Shelly X module X4L datasheet

Datasheet version 4.0

Hardware version V011

Table of contents

List of Tables

Features

CPU and On-Chip Memory

- HP RISC-V processor:
  - Clock speed: up to 160 MHz
  - Four stage pipeline
  - CoreMark® score: 496.66 CoreMark; 3.10 CoreMark/MHz (160 MHz)
- LP RISC-V processor:
  - Clock speed: up to 20 MHz
  - Two stage pipeline
- Flash: 8MB

*The flash is integrated into the chip's package. Flash supports more than **100,000 program/erase cycles** and more than **20 years** data retention time.*

Peripherals

Peripherals and communication protocols, accessible via the firmware platform:

- Up to **11 configurable IOs**
- Temperature (DS18B20) and humidity (DHT22) sensor support over 1-Wire
- UART serial connection for debugging and flashing

Power management

- Fine-resolution power control through a selection of clock frequency, duty cycle, Wi-Fi operating modes, and individual power control of internal components
- Four power modes designed for typical scenarios: Active, Modem-sleep, Light-sleep, Deep-sleep

Operating conditions

- Recommended input voltage: 3.3–3.6 V
- Operating ambient temperature: –40°C ~ 105 °C

Wi-Fi

- 1T1R in 2.4 GHz band
- Operating frequency: 2412 ~ 2484 MHz
- IEEE 802.11ax-compliant
  - 20 MHz-only non-AP mode
  - MCS0 ~MCS9
  - Uplink and downlink OFDMA, especially suitable for simultaneous connections in high-density environments
  - Downlink MU-MIMO (multi-user, multiple input, multiple output) to increase network capacity
  - Beamformee that improves signal quality
  - Channel quality indication (CQI)
  - DCM (dual carrier modulation) to improve link robustness
  - Spatial reuse to maximize parallel transmissions
  - Target wake time (TWT) that optimizes power saving mechanisms
- Fully compatible with IEEE 802.11b/g/n protocol
  - 20 MHz and 40 MHz bandwidth 7

Bluetooth®

- Bluetooth LE: Bluetooth 5.3
- High power mode (20 dBm)
- Speed: 125 Kbps, 500 Kbps, 1 Mbps, 2 Mbps
- Advertising extensions
- Multiple advertisement sets
- Channel selection algorithm #2
- LE power control

Internal co-existence mechanism between Wi-Fi and Bluetooth to share the same antenna

RF Module

- Antenna switches, RF balun, power amplifier, low-noise receive amplifier
- Up to +21 dBm of power for an 802.11b transmission
- Up to +19.5 dBm of power for an 802.11ax transmission
- Up to -106 dBm of sensitivity for Bluetooth LE receiver (125 Kbps)

Module overview

IO layout

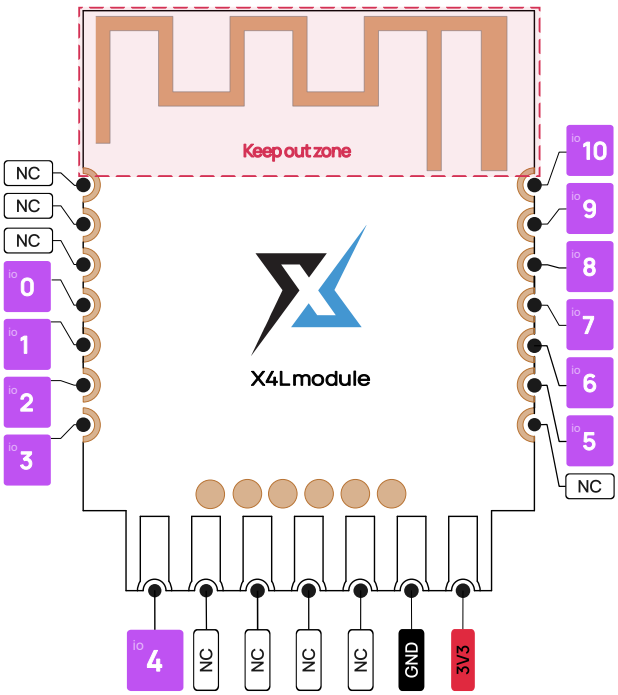

Figure 1 Module IO layout

Keep out zone

The exact dimesions are marked in the Module dimesnions schematic.

Module dimensions

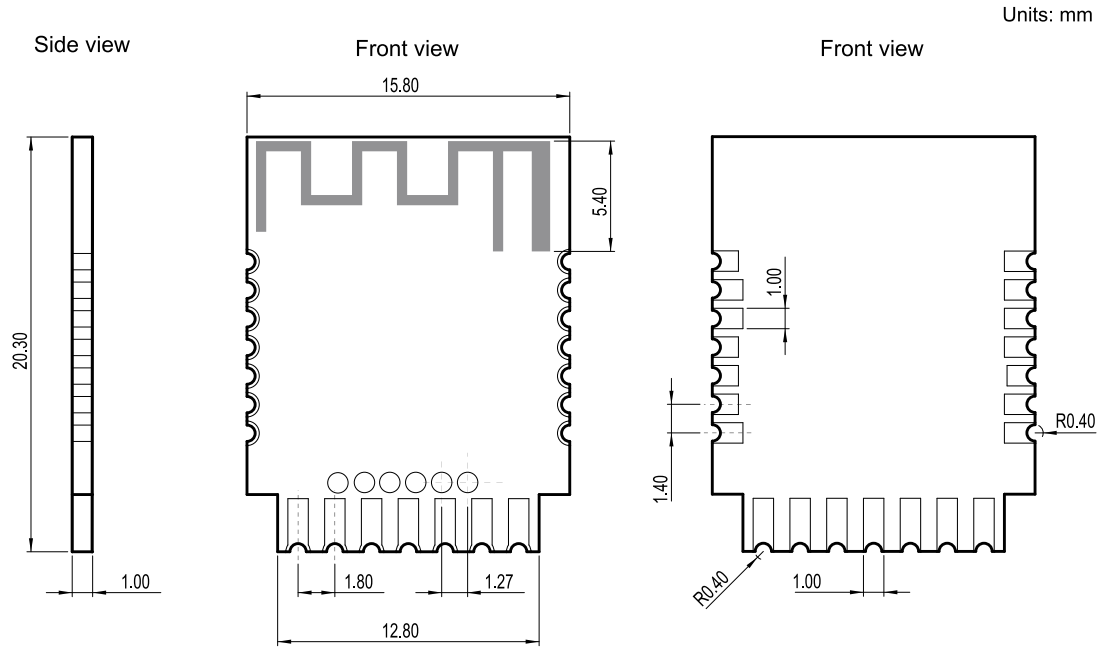

Figure 2 Module dimensions

Electrical Characteristics

Absolute Maximum Ratings

Stresses above those listed in **Table 1 Absolute Maximum Ratings** may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these or any other conditions beyond those indicated under **Table 2 Recommended Operating Conditions** is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

Parameter	Description	Min	Max	Unit
Input power pins	Allowed input voltage	-0.3	3.6	V
I_{output}[1]	Cumulative IO output current	—	1000	mA
T_{STORE}	Storage temperature	-40	150	°C

Table 1: Absolute Maximum Ratings

[1] *The product proved to be fully functional after all its IO pins were pulled high while being connected to ground for 24 consecutive hours at ambient temperature of 25 °C.*

Recommended Operating Conditions

Parameter[1]	Description	Min	Typ.	Max	Unit
VDDA1, VDDA2, VDDA3P3	Recommended input voltage	3.0	3.3	3.6	V
VDDPST1	Recommended input voltage	3.0	3.3	3.6	V
VDD_SPI (as input)	—	3.0	3.3	3.6	V
VDDPST2 [2,3]	Recommended input voltage	3.0	3.3	3.6	V
I_{VDD}	Cumulative input current	0.5	—	—	A
T_A	Ambient temperature	-40	—	85	°C

Table 2: Recommended operating conditions

[1] *See in conjunction with Section **Power Supply**.*

[2] *If VDDPST2 is used to power VDD_SPI (see Section **Power Scheme**), the voltage drop on R_{SPI} should be accounted for. See also Section **VDD_SPI Output Characteristics**.*

[3] *If writing to eFuses, the voltage on VDDPST2 should not exceed 3.3 V as the circuits responsible for burning eFuses are sensitive to higher voltages.*

DC Characteristics (3.3 V, 25 °C)

Symbol	Parameter	Min	Typ.	Max	Unit
C_{IN}	Pin capacitance	—	2	—	pF
V_{IH}	High-level input voltage	0.75 × VDD[1]	—	VDD[1] + 0.3	V
V_{IL}	Low-level input voltage	−0.3	—	0.25 × VDD[1]	V
I_{IH}	High-level input current	—	—	50	nA
I_{IL}	Low-level input current	—	—	50	nA
V_{OH}[2]	High-level output voltage	0.8 × VDD[1]	—	—	V
V_{OL}[2]	Low-level output voltage	—	—	0.1 × VDD[1]	V
I_{OH}	High-level source current (VDD[1] = 3.3 V, V_{OH} >= 2.64 V, PAD_DRIVER = 3)	—	40	—	mA
I_{OL}	Low-level sink current (VDD[1] = 3.3 V, V_{OL} =0.495 V, PAD_DRIVER = 3)	—	28	—	mA
R_{PU}	Internal weak pull-up resistor	—	45	—	kΩ
R_{PD}	Internal weak pull-down resistor	—	45	—	kΩ
V_{IH_nRST}	Chip reset release voltage CHIP_PU voltage is within the specified range)	0.75 × VDD[1]	—	VDD[1] + 0.3	V
V_{IL_nRST}	Chip reset voltage (CHIP_PU voltage is within the specified range)	−0.3	—	0.25 × VDD[1]	V

Table 3: DC Characteristics (3.3 V, 25 °C)

[1] *VDD voltage from a power pin of a respective power domain.*

[2] *V_{OH} and V_{OL} are measured using high-impedance load.*

Current Consumption Characteristics

Current Consumption in Active Mode

The current consumption measurements are taken with a **3.3 V** supply at **25 °C** ambient temperature.

TX current consumption is rated at a 100% duty cycle. RX current consumption is rated when the peripherals are disabled and the CPU idle.

Wi-Fi (2.4 GHz) in Active Mode

Work mode	Description		Peak (mA)
Active (RF working)	TX	802.11b, 1 Mbps, DSSS @ 21.0 dBm	354
		802.11g, 54 Mbps, OFDM @ 19.5 dBm	300
		802.11n, HT20, MCS7 @ 18.5 dBm	280
		802.11n, HT40, MCS7 @ 18.0 dBm	268
		802.11ax, MCS9, @ 16.5 dBm	252
	RX	802.11b/g/n, HT20	78
		802.11n, HT40	82
		802.11ax, HE20	78

Table 4: Current Consumption for Wi-Fi (2.4 GHz) in Active Mode

Bluetooth LE in Active Mode

Work Mode	RF Condition	Description	Peak (mA)
Active (RF working)	TX	Bluetooth LE @ 20.0 dBm	315
		Bluetooth LE @ 9.0 dBm	190
		Bluetooth LE @ 0 dBm	130
		Bluetooth LE @ –15.0 dBm	94
	RX	Bluetooth LE	71

Table 5: Current Consumption for Bluetooth LE in Active Mode

802.15.4 in Active Mode

Work Mode	RF Condition	Description	Peak (mA)
Active (RF working)	TX	802.15.4 @ 20.0 dBm	305
		802.15.4 @ 12.0 dBm	187
		802.15.4 @ 0 dBm	119
		802.15.4 @ –15.0 dBm	92
	RX	802.15.4	74

Table 6: Current Consumption for 802.15.4 in Active Mode

Current Consumption in Other Modes

Modem sleep mode

Mode	CPU Frequency (MHz)	Description	Typ	
			All Peripherals Clocks Disabled (mA)	All Peripherals Clocks Enabled (mA)[1]
Modem-sleep[2,3]	160	CPU is running	27	38
		CPU is idle	17	28
	80	CPU is running	19	30
		CPU is idle	14	25

Table 7: Current Consumption in Modem-sleep Mode

[1] *In practice, the current consumption might be different depending on which peripherals are enabled.*

[2] *In Modem-sleep mode, Wi-Fi is clock gated.*

[3] *In Modem-sleep mode, the consumption might be higher when accessing flash.*

Low power modes

Mode	Description	Typ (µA)
Light-sleep	CPU and wireless communication modules are powered down, peripheral clocks are disabled, and all GPIOs are high-impedance	180
	CPU, wireless communication modules and peripherals are powered down, and all GPIOs are high-impedance	35
Deep-sleep	RTC timer and LP memory are powered on	7
Power off	CHIP_PU is set to low level, the chip is powered off	1

Table 8: Current Consumption in Low-Power Modes

Reliability

Test Item	Test Conditions	Test Standard
HTOL (High Temperature Operating Life)	125 °C, 1000 hours	JESD22-A108
ESD (Electro-Static Discharge Sensitivity)	HBM (Human Body Mode)[1] ± 2000 V	JS-001
	CDM (Charge Device Mode)[2] ± 1000 V	JS-002
Latch up	Current trigger ± 200 mA	JESD78
	Voltage trigger 1.5 × VDDmax	
Preconditioning	Bake 24 hours @125 °C Moisture soak (level 3: 192 hours @30 °C, 60% RH) IR reflow solder: 260 + 0 °C, 20 seconds, three times	J-STD-020, JESD47, JESD22-A113

TCT (Temperature Cycling Test)	–65 °C / 150 °C, 500 cycles	JESD22-A104
uHAST (Highly Accelerated Stress Test, unbiased)	130 °C, 85% RH, 96 hours	JESD22-A118
HTSL (High Temperature Storage Life)	150 °C, 1000 hours	JESD22-A103
LTSL (Low Temperature Storage Life)	–40 °C, 1000 hours	JESD22-A119

Table 9: Reliability

[1] JEDEC document JEP155 states that 500 V HBM allows safe manufacturing with a standard ESD control process.

[2] JEDEC document JEP157 states that 250 V CDM allows safe manufacturing with a standard ESD control process.

RF Characteristics

The RF data is measured at the antenna port, where RF cable is connected, including the front-end loss. The front-end circuit is a 0Ω resistor.

Devices should operate in the center frequency range allocated by regional regulatory authorities.

Unless otherwise stated, the RF tests are conducted with a 3.3 V (±5%) supply at 25 ^{0}C ambient temperature.

Wi-Fi Radio

Name	Description
Center frequency range of operating channel	2412 ~ 2484 MHz
Wi-Fi wireless standard	IEEE 802.11b/g/n/ax

Table 10: Wi-Fi RF Characteristics

Wi-Fi RF Transmitter (TX) Characteristics

TX Power with Spectral Mask and EVM Meeting 802.11 Standards

Rate	Min (dBm)	Typ (dBm)	Max (dBm)
802.11b, 1 Mbps, DSSS	—	21.0	—
802.11b, 11 Mbps, CCK	—	21.0	—
802.11g, 6 Mbps, OFDM	—	20.5	—
802.11g, 54 Mbps, OFDM	—	19.5	—
802.11n, HT20, MCS0	—	19.5	—
802.11n, HT20, MCS7	—	18.5	—
802.11n, HT40, MCS0	—	19.0	—
802.11n, HT40, MCS7	—	18.0	—
802.11ax, HE20, MCS0	—	19.5	—
802.11ax, HE20, MCS9	—	16.5	—

Table 11: TX Power with Spectral Mask and EVM Meeting 802.11 Standards

TX EVM Test[1]

Rate	Min (dB)	Typ (dB)	Limit (dB)
802.11b, 1 Mbps, DSSS	—	–25.5	–10.0
802.11b, 11 Mbps, CCK	—	–25.5	–10.0
802.11g, 6 Mbps, OFDM	—	–26.5	–5.0
802.11g, 54 Mbps, OFDM	—	–29.0	–25.0
802.11n, HT20, MCS0	—	–29.0	–5.0
802.11n, HT20, MCS7	—	–30.0	–27.0
802.11n, HT40, MCS0	—	–28.5	–5.0
802.11n, HT40, MCS7	—	–29.5	–27.0
802.11ax, HE20, MCS0	—	–29.0	–5.0
802.11ax, HE20, MCS9	—	–34.0	–32.0

Table 12: TX EVM Test[1]

[1] *EVM is measured at the corresponding typical TX power provided in* ***TX Power with Spectral Mask and EVM Meeting 802.11 Standards*** *above.*

Wi-Fi RF Receiver (RX) Characteristics

For RX tests, the PER (packet error rate) limit is 8% for 802.11b, and 10% for 802.11g/n/ax.

RX Sensitivity

Rate	Min (dBm)	Typ (dBm)	Max (dBm)
802.11b, 1 Mbps, DSSS	—	-99.2	—
802.11b, 2 Mbps, DSSS	—	-96.8	—
802.11b, 5.5 Mbps, CCK	—	-93.8	—
802.11b, 11 Mbps, CCK	—	-90.0	—
802.11g, 6 Mbps, OFDM	—	-94.0	—
802.11g, 9 Mbps, OFDM	—	-93.2	—
802.11g, 12 Mbps, OFDM	—	-92.6	—
802.11g, 18 Mbps, OFDM	—	-90.0	—
802.11g, 24 Mbps, OFDM	—	-86.8	—
802.11g, 36 Mbps, OFDM	—	-83.2	—
802.11g, 48 Mbps, OFDM	—	-79.0	—
802.11g, 54 Mbps, OFDM	—	-77.6	—
802.11n, HT20, MCS0	—	-93.6	—
802.11n, HT20, MCS1	—	-92.4	—
802.11n, HT20, MCS2	—	-89.6	—
802.11n, HT20, MCS3	—	-86.2	—
802.11n, HT20, MCS4	—	-82.8	—
802.11n, HT20, MCS5	—	-78.8	—
802.11n, HT20, MCS6	—	-77.2	—
802.11n, HT20, MCS7	—	-75.6	—
802.11n, HT40, MCS0	—	-91.0	—
802.11n, HT40, MCS1	—	-90.0	—
802.11n, HT40, MCS2	—	-87.4	—
802.11n, HT40, MCS3	—	-83.8	—
802.11n, HT40, MCS4	—	-80.8	—
802.11n, HT40, MCS5	—	-76.6	—
802.11n, HT40, MCS6	—	-75.0	—
802.11n, HT40, MCS7	—	-73.4	—
802.11ax, HE20, MCS0	—	-93.8	—
802.11ax, HE20, MCS1	—	-91.2	—
802.11ax, HE20, MCS2	—	-88.4	—

802.11ax, HE20, MCS3	–	-85.6	–
802.11ax, HE20, MCS4	–	-82.2	–
802.11ax, HE20, MCS5	–	-78.4	–
802.11ax, HE20, MCS6	–	-76.6	–
802.11ax, HE20, MCS7	–	-74.8	–
802.11ax, HE20, MCS8	–	-71.0	–
802.11ax, HE20, MCS9	–	-69.0	–

Table 13: RX Sensitivity

Maximum RX level

Rate	Min (dBm)	Typ (dBm)	Max (dBm)
802.11b, 1 Mbps, DSSS	–	5	–
802.11b, 11 Mbps, CCK	–	5	–
802.11g, 6 Mbps, OFDM	–	5	–
802.11g, 54 Mbps, OFDM	–	0	–
802.11n, HT20, MCS0	–	5	–
802.11n, HT20, MCS7	–	0	–
802.11n, HT40, MCS0	–	5	–
802.11n, HT40, MCS7	–	0	–
802.11ax, HE20, MCS0	–	5	–
802.11ax, HE20, MCS9	–	0	–

Table 14: Maximum RX Level

RX Adjacent channel rejection

Rate	Min (dB)	Typ (dB)	Max (dB)
802.11b, 1 Mbps, DSSS	–	38	–
802.11b, 11 Mbps, CCK	–	38	–
802.11g, 6 Mbps, OFDM	–	31	–
802.11g, 54 Mbps, OFDM	–	20	–
802.11n, HT20, MCS0	–	31	–
802.11n, HT20, MCS7	–	16	–
802.11n, HT40, MCS0	–	28	–
802.11n, HT40, MCS7	–	10	–
802.11ax, HE20, MCS0	–	25	–
802.11ax, HE20, MCS9	–	2	–

Table 15: RX Adjacent Channel Rejection

Bluetooth 5 (LE) Radio

Bluetooth LE RF Characteristics

Name	Description
Center frequency range of operating channel	2402 ~ 2480 MHz
RF transmit power range	–15.0 ~ 20.0 dBm

Table 16: Bluetooth LE RF Characteristics

Bluetooth LE RF Transmitter (TX) Characteristics

Bluetooth LE - Transmitter Characteristics - 1 Mbps

Parameter	Description	Min	Typ	Max	Unit
Carrier frequency offset and drift	Max. $\lvert f_n \rvert_{n=0, 1, 2, 3, \ldots k}$	—	1.3	—	kHz
	Max. $\lvert f_0 - f_n \rvert_{n=2, 3, 4, \ldots k}$	—	1.5	—	kHz
	Max. $\lvert f_n - f_{n-5} \rvert_{n=6, 7, 8, \ldots k}$	—	0.9	—	kHz
	$\lvert f_1 - f_0 \rvert$	—	0.6	—	kHz
Modulation characteristics	$\Delta F1_{avg}$	—	249.9	—	kHz
	Min. $\Delta F2_{max}$ (for at least 99.9% of all $\Delta F2_{max}$)	—	212.1	—	kHz
	$\Delta F2_{avg} / \Delta F1_{avg}$	—	0.88	—	—
In-band emissions	± 2 MHz offset	—	–29	—	dBm
	± 3 MHz offset	—	–36	—	dBm
	> ± 3 MHz offset	—	–39	—	dBm

Table 17: Bluetooth LE - Transmitter Characteristics - 1 Mbps

Bluetooth LE - Transmitter Characteristics - 2 Mbps

Parameter	Description	Min	Typ	Max	Unit
Carrier frequency offset and drift	Max. $\lvert f_n \rvert_{n=0, 1, 2, 3, \ldots k}$	—	2.2	—	kHz
	Max. $\lvert f_0 - f_n \rvert_{n=2, 3, 4, \ldots k}$	—	1.1	—	kHz
	Max. $\lvert f_n - f_{n-5} \rvert_{n=6, 7, 8, \ldots k}$	—	1.1	—	kHz
	$\lvert f_1 - f_0 \rvert$	—	0.5	—	kHz
Modulation characteristics	$\Delta F1_{avg}$	—	499.4	—	kHz
	Min. $\Delta F2_{max}$ (for at least 99.9% of all $\Delta F2_{max}$)	—	443.5	—	kHz
	$\Delta F2_{avg} / \Delta F1_{avg}$	—	0.95	—	—

In-band emissions	± 4 MHz offset	—	−40	—	dBm
	± 5 MHz offset	—	−41	—	dBm
	> ± 5 MHz offset	—	−42	—	dBm

Table 18: Bluetooth LE - Transmitter Characteristics - 2 Mbps

Bluetooth LE - Transmitter Characteristics - 125 Kbps

Parameter	Description	Min	Typ	Max	Unit
Carrier frequency offset and drift	Max. $\lvert f_n \rvert_{n=0, 1, 2, 3, \ldots k}$	—	0.7	—	kHz
	Max. $\lvert f_0 - f_n \rvert_{n=1, 2, 3, \ldots k}$	—	0.3	—	kHz
	$\lvert f_0 - f_3 \rvert$	—	0.1	—	kHz
	Max. $\lvert f_n - f_{n-3} \rvert_{n=7, 8, 9, \ldots k}$	—	0.4	—	kHz
Modulation characteristics	$\Delta F1_{avg}$	—	250.0	—	kHz
	Min. $\Delta F1_{max}$ (for at least 99.9% of all $\Delta F1_{max}$)	—	238.0	—	kHz
In-band emissions	± 2 MHz offset	—	−29	—	dBm
	± 3 MHz offset	—	−36	—	dBm
	> ± 3 MHz offset	—	−39	—	dBm

Table 19: Bluetooth LE - Transmitter Characteristics - 125 Kbps

Bluetooth LE - Transmitter Characteristics - 500 Kbps

Parameter	Description	Min	Typ	Max	Unit
Carrier frequency offset and drift	Max. $\lvert f_n \rvert_{n=0, 1, 2, 3, \ldots k}$	—	0.5	—	kHz
	Max. $\lvert f_0 - f_n \rvert_{n=1, 2, 3, \ldots k}$	—	0.3	—	kHz
	$\lvert f_0 - f_3 \rvert$	—	0.1	—	kHz
	Max. $\lvert f_n - f_{n-3} \rvert_{n=7, 8, 9, \ldots k}$	—	0.4	—	kHz
Modulation characteristics	$\Delta F2_{avg}$	—	230.7	—	kHz
	Min. $\Delta F2_{max}$ (for at least 99.9% of all $\Delta F2_{max}$)	—	217.6	—	kHz
In-band emissions	± 2 MHz offset	—	−28	—	dBm
	± 3 MHz offset	—	−36	—	dBm
	> ± 3 MHz offset	—	−39	—	dBm

Table 20: Bluetooth LE - Transmitter Characteristics - 500 Kbps

Bluetooth LE RF Receiver (RX) Characteristics

Bluetooth LE - Receiver Characteristics - 1 Mbps

Parameter		Description	Min	Typ	Max	Unit
Sensitivity @30.8% PER		—	—	−98.5	—	dBm
Maximum received signal @30.8% PER		—	—	8	—	dBm
C/I and receiver selectivity performance	Co-channel	F = F0 MHz	—	7	—	dB
	Adjacent channel	F = F0 + 1 MHz	—	4	—	dB
		F = F0 − 1 MHz	—	3	—	dB
		F = F0 + 2 MHz	—	−21	—	dB
		F = F0 − 2 MHz	—	−22	—	dB
		F = F0 + 3 MHz	—	−28	—	dB
		F = F0 − 3 MHz	—	−36	—	dB
		F ≥ F0 + 4 MHz	—	−27	—	dB
		F ≤ F0 − 4 MHz	—	−36	—	dB
	Image frequency	—	—	−26	—	dB
	Adjacent channel to image frequency	F = F_{image} + 1 MHz	—	−29	—	dB
		F = F_{image} − 1 MHz	—	−28	—	dB
Out-of-band blocking performance		30 MHz ~ 2000 MHz	—	−16	—	dBm
		2003 MHz ~ 2399 MHz	—	−24	—	dBm
		2484 MHz ~ 2997 MHz	—	−16	—	dBm
		3000 MHz ~ 12.75 GHz	—	−1	—	dBm
Intermodulation		—	—	−27	—	dBm

Table 21: Bluetooth LE - Receiver Characteristics - 1 Mbps

Bluetooth LE - Receiver Characteristics - 2 Mbps

Parameter		Description	Min	Typ	Max	Unit
Sensitivity @30.8% PER		—	—	−95.5	—	dBm
Maximum received signal @30.8% PER		—	—	8	—	dBm
C/I and receiver selectivity performance	Co-channel	F = F0 MHz	—	8	—	dB
	Adjacent channel	F = F0 + 2 MHz	—	3	—	dB
		F = F0 − 2 MHz	—	2	—	dB
		F = F0 + 4 MHz	—	−23	—	dB
		F = F0 − 4 MHz	—	−25	—	dB
		F = F0 + 6 MHz	—	−31	—	dB
		F = F0 − 6 MHz	—	−35	—	dB
		F ≥ F0 + 8 MHz	—	−36	—	dB

		F ≤ F0 – 8 MHz	—	–36	—	dB
	Image frequency	—	—	–23	—	dB
	Adjacent channel to image frequency	F = F_{image} + 2 MHz	—	–30	—	dB
		F = F_{image} – 2 MHz	—	3	—	dB
Out-of-band blocking performance		30 MHz ~ 2000 MHz	—	–18	—	dBm
		2003 MHz ~ 2399 MHz	—	–28	—	dBm
		2484 MHz ~ 2997 MHz	—	–16	—	dBm
		3000 MHz ~ 12.75 GHz	—	–1	—	dBm
Intermodulation		—	—	–29	—	dBm

Table 22: Bluetooth LE - Receiver Characteristics - 2 Mbps

Bluetooth LE - Receiver Characteristics - 125 Kbps

Parameter		Description	Min	Typ	Max	Unit
Sensitivity @30.8% PER		—	—	–106.0	—	dBm
Maximum received signal @30.8% PER		—	—	8	—	dBm
C/I and receiver selectivity performance	Co-channel	F = F0 MHz	—	2	—	dB
	Adjacent channel	F = F0 + 1 MHz	—	–1	—	dB
		F = F0 – 1 MHz	—	–3	—	dB
		F = F0 + 2 MHz	—	–31	—	dB
		F = F0 – 2 MHz	—	–27	—	dB
		F = F0 + 3 MHz	—	–33	—	dB
		F = F0 – 3 MHz	—	–42	—	dB
		F ≥ F0 + 4 MHz	—	–31	—	dB
		F ≤ F0 – 4 MHz	—	–48	—	dB
	Image frequency	—	—	–31	—	dB
	Adjacent channel to image frequency	F = Fimage + 1 MHz	—	–36	—	dB
		F = Fimage – 1 MHz	—	–33	—	dB

Table 23: Bluetooth LE - Receiver Characteristics - 125 Kbps

Bluetooth LE - Receiver Characteristics - 500 Kbps

Parameter		Description	Min	Typ	Max	Unit
Sensitivity @30.8% PER		—	—	-102.0	—	dBm
Maximum received signal @30.8% PER		—	—	8	—	dBm
C/I and receiver selectivity performance	Co-channel	F = F0 MHz	—	4	—	dB
	Adjacent channel	F = F0 + 1 MHz	—	-1	—	dB
		F = F0 – 1 MHz	—	-1	—	dB
		F = F0 + 2 MHz	—	-23	—	dB
		F = F0 – 2 MHz	—	-24	—	dB
		F = F0 + 3 MHz	—	-33	—	dB
		F = F0 – 3 MHz	—	-41	—	dB
		F ≥ F0 + 4 MHz	—	-31	—	dB
		F ≤ F0 – 4 MHz	—	-41	—	dB
	Image frequency	—	—	-30	—	dB
	Adjacent channel to image frequency	$F = F_{image} + 1$ MHz	—	-35	—	dB
		$F = F_{image} - 1$ MHz	—	-27	—	dB

Table 24: Bluetooth LE - Receiver Characteristics - 500 Kbps

802.15.4 Radio

802.15.4 RF Characteristics

Name	Description
Center frequency range of operating channel	2405 ~ 2480 MHz

Table 25: 802.15.4 RF Characteristics

[1] Zigbee in the 2.4 GHz range supports 16 channels at 5 MHz spacing from channel 11 to channel 26.

802.15.4 RF Transmitter (TX) Characteristics

802.15.4 Transmitter Characteristics - 250 Kbps

Name	Min	Typ	Max	Unit
RF transmit power range	-15.0	—	20.0	dBm
EVM	—	13%	—	—

Table 26: 802.15.4 Transmitter Characteristics - 250 Kbps

802.15.4 RF Receiver (RX) Characteristics

802.15.4 Receiver Characteristics - 250 Kbps

Parameter		Description	Min	Typ	Max	Unit
Sensitivity @30.8% PER		—	—	-104.0	—	dBm
Maximum received signal @1% PER		—	—	8	—	dBm
Relative jamming level	Adjacent channel	F = F0 + 5 MHz	—	27	—	dB
		F = F0 - 5 MHz		32		dB
	Alternate channel	F = F0 + 10 MHz	—	47	—	dB
		F = F0 – 10 MHz	—	50	—	dB

Table 27: 802.15.4 Receiver Characteristics - 250 Kbps

Revision history

Date	Version	Release notes
2025-09-12	V2.0	1. Added Revision history table.
2025-12-01	V2.1	1. Style adjustments for *Wi-Fi* section in *Features*. 2. Non-working links removed from Table of content and List of tables.
2026-03-30	V3.0	1. 802.15.4 Current Consumption for 802.15.4 in Active Mode table fixed.
2026-05-07	V4.0	1. IOs description updated.