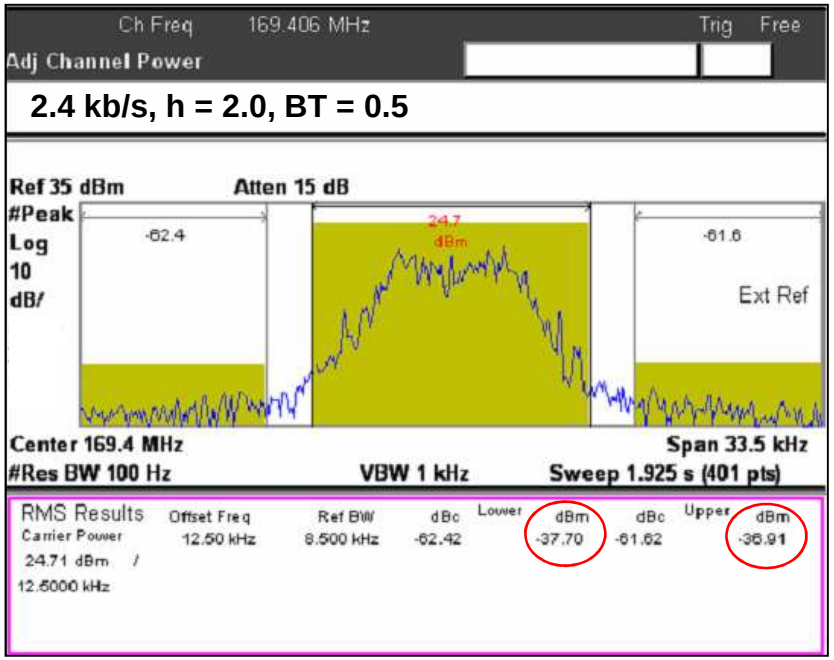
  - 25 kb/s ERP ~ 10 - 25 mW depending upon TX source
  - 12.5 kb/s ERP ~ 500 mW if BT = 0.3
    - BT = 0.3 increases Eb/No requirements at RX
  - Only single channel specified: Network capacity issues

- New Sub-GHz PHY Bands
- European 169 MHz Band Proposal
  - Alternate PHY proposal
  - PHY compatible with Wireless M-bus Mode N
    - 15-11-0651-01-004g
- LECIM FSK modulation and channel parameters
  - 4.8 kb/s PHY Mode GFSK modulation BT = 0.5
  - 2.4 kb/s PHY mode GFSK modulation BT = 0.5

FREQ BAND (MHz)	PARAMETER	4.8 kb/s	2.4 kb/s
169.400 – 169.475 (Europe)	End device to coordinator	GFSK / P-GFSK	GFSK / P-GFSK
	Coordinator to end device	GFSK / P-GFSK	GFSK / P-GFSK
	Modulation index	0.5	2.0
	Channel spacing (kHz)	12.5	12.5

- European 169 MHz Band Proposal
- Transmit spectral mask analysis
  - ETSI EN 300 220-1 Section 7.6 (Adjacent Channel Power) applies
  - Adjacent channel power must be at least 10 µW (-20 dBm) / 8.5 kHz BW





  - Phase noise / spectral regrowth will limit maximum TX output power
  - 6 channel available

- New Sub-GHz PHY Bands
- 434 MHz Band Proposal
  - 15-12-0094-00-004k
  - 433.05 – 434.79 MHz (1.74 MHz)
  - Output power varies between 0 dBm (LHM application to FCC) to +10 dBm (EU)
- LECIM FSK modulation and channel parameters
  - 100 kHz channel spacing as per 863 – 870 MHz and 902 – 928 MHz FSK PHY proposals
  - Up to 17 channels available
  - No regulatory issues envisaged

- 8.1.2 Channel Assignment
- Tables 1 and 2 define channel assignments for 200 kHz and alternate 100 kHz channel spacing
  - Channel center frequencies are offset by 100 kHz
  - EFFECTIVE channel spacing for co-located LECIM networks may be only 100 kHz – De facto 100 kHz channel plan
- Modulation and channel parameters (Table 78 and 79) allow for both Gaussian filtered and non-filtered FSK
  - For 100 kHz channel spacing Gaussian filtering provides additional band edge margin
  - Gaussian / “Gaussian-like” shaping function available on low cost integrated silicon
  - Mandate GFSK BT = 0.5 for FSK PHY

- 19.2.4.6 Receiver Sensitivity
- Channel model Examples
  - Hata suburban channel model used with worst case shadowing / penetration losses
    - Shadowing / fading can be destructive (as per analysis) or constructive
  - Path loss delta

FREQ (MHz)	HATA CHANNEL MODEL LOSS (dB)		DELTA (dB)
	LARGE CITY	OPEN SPACE	
169	113	89	24
434	124	98	26
490	125	99	26
783	130	103	27
900	132	104	28

  - For License-exempt (ISM) operation channel model losses typically higher in a poorly defined, lightly regulated market (N.A.) than a channelized or regulated environment (EU)

- Receiver Sensitivity
  - 169 MHz PHY
- RX Equations:
  - 25 kb/s PHY
    - Signal BW = 25 kHz
    - FSK noise floor = -111 dBm
    - P-FSK noise floor = -113 dBm
  - 12.5 kb/s PHY
    - Signal BW = 25 kHz
    - FSK noise floor = -111 dBm
    - P-FSK noise floor = -113 dBm
  - 4.8 kb/s PHY
    - Signal BW = 7.2 kHz
    - FSK noise floor = -118 dBm
    - P-FSK noise floor = -120 dBm
  - 2.4 kb/s PHY
    - Signal BW = 7.2 kHz
    - FSK noise floor = -118 dBm
    - P-FSK noise floor = -120 dBm

Frequency (MHz)	169	Valid Range 150-2400 MHz
Collector Antenna Height (m)	10	Hata Valid Range 30-200 m, including terrain. Erceg Valid Range 10-80m, including terrain
Endpoint Antenna Height (m)	2	Hata Valid Range 1-10 m, Erceg Fixed to 2m.
Distance (km)	1	Valid Range Hata 1-20 km, Valid Range Erceg 100m-8km
Downlink Path Loss Calculation		Notes
Collector Tx Power (dBm)	27	Subject to Tx Power Regulations
Collector Tx Antenna Gain (dBi)	0	Subject to Tx Power Regulations
Path Loss (dB)	-106.51	Must reference the right path loss from the Hata or Erceg worksheet
Shadowing Margin (dB)	-16	To buffer against variable shadowing loss
Penetration Loss (dB)	-10	For underground vaults, etc.
Endpoint Rx Antenna Gain (dBi)	0	If using same antenna for Tx, must be same as in Uplink Table
Endpoint Interference (dB)	1	Rise over Thermal Interference
Rx Power at Endpoint (dBm)	-104.51	Compare against Rx sensitivity
Uplink Path Loss Calculation		Notes
Endpoint Tx Power (dBm)	27	Subject to Tx Power Regulations. Can be different from Collector
Endpoint Tx Antenna Gain (dBi)	0	Subject to Tx Power Regulations
Penetration Loss (dB)	-10	For underground vaults, etc.
Path Loss (dB)	-106.51	Same as Downlink
Shadowing Margin (dB)	-16	Same as Downlink
Collector Rx Antenna Gain (dBi)	0	If using same antenna for Tx, must be same as in Downlink Table
Collector Interference (dB)	2	Rise over Thermal Interference
Rx Power at Collector (dBm)	-103.51	Compare against Rx sensitivity

- Receiver Sensitivity
  - 434 MHz PHY (NA)
- RX Equations:
  - 37.5 kb/s PHY
    - Signal BW = 56.25 kHz
    - FSK noise floor = -109 dBm
    - P-FSK nose floor = -111 dBm
  - 25 kb/s PHY
    - Signal BW = 50 kHz
    - FSK noise floor = -110 dBm
    - P-FSK noise floor = -112 dBm
  - 12.5 kb/s PHY
    - Signal BW = 37.5 kHz
    - FSK noise floor = -111 dBm
    - P-FSK noise floor = -113 dBm

Frequency (MHz)	434	Valid Range 150-2400 MHz
Collector Antenna Height (m)	10	Hata Valid Range 30-200 m, including terrain. Erceg Valid Range 10-80m, including terrain
Endpoint Antenna Height (m)	2	Hata Valid Range 1-10 m, Erceg Fixed to 2m.
Distance (km)	1	Valid Range Hata 1-20 km, Valid Range Erceg 100m-8km
Downlink Path Loss Calculation		Notes
Collector Tx Power (dBm)	0	Subject to Tx Power Regulations
Collector Tx Antenna Gain (dBi)	0	Subject to Tx Power Regulations
Path Loss (dB)	-115.45	Must reference the right path loss from the Hata or Erceg worksheet
Shadowing Margin (dB)	-16	To buffer against variable shadowing loss
Penetration Loss (dB)	-10	For underground vaults, etc.
Endpoint Rx Antenna Gain (dBi)	0	If using same antenna for Tx, must be same as in Uplink Table
Endpoint Interference (dB)	1	Rise over Thermal Interference
Rx Power at Endpoint (dBm)	-140.45	Compare against Rx sensitivity
Uplink Path Loss Calculation		Notes
Endpoint Tx Power (dBm)	0	Subject to Tx Power Regulations. Can be different from Collector
Endpoint Tx Antenna Gain (dBi)	0	Subject to Tx Power Regulations
Penetration Loss (dB)	-10	For underground vaults, etc.
Path Loss (dB)	-115.45	Same as Downlink
Shadowing Margin (dB)	-16	Same as Downlink
Collector Rx Antenna Gain (dBi)	0	If using same antenna for Tx, must be same as in Downlink Table
Collector Interference (dB)	2	Rise over Thermal Interference
Rx Power at Collector (dBm)	-139.45	Compare against Rx sensitivity

- Receiver Sensitivity
  - 434 MHz PHY (EU)
- RX Equations:
  - 37.5 kb/s PHY
    - Signal BW = 56.25 kHz
    - FSK noise floor = -109 dBm
    - P-FSK nose floor = -111 dBm
  - 25 kb/s PHY
    - Signal BW = 50 kHz
    - FSK noise floor = -110 dBm
    - P-FSK noise floor = -112 dBm
  - 12.5 kb/s PHY
    - Signal BW = 37.5 kHz
    - FSK noise floor = -111 dBm
    - P-FSK noise floor = -113 dBm

Frequency (MHz)	434	Valid Range 150-2400 MHz
Collector Antenna Height (m)	10	Hata Valid Range 30-200 m, including terrain. Erceg Valid Range 10-80m, including terrain
Endpoint Antenna Height (m)	2	Hata Valid Range 1-10 m, Erceg Fixed to 2m.
Distance (km)	1	Valid Range Hata 1-20 km, Valid Range Erceg 100m-8km
Downlink Path Loss Calculation		Notes
Collector Tx Power (dBm)	10	Subject to Tx Power Regulations
Collector Tx Antenna Gain (dBi)	0	Subject to Tx Power Regulations
Path Loss (dB)	-115.45	Must reference the right path loss from the Hata or Erceg worksheet
Shadowing Margin (dB)	-16	To buffer against variable shadowing loss
Penetration Loss (dB)	-10	For underground vaults, etc.
Endpoint Rx Antenna Gain (dBi)	0	If using same antenna for Tx, must be same as in Uplink Table
Endpoint Interference (dB)	1	Rise over Thermal Interference
Rx Power at Endpoint (dBm)	-130.45	Compare against Rx sensitivity
Uplink Path Loss Calculation		Notes
Endpoint Tx Power (dBm)	10	Subject to Tx Power Regulations. Can be different from Collector
Endpoint Tx Antenna Gain (dBi)	0	Subject to Tx Power Regulations
Penetration Loss (dB)	-10	For underground vaults, etc.
Path Loss (dB)	-115.45	Same as Downlink
Shadowing Margin (dB)	-16	Same as Downlink
Collector Rx Antenna Gain (dBi)	0	If using same antenna for Tx, must be same as in Downlink Table
Collector Interference (dB)	2	Rise over Thermal Interference
Rx Power at Collector (dBm)	-129.45	Compare against Rx sensitivity

- Receiver Sensitivity
  - 470 MHz PHY (PRC)
- RX Equations:
  - 37.5 kb/s PHY
    - Signal BW = 56.25 kHz
    - FSK noise floor = -109 dBm
    - P-FSK nose floor = -111 dBm
  - 25 kb/s PHY
    - Signal BW = 50 kHz
    - FSK noise floor = -110 dBm
    - P-FSK noise floor = -112 dBm
  - 12.5 kb/s PHY
    - Signal BW = 37.5 kHz
    - FSK noise floor = -111 dBm
    - P-FSK noise floor = -113 dBm

Frequency (MHz)	490	Valid Range 150-2400 MHz
Collector Antenna Height (m)	10	Hata Valid Range 30-200 m, including terrain. Erceg Valid Range 10-80m, including terrain
Endpoint Antenna Height (m)	2	Hata Valid Range 1-10 m, Erceg Fixed to 2m.
Distance (km)	1	Valid Range Hata 1-20 km, Valid Range Erceg 100m-8km
Downlink Path Loss Calculation		Notes
Collector Tx Power (dBm)	17	Subject to Tx Power Regulations
Collector Tx Antenna Gain (dBi)	0	Subject to Tx Power Regulations
Path Loss (dB)	-116.57	Must reference the right path loss from the Hata or Erceg worksheet
Shadowing Margin (dB)	-16	To buffer against variable shadowing loss
Penetration Loss (dB)	-10	For underground vaults, etc.
Endpoint Rx Antenna Gain (dBi)	0	If using same antenna for Tx, must be same as in Uplink Table
Endpoint Interference (dB)	1	Rise over Thermal Interference
Rx Power at Endpoint (dBm)	-124.57	Compare against Rx sensitivity
Uplink Path Loss Calculation		Notes
Endpoint Tx Power (dBm)	17	Subject to Tx Power Regulations. Can be different from Collector
Endpoint Tx Antenna Gain (dBi)	0	Subject to Tx Power Regulations
Penetration Loss (dB)	-10	For underground vaults, etc.
Path Loss (dB)	-116.57	Same as Downlink
Shadowing Margin (dB)	-16	Same as Downlink
Collector Rx Antenna Gain (dBi)	0	If using same antenna for Tx, must be same as in Downlink Table
Collector Interference (dB)	2	Rise over Thermal Interference
Rx Power at Collector (dBm)	-123.57	Compare against Rx sensitivity

- Receiver Sensitivity
  - 780 MHz PHY (PRC)
- RX Equations:
  - 37.5 kb/s PHY
    - Signal BW = 56.25 kHz
    - FSK noise floor = -109 dBm
    - P-FSK nose floor = -111 dBm
  - 25 kb/s PHY
    - Signal BW = 50 kHz
    - FSK noise floor = -110 dBm
    - P-FSK noise floor = -112 dBm
  - 12.5 kb/s PHY
    - Signal BW = 37.5 kHz
    - FSK noise floor = -111 dBm
    - P-FSK noise floor = -113 dBm

Frequency (MHz)	783	Valid Range 150-2400 MHz
Collector Antenna Height (m)	10	Hata Valid Range 30-200 m, including terrain. Erceg Valid Range 10-80m, including terrain
Endpoint Antenna Height (m)	2	Hata Valid Range 1-10 m, Erceg Fixed to 2m.
Distance (km)	1	Valid Range Hata 1-20 km, Valid Range Erceg 100m-8km
Downlink Path Loss Calculation		Notes
Collector Tx Power (dBm)	17	Subject to Tx Power Regulations
Collector Tx Antenna Gain (dBi)	0	Subject to Tx Power Regulations
Path Loss (dB)	-120.80	Must reference the right path loss from the Hata or Erceg worksheet
Shadowing Margin (dB)	-16	To buffer against variable shadowing loss
Penetration Loss (dB)	-10	For underground vaults, etc.
Endpoint Rx Antenna Gain (dBi)	0	If using same antenna for Tx, must be same as in Uplink Table
Endpoint Interference (dB)	1	Rise over Thermal Interference
Rx Power at Endpoint (dBm)	-128.80	Compare against Rx sensitivity
Uplink Path Loss Calculation		Notes
Endpoint Tx Power (dBm)	17	Subject to Tx Power Regulations. Can be different from Collector
Endpoint Tx Antenna Gain (dBi)	0	Subject to Tx Power Regulations
Penetration Loss (dB)	-10	For underground vaults, etc.
Path Loss (dB)	-120.80	Same as Downlink
Shadowing Margin (dB)	-16	Same as Downlink
Collector Rx Antenna Gain (dBi)	0	If using same antenna for Tx, must be same as in Downlink Table
Collector Interference (dB)	2	Rise over Thermal Interference
Rx Power at Collector (dBm)	-127.80	Compare against Rx sensitivity

- Receiver Sensitivity
  - 868 MHz PHY (EU)
- RX Equations:
  - 37.5 kb/s PHY
    - Signal BW = 56.25 kHz
    - FSK noise floor = -109 dBm
    - P-FSK nose floor = -111 dBm
  - 25 kb/s PHY
    - Signal BW = 50 kHz
    - FSK noise floor = -110 dBm
    - P-FSK noise floor = -112 dBm
  - 12.5 kb/s PHY
    - Signal BW = 37.5 kHz
    - FSK noise floor = -111 dBm
    - P-FSK noise floor = -113 dBm

Frequency (MHz)	868	Valid Range 150-2400 MHz
Collector Antenna Height (m)	10	Hata Valid Range 30-200 m, including terrain. Erceg Valid Range 10-80m, including terrain
Endpoint Antenna Height (m)	2	Hata Valid Range 1-10 m, Erceg Fixed to 2m.
Distance (km)	1	Valid Range Hata 1-20 km, Valid Range Erceg 100m-8km
Downlink Path Loss Calculation		Notes
Collector Tx Power (dBm)	14	Subject to Tx Power Regulations
Collector Tx Antenna Gain (dBi)	0	Subject to Tx Power Regulations
Path Loss (dB)	-121.71	Must reference the right path loss from the Hata or Erceg worksheet
Shadowing Margin (dB)	-16	To buffer against variable shadowing loss
Penetration Loss (dB)	-10	For underground vaults, etc.
Endpoint Rx Antenna Gain (dBi)	0	If using same antenna for Tx, must be same as in Uplink Table
Endpoint Interference (dB)	1	Rise over Thermal Interference
Rx Power at Endpoint (dBm)	-132.71	Compare against Rx sensitivity
Uplink Path Loss Calculation		Notes
Endpoint Tx Power (dBm)	14	Subject to Tx Power Regulations. Can be different from Collector
Endpoint Tx Antenna Gain (dBi)	0	Subject to Tx Power Regulations
Penetration Loss (dB)	-10	For underground vaults, etc.
Path Loss (dB)	-121.71	Same as Downlink
Shadowing Margin (dB)	-16	Same as Downlink
Collector Rx Antenna Gain (dBi)	0	If using same antenna for Tx, must be same as in Downlink Table
Collector Interference (dB)	2	Rise over Thermal Interference
Rx Power at Collector (dBm)	-131.71	Compare against Rx sensitivity

- Receiver Sensitivity
  - 915 MHz PHY (NA)
- RX Equations:
  - 37.5 kb/s PHY
    - Signal BW = 56.25 kHz
    - FSK noise floor = -109 dBm
    - P-FSK nose floor = -111 dBm
  - 25 kb/s PHY
    - Signal BW = 50 kHz
    - FSK noise floor = -110 dBm
    - P-FSK noise floor = -112 dBm
  - 12.5 kb/s PHY
    - Signal BW = 37.5 kHz
    - FSK noise floor = -111 dBm
    - P-FSK noise floor = -113 dBm

Frequency (MHz)	915	Valid Range 150-2400 MHz
Collector Antenna Height (m)	10	Hata Valid Range 30-200 m, including terrain. Erceg Valid Range 10-80m, including terrain
Endpoint Antenna Height (m)	2	Hata Valid Range 1-10 m, Erceg Fixed to 2m.
Distance (km)	1	Valid Range Hata 1-20 km, Valid Range Erceg 100m-8km
Downlink Path Loss Calculation		Notes
Collector Tx Power (dBm)	30	Subject to Tx Power Regulations
Collector Tx Antenna Gain (dBi)	6	Subject to Tx Power Regulations
Path Loss (dB)	-122.17	Must reference the right path loss from the Hata or Erceg worksheet
Shadowing Margin (dB)	-16	To buffer against variable shadowing loss
Penetration Loss (dB)	-10	For underground vaults, etc.
Endpoint Rx Antenna Gain (dBi)	0	If using same antenna for Tx, must be same as in Uplink Table
Endpoint Interference (dB)	1	Rise over Thermal Interference
Rx Power at Endpoint (dBm)	-111.17	Compare against Rx sensitivity
Uplink Path Loss Calculation		Notes
Endpoint Tx Power (dBm)	30	Subject to Tx Power Regulations. Can be different from Collector
Endpoint Tx Antenna Gain (dBi)	0	Subject to Tx Power Regulations
Penetration Loss (dB)	-10	For underground vaults, etc.
Path Loss (dB)	-122.17	Same as Downlink
Shadowing Margin (dB)	-16	Same as Downlink
Collector Rx Antenna Gain (dBi)	0	If using same antenna for Tx, must be same as in Downlink Table
Collector Interference (dB)	2	Rise over Thermal Interference
Rx Power at Collector (dBm)	-116.17	Compare against Rx sensitivity

- Receiver Sensitivity
  - 917 MHz PHY (Korea)
- RX Equations:
  - 37.5 kb/s PHY
    - Signal BW = 56.25 kHz
    - FSK noise floor = -109 dBm
    - P-FSK nose floor = -111 dBm
  - 25 kb/s PHY
    - Signal BW = 50 kHz
    - FSK noise floor = -110 dBm
    - P-FSK noise floor = -112 dBm
  - 12.5 kb/s PHY
    - Signal BW = 37.5 kHz
    - FSK noise floor = -111 dBm
    - P-FSK noise floor = -113 dBm
  - 3mW case decreases RX power by 5 dB

Frequency (MHz)	920	Valid Range 150-2400 MHz
Collector Antenna Height (m)	10	Hata Valid Range 30-200 m, including terrain. Erceg Valid Range 10-80m, including terrain
Endpoint Antenna Height (m)	2	Hata Valid Range 1-10 m, Erceg Fixed to 2m.
Distance (km)	1	Valid Range Hata 1-20 km, Valid Range Erceg 100m-8km
Downlink Path Loss Calculation		Notes
Collector Tx Power (dBm)	10	Subject to Tx Power Regulations
Collector Tx Antenna Gain (dBi)	0	Subject to Tx Power Regulations
Path Loss (dB)	-122.22	Must reference the right path loss from the Hata or Erceg worksheet
Shadowing Margin (dB)	-16	To buffer against variable shadowing loss
Penetration Loss (dB)	-10	For underground vaults, etc.
Endpoint Rx Antenna Gain (dBi)	0	If using same antenna for Tx, must be same as in Uplink Table
Endpoint Interference (dB)	1	Rise over Thermal Interference
Rx Power at Endpoint (dBm)	-137.22	Compare against Rx sensitivity
Uplink Path Loss Calculation		Notes
Endpoint Tx Power (dBm)	10	Subject to Tx Power Regulations. Can be different from Collector
Endpoint Tx Antenna Gain (dBi)	0	Subject to Tx Power Regulations
Penetration Loss (dB)	-10	For underground vaults, etc.
Path Loss (dB)	-122.22	Same as Downlink
Shadowing Margin (dB)	-16	Same as Downlink
Collector Rx Antenna Gain (dBi)	0	If using same antenna for Tx, must be same as in Downlink Table
Collector Interference (dB)	2	Rise over Thermal Interference
Rx Power at Collector (dBm)	-136.22	Compare against Rx sensitivity

- Receiver Sensitivity
  - 920 MHz PHY (Japan)
- RX Equations:
  - 37.5 kb/s PHY
    - Signal BW = 56.25 kHz
    - FSK noise floor = -109 dBm
    - P-FSK nose floor = -111 dBm
  - 25 kb/s PHY
    - Signal BW = 50 kHz
    - FSK noise floor = -110 dBm
    - P-FSK noise floor = -112 dBm
  - 12.5 kb/s PHY
    - Signal BW = 37.5 kHz
    - FSK noise floor = -111 dBm
    - P-FSK noise floor = -113 dBm

Frequency (MHz)	924	Valid Range 150-2400 MHz
Collector Antenna Height (m)	10	Hata Valid Range 30-200 m, including terrain. Erceg Valid Range 10-80m, including terrain
Endpoint Antenna Height (m)	2	Hata Valid Range 1-10 m, Erceg Fixed to 2m.
Distance (km)	1	Valid Range Hata 1-20 km, Valid Range Erceg 100m-8km
Downlink Path Loss Calculation		Notes
Collector Tx Power (dBm)	24	Subject to Tx Power Regulations
Collector Tx Antenna Gain (dBi)	0	Subject to Tx Power Regulations
Path Loss (dB)	-122.25	Must reference the right path loss from the Hata or Erceg worksheet
Shadowing Margin (dB)	-16	To buffer against variable shadowing loss
Penetration Loss (dB)	-10	For underground vaults, etc.
Endpoint Rx Antenna Gain (dBi)	0	If using same antenna for Tx, must be same as in Uplink Table
Endpoint Interference (dB)	1	Rise over Thermal Interference
Rx Power at Endpoint (dBm)	-123.25	Compare against Rx sensitivity
Uplink Path Loss Calculation		Notes
Endpoint Tx Power (dBm)	24	Subject to Tx Power Regulations. Can be different from Collector
Endpoint Tx Antenna Gain (dBi)	0	Subject to Tx Power Regulations
Penetration Loss (dB)	-10	For underground vaults, etc.
Path Loss (dB)	-122.25	Same as Downlink
Shadowing Margin (dB)	-16	Same as Downlink
Collector Rx Antenna Gain (dBi)	0	If using same antenna for Tx, must be same as in Downlink Table
Collector Interference (dB)	2	Rise over Thermal Interference
Rx Power at Collector (dBm)	-122.25	Compare against Rx sensitivity

- 19.2.4.6 Receiver Sensitivity
  - PAR Scope: "...Propagation path loss of at least 120 dB…"
  - Regulatory TX ERP limits

PHY (MHz)	REGULATORY DOMAIN	MAX TX ERP		MIN RX SENS (dBm)
		(W)	(dBm)	
169	EU	0.5	+27	-93
434	FCC	0.001	0	-120
	EU	0.01	+10	-110
470	PRC	0.05	+17	-103
780	PRC	0.05	+17	-103
863	EU	0.025	+14	-106
915	N.A.	1	+30	-90
917	KOREA	0.01	+10	-110
		0.003	+5	-115
920	JAPAN	0.02	+13	-107
	JAPAN (920.5 – 923.5 MHz)	0.25	+24	-96

- 19.2.4.6 Receiver Sensitivity
  - RX noise floor (dBm): -174 + BW_{Rx} + NF_{RX} + SNR_{demod}
- Reduce NF_{RX} with an external LNA
  - 7 - 8 dB is a good figure of merit for typical silicon NF
- Reduce SNR_{demod} through mod, spreading and coding gain
  - Modulation gain
    - +1 dB using coherent demod – longer training sequence
    - +2 dB P-FSK modulation
  - Coding gain
    - Theory vs. practice?
    - Typical FSK systems only offer ~ 2 to 3 dB of coding gain (ref: TI DN 504)
  - Spreading gain
    - Theoretically 10*log(SF)
    - Co-channel rejection is figure of merit for FSK demodulation
    - Fast hopping interference appears as an AM pulse – IM2 limitation
    - Spreading will only be effective in well defined channel cases

- 19.2.4.6 Receiver Sensitivity
- Assumption that spreading / coding gain allows receiver to meet minimum 120 dB propagation loss requirement if transmitter transmits at maximum ERP allowed by regulations
  - Max spreading gain = 10*log(SF) = 12 dB
  - Max coding gain = 6 dB
  - Achievable in noise free channel. Real world?
- Two options to define receiver sensitivity
  - Baseline sensitivity similar to definition of 15.4g
  - Receiver sensitivity to meet PAR propagation loss for stated transmitter output power

- 19.2.4.6 Receiver Sensitivity
- Baseline sensitivity definition
  - Minimum sensitivity NA 915 MHz band = -90 dBm
  - Minimum sensitivity NA 434 MHz band = -120 dBm!
    - NA 434 MHz band requires new PHY definition…
  - Minimum sensitivity Korea 917 MHz band = -115 dBm

- How to agree / determine a minimum receiver sensitivity specification with such a wide variation in required sensitivity?

- 19.2.4.6 Receiver Sensitivity
- Receiver sensitivity defined to meet PAR propagation loss for stated transmitter output power
- Define receiver sensitivity at minimum PHY BR or minimum defined PHY BR of device
  - $S_0 = (P_{TX} – 120)$ (dBm)
    - S_0 = minimum sensitivity level at the minimum defined BR for the FSK PHY (dBm)
    - P_{TX} = stated transmitted output power of the device (dBm)
  - $S = [S_0 + 10*\log(R/R_0)]$ (dBm)
    - S = required minimum sensitivity level (dBm)
    - R_0 = symbol rate at minimum BR for the FSK PHY (kb/s)
    - R = symbol rate (kb/s)
  - Spreading and / or FEC may be implemented to meet sensitivity limit

- 19.2.4.7 Receiver Interference Rejection
  - From 15-12-0014-02-004k:

CHANNEL SPACING (kHz)	ADJACENT CHANNEL REJECTION (dBm)	ALTERNATE CHANNEL REJECTION (dBm)
12.5 / 100	25	35
200	30	45

  - Negligible difference between ACR / AACR data for modulated or unmodulated interferer
- Since FSK sensitivity may require Spreading and / or FEC and co-channel rejection is figure of merit for FSK demodulator – define CCR specification
  - CCR = -10 dB
  - Spreading and / or FEC may be enabled

- 19.2.4.7 Receiver Interference Rejection
  - For mixed environment operation (license-exempt frequency bands) consider for interference rejection from non-linear interfering mechanisms
    - Blocking interference is more likely interfering mechanism than ACR / AACR
    - Primary usage of frequency band is licensed system
    - Licensed systems operating at or close to band edge

FREQUENCY OFFSET (MHz)	BLOCKING IMMUNITY (dBm)
1	-50
2	-45
10	-40

  - Spreading and / or FEC may be enabled

- Recommendations
  - Allow all available PHYs to be available between coordinator and end device
  - 100 kHz channel spacing for EU 434 MHz and 863 MHz PHYs
  - Adopt W M-Bus compatible PHY for EU 169 MHz band
  - New PHY definition required for NA 434 MHz band
  - Adopt GFSK BT = 0.5 for all FSK PHYs
  - Adopt adaptive receiver sensitivity definition of Slide #26
  - Adopt receiver interference rejection limits of Slide #27
  - Adopt receiver CCR limits of Slide #27
  - Adopt blocking specification limits of Slide #28
- Further discussions
  - All of the above!
  - 2450 MHz FSK PHY
  - Adaptive data rate mechanism

References:

- 15-12-0089-02-004k “Preliminary draft for 4k” (Brown)
- 15-11-0864-04-004k “FSK PHY Working Draft” (Johnson)
- 15-12-0094-00-004k "Proposed Resolutions to various TBDs in the FSK Draft" (Seibert)
- 15-12-0014-02-004k “Radio Specification Analysis of Draft FSK PHY” (Jillings)
- 15-11-0651-01-004g “Comment resolution for 4g sponsor ballot” (Popa, Salazar)