Single-Cell Battery *Bluetooth* Low Energy Controller

Description

The EM9301 is a low-voltage, low-power, fully-integrated, single-chip *Bluetooth*[1] Low Energy (BLE) controller.

It features a low-power physical layer, a link layer with an embedded security engine, a Host/Controller Interface (HCI), and a powerful power management which allows operation using efficiently all kinds of batteries down to 1.9V. This feature provides the required voltage to the integrated low-power RF core.

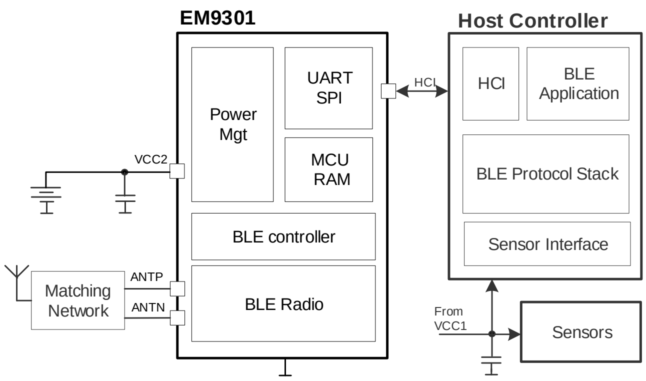
EM9301 can be ordered for all applications where a supply voltage from a typical 3V battery or from any other source is available in the system.

This BLE controller offers performances tailored for extremely low-power applications. Furthermore, the minimum amount of external components required makes the EM9301 suitable for applications where the form factor is a fundamental parameter.

The EM9301 controller is designed to act as BLE master or slave according to the *Bluetooth* specification V4.1 (Declaration ID D025195). It can be controlled by any external microcontroller featuring BLE profiles and applications through the standard *Bluetooth* HCI interface. UART and SPI interfaces are available as HCI transport layers. Moreover, during the intervals with no active BLE RF connection, the EM9301 features a proprietary low-power mode which can further reduce the power consumption.

With its high level of flexibility the EM9301 is the best choice for a *Bluetooth SMART* [1] product.

Typical Application Schematic



*Not all connections shown.

Main Features

- Master and slave BLE controller compliant to Bluetooth specification V4.1
- Operating directly from a single 3.0V
- Functional down to 1.9V
- Low average and peak current consumptions allowing the use of low-cost button-cell batteries
- Widely-spread, low-cost 26MHz quartz reference
- 1Mbps on-air data rate
- 200Ω differential impedance of antenna port, no antenna matching elements needed through appropriate PCB antenna design
- Programmable RF output level from -18dBm to +4dBm to optimize current consumption for a wide range of applications
- Supply Voltage Level Detector (SVLD) function enables monitoring the battery charge condition
- QFN24 5mm x 5mm package or die form available

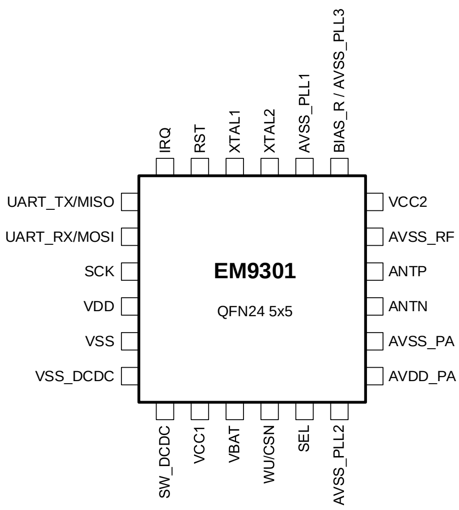
Typical Current consumptions

12mA	Tx current at 0dBm output power
13mA	Rx current
9µA	BLE Idle State
< 0.5µA	OFF Mode

Typical Applications

- Remote sensing
- Wireless mouse and keyboard
- Wireless sensors for watches
- Wireless sport equipment
- Alarm and security systems
- Wireless health care systems
- Beacon applications

Pin Assignment



[1] *Bluetooth* and *Bluetooth SMART* are trademarks owned by the *Bluetooth* Special Interest Group (SIG).

Table of contents

Table of contents **2**
List of tables 4
List of figures 4
1. Introduction **5**
1.1 Related documents 6
1.2 Block diagram 6
1.3 Pins description 7
1.4 Power pins configuration and description 8
2. Reference design **10**
2.1.1 Bill of materials (BOM) 10
2.1.2 Schematic and PCB layout 11
3. Absolute maximum ratings **13**
3.1 Handling procedures 13
4. General operating conditions **13**
5. Electrical characteristics **14**
5.1 DC characteristics 14
5.1.1 Power supply characteristics 14
5.1.2 Current consumption 14
5.2 Digital interface characteristics 15
5.2.1 Digital Input/Output pins characteristics 15
5.2.2 Digital interface timing characteristics 15
5.3 RF characteristics 16
5.3.1 General RF characteristics 16
5.3.2 Xtal oscillator characteristics 16
5.3.3 RF timing characteristics 16
5.3.4 Transmitter characteristics 17
5.3.5 Receiver characteristics 18
6. Functional description **19**
6.1 EM9301 start up 19
6.1.1 Start-up sequence 19
6.1.2 End of the boot-up procedure 19
6.1.3 Standby Mode 19
6.1.4 Xtreme Mode 19
6.1.5 Quiescent Mode 19
6.2 EM9301 operating states 19
6.2.1 State diagram 19
6.2.2 Standby State 20
6.2.3 Sleep State 21
6.2.4 Deep-Sleep State 21
6.2.5 BLE Active State 21
6.2.6 BLE Idle State 21
6.3 Optimizations of power consumption on EM9301 version 022 22
6.3.1 BLE Idle State using external time reference (version 022 only) 22
6.3.2 Configurable RF auto-calibration system (version 022 only) 23
6.3.3 RF activity signalization (version 022 only) 24
6.3.4 Crystal oscillator start-up time optimization (version 022 only) 25
6.4 EM9301 reset structure 25
7. Host/Controller Interface (HCI) **26**
7.1 List of supported HCI commands 27
7.1.1 Vendor specific HCI commands 28
7.2 List of supported HCI events 29
7.2.1 Vendor specific HCI events 29
7.3 HCI UART transport layer 30
7.3.1 UART interface 30
7.3.2 UART Settings 30
7.4 HCI SPI transport layer 30
7.4.1 SPI interface 30
7.4.2 SPI flow control 31
8. Peripherals information **32**
8.1 AES encryption/decryption accelerator 32
8.2 Random Number Generator (RNG) 32
8.3 Supply Voltage Level Detector (SVLD) 32
9. Application design guidelines **33**
9.1 Antenna port 33

9.1.1 Folded dipole antenna 33
9.2 Xtal oscillator 34
9.2.1 Frequency deviation 34
9.2.2 Reference quartz crystals 35
9.3 Power supplies 35
9.4 EM_WRITE_DATA 36
9.5 EM_READ_DATA 36
9.6 EM_SET_PUBLIC_ADDRESS 37
9.7 EM_SET_OPERATING_STATE 37
9.8 EM_SVLD 38
9.9 EM_SET_RF_POWER_LEVEL 38
9.10 EM_POWER_MODE_CONFIGURATION 39
9.11 EM_SET_UART_BAUD_RATE 39
9.12 EM_BLE_IDLE_LEAVE 40
9.13 EM_SET_RF_ACTIVITY 40
9.14 EM_SET_XTAL_STARTUP_TIME 41
9.15 EM_SET_RF_AUTOCAL_CONFIG 41
9.16 EM_SET_RF_INITIALIZATION_CONFIG 42
9.17 EM_READ_RF_CALIBRATION_VALUES 42
9.18 EM_WRITE_RF_CALIBRATION_VALUES 43
9.19 EM_SET_BLE_IDLE_PARAMETERS 44
9.20 EM_TRANSMITTER_TEST 45
9.21 EM_TRANSMITTER_TEST_END 46
10. Vendor HCI events 47
10.1 EM_STANDBY_STATE 47
10.2 EM_BLE_IDLE_ENTERED 47
10.3 Additional Hardware Error Event codes 47
11. Versions and ordering information 48
11.1 Ordering information 48
11.2 Package marking 49
11.3 Firmware update 49
12. Package information 50

List of tables

Table 1.1 EM9301 pins description....7
Table 1.2 Power supply pins description....9
Table 1.3 Recommended component list for the power section of the EM9301....9
Table 2.1 Reference design bill of materials (BOM)....10
Table 3.1 Absolute maximum ratings....13
Table 4.1 General operating conditions....13
Table 5.1 Power supply characteristics....14
Table 5.2 Current consumption....14
Table 5.3 Digital Input/Output pins characteristics....15
Table 5.4 Digital interface timing characteristics....15
Table 5.5 General RF characteristics....16
Table 5.6 Xtal oscillator characteristics....16
Table 5.7 Quartz crystal general specifications....16
Table 5.8 RF timing characteristics....16
Table 5.9 Transmitter characteristics....17
Table 5.10 Receiver characteristics....18
Table 6.1 EM9301 operating states and power modes....20
Table 7.1 HCI Command formats....26
Table 7.2 HCI event formats....26
Table 7.3 List of supported HCI commands....27
Table 7.4 Vendor specific HCI commands....28
Table 7.5 Supported HCI events....29
Table 7.6 Vendor specific HCI events....29
Table 8.1 Function of SVLD thresholds....32
Table 10.1 Additional Hardware Error Event codes....47
Table 11.1 EM9301 versions....48
Table 11.2 Ordering information....48
Table 11.3 EM9301 package marking for version 002....49
Table 11.4 EM9301 package marking for version 022....49

List of figures

Figure 1.1 BLE stack....5
Figure 1.2 Simplified EM9301 block diagram....6
Figure 1.3 EM9301 power configurations: (a) version 002; (b) version 022....8
Figure 2.1 Design reference schematic....11
Figure 2.2 Design reference PCB layout....12
Figure 6.1 EM9301 state diagram....20
Figure 6.2: BLE Idle State using external time reference (version 022 only)....22
Figure 6.3: RF activity signalization (version 022 only)....24
Figure 7.1 SPI writing transaction, with a wait state at start of the transaction....31
Figure 7.2 SPI writing transaction with a wait state after the first byte received....31
Figure 7.3 SPI read transaction with a empty buffer after the second byte....31
Figure 9.1 Layout example of a folded dipole antenna....33
Figure 9.2 Xtal oscillator block diagram....34
Figure 12.1 Package information....50

1. Introduction

The EM9301 is a low-power and low-voltage single-mode *Bluetooth* Low Energy (BLE) controller compliant with the *Bluetooth* specification V4.0. It consists of a low-power physical layer, a link layer with an embedded security engine, a Host/Controller Interface (HCI), and a powerful power management which allows operation using efficiently all kinds of batteries down to 0.8V.

The HCI communications can be performed using either UART or SPI as transport layer. This flexibility makes possible to interface this BLE controller with several external microcontrollers where the *Bluetooth* Low Energy protocol stack can be integrated together with any possible user application. A conceptual drawing of the BLE stack is depicted in Figure 1.1.

The EM9301 front end has been designed specifically for low-power applications. The Tx output power can be digitally controlled in a wide range (-18dBm to +4dBm) by the BLE host in order to optimize the current consumption for a wide set of applications. The robust Rx architecture allows the EM9301 to operate without the need of expensive external filters to attenuate undesired signals. The differential real impedance of 200Ω on the antenna port allows employing a simple PCB antenna while reducing the Bill-Of-Materials (BOM) count. Adaptation to any other antenna impedance is also granted by a simple matching network.

EM9301 features a high-efficiency power-management system and is available in three hardware versions:

002: allows operation on a single 3V battery cell

022: allows operation on a single 3V battery or other supplies down to 1.9V

Embedded features like Power-On Reset (POR) and Supply Voltage Level Detector (SVLD) ensure the correct start up of the system and allow the host to provide an accurate protection against complete discharge of batteries.

The bill-of-materials is further reduced and the power consumption can be further optimized thanks to an additional low-power mode called Quiescent Mode in which all clock sources are switched off.

All this features make the EM9301 an attractive choice for a broad range of wireless applications where power-efficient single-battery operation as well as multi-cell battery operation is needed. Thanks to the minimized amount of external components, the EM9301 is the right choice that can make the difference in terms of complete system cost.

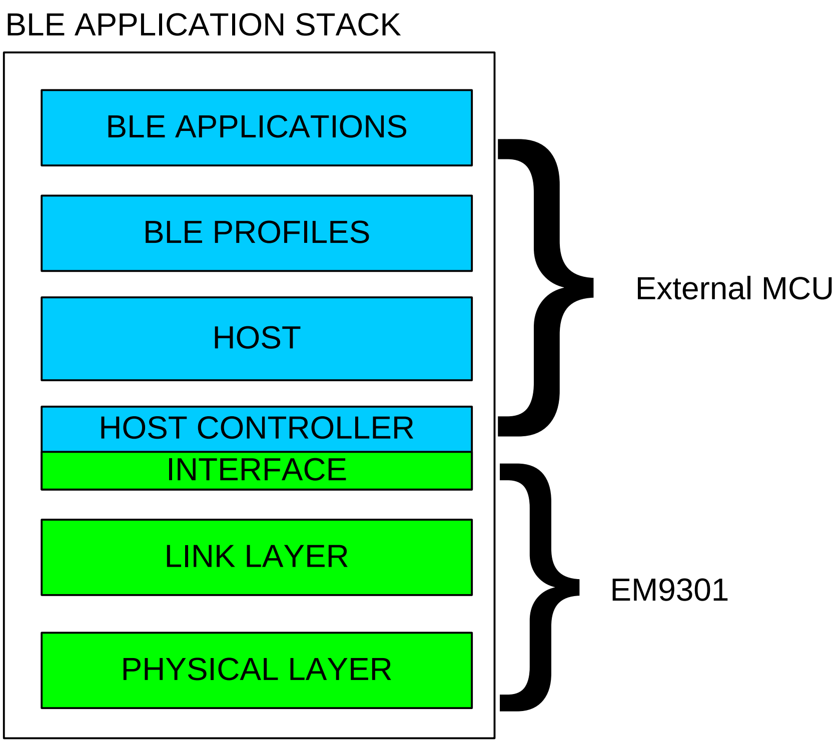


Figure 1.1 BLE stack

1.1 Related documents

The EM9301 was designed to comply with the following *Bluetooth* specifications published by the *Bluetooth* Special Interest Group (SIG) on www.bluetooth.org:

[1] *Bluetooth* Core Specifications, Version 4.1, *Bluetooth* SIG, 03.12.2013

[2] *Bluetooth* Low Energy RF-PHY Test Specifications, Version 4.1.1, *Bluetooth* SIG, 07.07.2014

[3] *Bluetooth* 4.1 Link Layer Test Specifications, Version 4.1.0, *Bluetooth* SIG, 03.12.2013

In addition, the EM9301 controller was tested for compliance with the following standards:

[4] ETSI EN 300 440-1, Version 1.6.1, August 2010

[5] ETSI EN 300 328, Version 1.8.1, June 2012

[6] FCC Regulations Part 15, §15.247, July 2012

Customers are however recommended to test the compliance of their final systems incorporating or embedding the EM9301 with these or other standards as they may apply and to obtain all necessary licenses and authorizations.

1.2 Block diagram

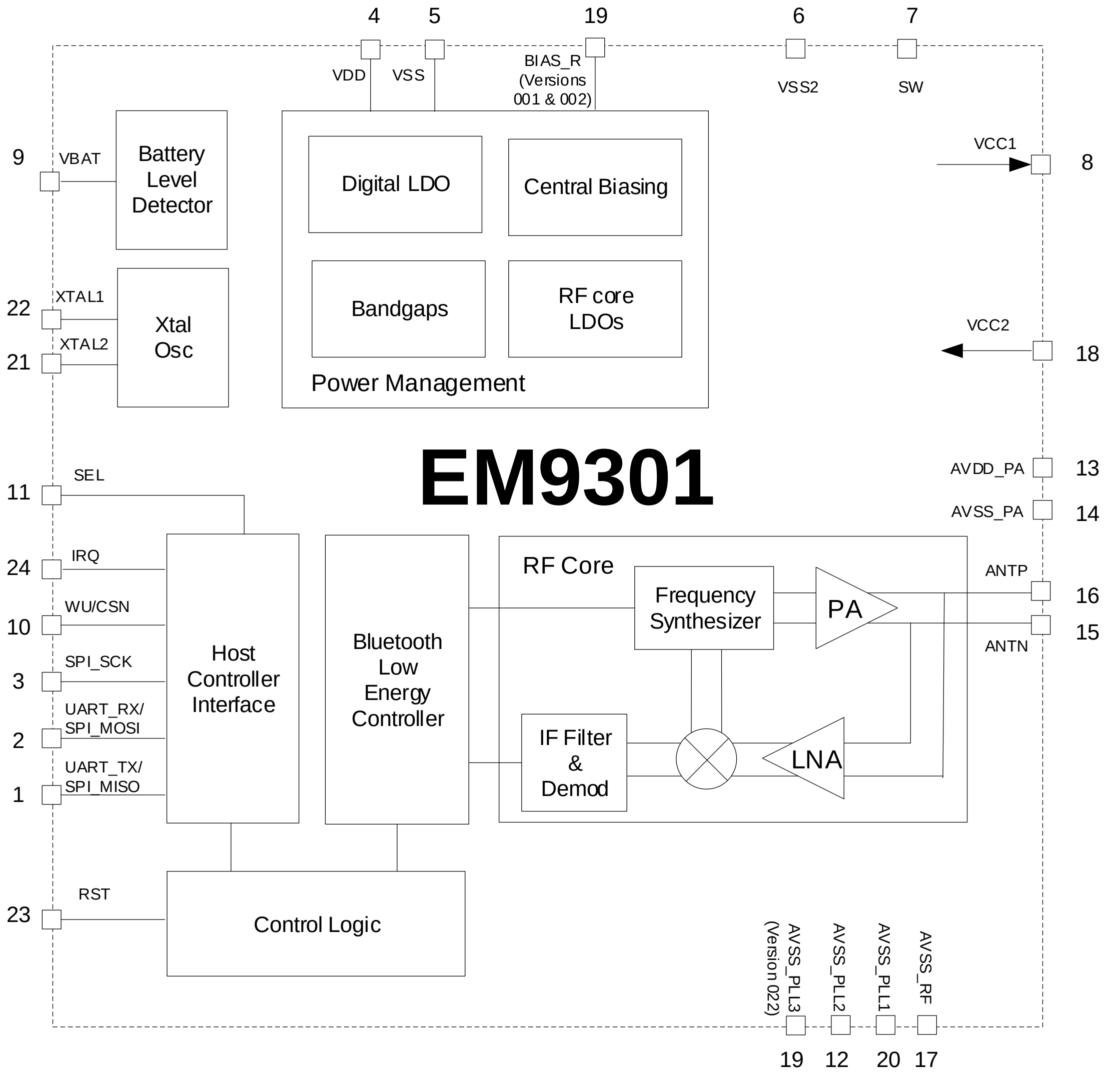


Figure 1.2 Simplified EM9301 block diagram

1.3 Pins description

Pin Nr	Name	Type	Description
0		Ground	Die paddle (package ground contact) [2]
1	UART_TX / SPI_MISO	Digital Output	UART TX / SPI Data Output (SDO)
2	UART_RX / SPI_MOSI	Digital Input	UART RX / SPI Data Input (SDI)
3	SPI_SCK	Digital Input	SPI clock input (SCK)
4	VDD	Power	Positive supply for the digital part [3]
5	VSS	Ground	Negative supply for the digital part [2]
6	VSS2	Ground	Negative supply[2]
7	SW	Power	Input (shall be grounded)
8	VCC1	Power	Output (shall be grounded)
9	VBAT	Analog	Power supply (shall be grounded)
10	WU / CSN	Digital Input	UART Wake Up from Sleep or Deep-Sleep State / SPI chip select.
11	SEL (vaersion 002); SEL (version 022)	Digital Input; Digital Input/Output	Interface selection (0 = UART, 1 = SPI); Interface selection (0 = UART, 1 = SPI) / RF activity signalization and external clock synchronization.
12	AVSS_PLL2	Ground	Negative supply of PLL [2]
13	AVDD_PA	Power	Regulated output voltage for the power amplifier [3]
14	AVSS_PA	Ground	Negative supply for the power amplifier [2]
15	ANTN	RF	Differential RF ports
16	ANTP	RF	
17	AVSS_RF	Ground	Negative supply of RF part [2]
18	VCC2	Power	Main supply for the chip
19	BIAS_R (versions 001&002); AVSS_PLL3 (version 022)	Analog ; Ground	Pin for bias setting resistor ; Negative supply of PLL [2]
20	AVSS_PLL1	Ground	Negative supply of PLL [2]
21	XTAL2	Analog	Xtal oscillator ports
22	XTAL1	Analog	
23	RST	Digital Input	Reset
24	IRQ	Digital Output	SPI Interrupt Request

Table 1.1 EM9301 pins description

[2] For proper circuit operation, this terminal shall be connected to a common ground plane.
[3] For proper circuit operation, this terminal shall not be loaded by any external circuitry.

1.4 Power pins configuration and description

This section describes how the power supply shall be connected for the different versions of the EM9301. Figure 1.3 shows configuration schematics for the power lines, Table 1.2 gives a description of the EM9301 supply pins and Table 1.3 summarizes a list of recommended external components. For a proper operation of the chip, all pins with labels VSS or AVSS shall be connected to the common PCB ground plane.

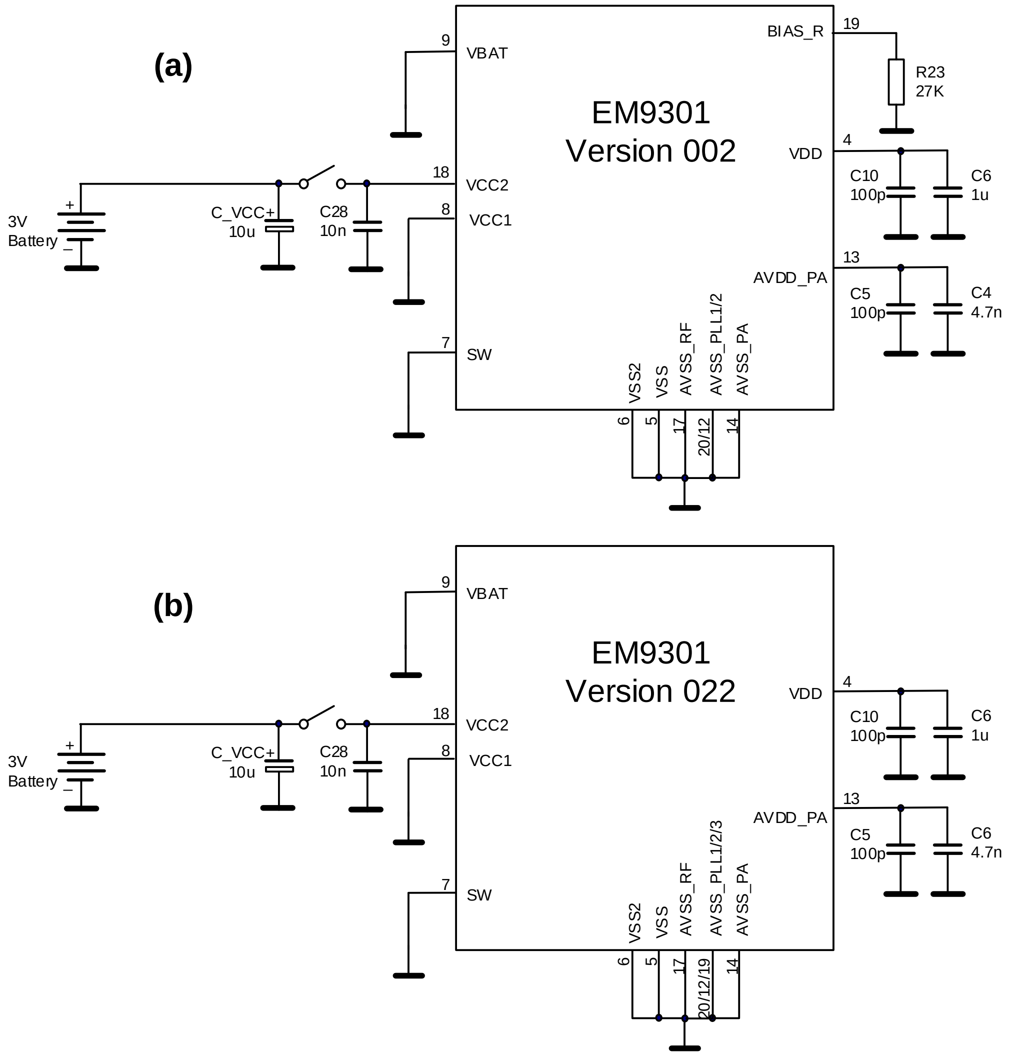


Figure 1.3 EM9301 power configurations: (a) version 002; (b) version 022

Name	Description
VCC2	EM9301 main power supply. This pin is connected to an external power supply (e.g. a 3V battery) as shown in Figure 1.3(a) and Figure 1.3(b).
VDD	Digital power supply. This pin is needed only for decoupling reasons. It shall not be loaded by any external circuit.
AVDD_PA	RF power amplifier supply voltage. This pin is needed only for decoupling purposes. To avoid the injection of parasitic RF signals into the internal power amplifier, the decoupling capacitors (C4 and C5) shall be placed as close as possible to this pin. It shall not be loaded by any external circuitry.
VBAT	This pin is not used and shall be grounded.
VCC1	This pin is not used and shall be grounded
SW	This pin is not used and shall be grounded

Table 1.2 Power supply pins description

Component	Value	Footprint	Description
C28	10nF	0402	VCC2 decoupling capacitor, ±20%, 50V
C4	4.7nF	0402	LDO-PA decoupling capacitor, ±20%, 50V
C5	100pF	0402	LDO-PA decoupling capacitor, ±10%, 50V
C6	1uF	0603	LDO-Digital decoupling capacitor, ±10%, 16V, ESR@1MHz<0.5Ω
C10	100pF	0402	LDO-Digital decoupling capacitor, ±10%, 50V
R23	27KΩ	0402	Biasing resistor, ±1% (only for version 002, not needed for version 022)
C_VCC	10uF	0603	VCC2 decoupling capacitor, ±20%, 10V

Table 1.3 Recommended component list for the power section of the EM9301

2. Reference design

The reference design is a printed circuit board (PCB) consisting of a 0.8mm-thick FR4 substrate with 35µm-thick copper layers on the top and bottom sides. Gerber files are available on request.

2.1.1 Bill of materials (BOM)

Component	Value	Footprint	Description
U1	EM9301 V022	QFN24	Single-Cell Battery *Bluetooth* Low Energy controller
Power supply:			
C28	10nF	0402	VCC2 decoupling capacitor, ±20%, 50V Short
C4	4.7nF	0402	LDO-PA decoupling capacitor, ±20%, 50V
C5	100pF	0402	LDO-PA decoupling capacitor, ±10%, 50V
C6	1uF	0603	LDO-Digital decoupling capacitor, ±10%, 16V, ESR@1MHz<0.5Ω
C10	100pF	0402	LDO-Digital decoupling capacitor, ±10%, 50V
C_VCC	10uF	1206	VCC2 decoupling capacitor, ±20%, 10V
Z1	NX2301P	SOT23	P-Channel MOSFET R_{DSon}<270mΩ @ VGS=-1.8V, ID=-0.2A
R52	270 kΩ	0402	Pull-Down resistor (optional)
R45	100 kΩ	0402	Pull-Down resistor (optional)
Xtal oscillator:			
Y1	ABM8-26.000MHz-10-D7G	3.2mmx2.5mm	Quartz crystal, 26MHz, 10pF load capacitance, ±35ppm total frequency tolerance
C21	15pF	0402	Xtal oscillator capacitor, ±1%
C22	15pF	0402	Xtal oscillator capacitor, ±1%
Balun and impedance matching network:			
LDB1	LDB212G4020C	0805	Murata Chip Multilayer Hybrid Balun 200:50Ω; 1.05dB max IL
C7	0 Ω	0402	Resistor - spare impedance matching component
J1	00200CA2GP909L	SMA	Woken 50Ω SMA edge type PCB connector

Table 2.1 Reference design bill of materials (BOM)

2.1.2 Schematic and PCB layout

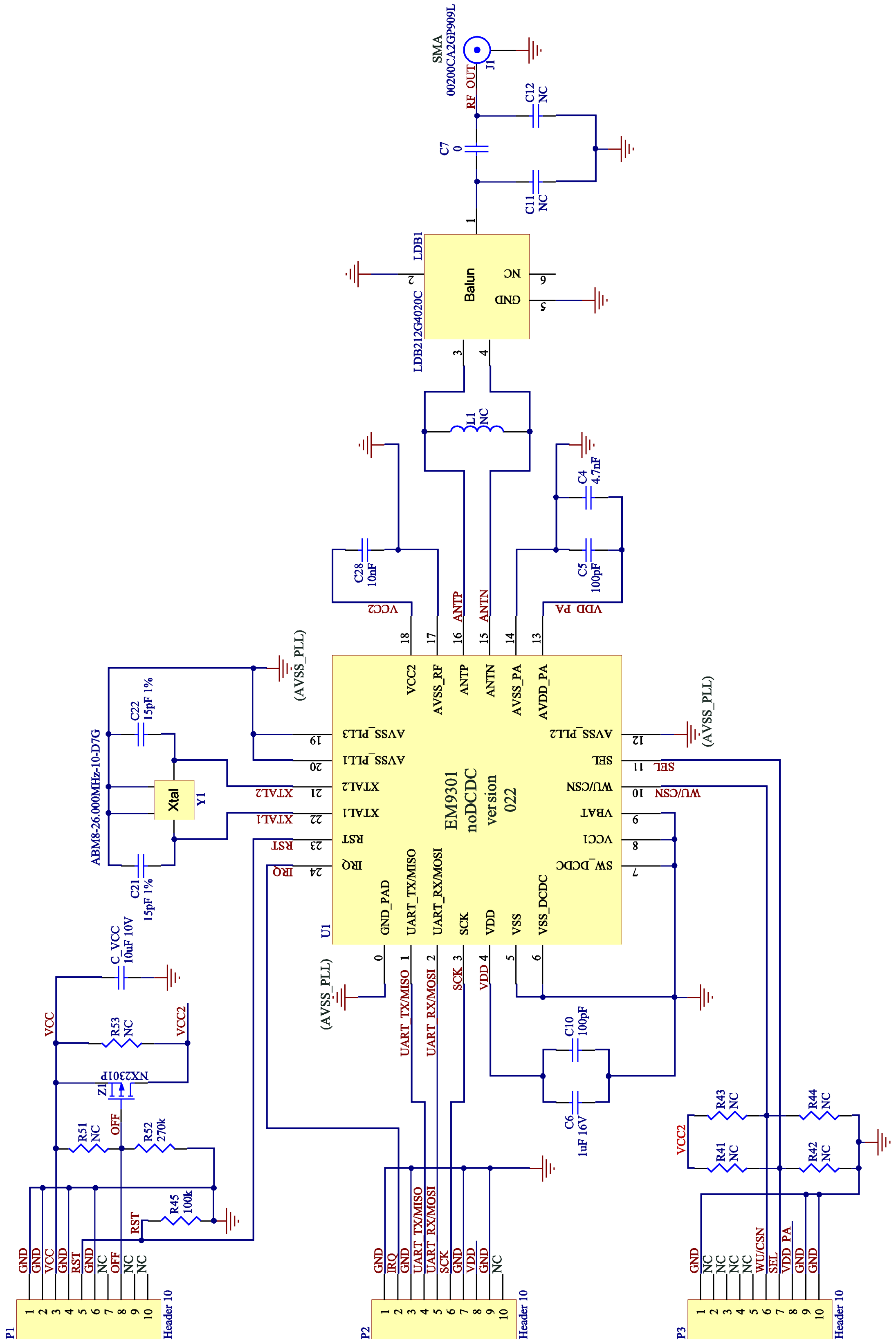


Figure 2.1 Design reference schematic

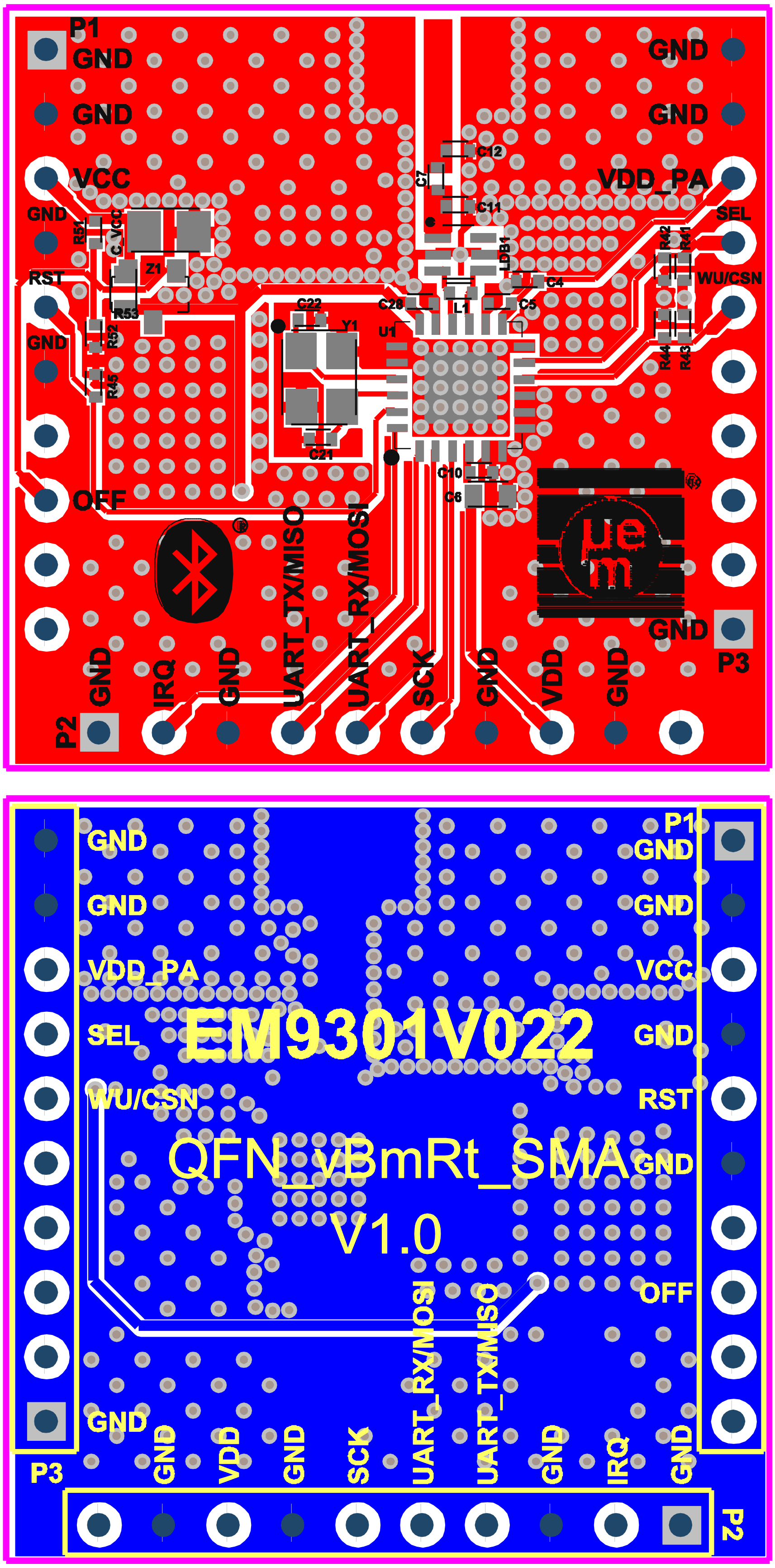


Figure 2.2 Design reference PCB layout

3. Absolute maximum ratings

Table 3.1 summarizes the absolute maximum ratings for the EM9301. Stresses above these listed maximum ratings may cause permanent damages to the device. Exposure beyond specified operating conditions may affect device reliability or cause malfunction.

All DC voltages are referred to the absolute voltage at the pin VSS.

Parameter	Symbol	Min.	Max.	Unit
Voltage at any ground pin [4]	*Vgnd*	-0.2	0.2	V
Supply voltage	V_{BAT}	-0.2	0.2	V
Supply Voltage	V_{CC2}	-0.2	3.8	V
Voltage at any remaining pin	V_{PIN}	-0.2	V_{CC2} + 0.2	V
Storage temperature	T_{st}	-50	150	°C
Electrostatic discharge HBM according to JS-001 with reference to GND	V_{ESDHBM}	-2000	+2000	V
Electrostatic discharge CDM according to JS-002	V_{ESDCDM}	-500	+500	V
Maximum soldering conditions	As per Jedec J-STD-020 standard			

Table 3.1 Absolute maximum ratings

3.1 Handling procedures

This device has built-in protection against high static voltages or electric fields; however, anti-static precautions must be taken as for any other CMOS component. Unless otherwise specified, proper operation can only occur when all terminal voltages are kept within the voltage range. Unused inputs must always be tied to a defined logic voltage level unless otherwise specified.

4. General operating conditions

All DC voltages are referred to the absolute voltage at the pin VSS.

Parameter	Symbol	Min	Max	Unit
Supply voltage EM9301 version 002	V_{CC2}	2.3	3.6	V
Supply voltage EM9301 version 022	V_{CC2}	1.9	3.6	V
Operating temperature range	T_{op}	-40	+85	ºC

Table 4.1 General operating conditions

[4] Ground pins defined in Table 1.1.

5. Electrical characteristics

The power modes and the operating states are defined in sections 0 and 6.2 respectively.

Unless otherwise specified:

- All DC voltages are referred to the absolute voltage at the pin VSS.
- Typical values are measured at 25°C; minimal and maximal values are measured from -40°C to +85°C.
- Parameters are measured using the schematics on Figure 1.3(a) or Figure 1.3(b) and with the component list showed on Table 1.3, the supply voltage V_{CC2} is assumed to be 2.5V.

5.1 DC characteristics

5.1.1 Power supply characteristics

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Supply Voltage Level Detector (SVLD) threshold levels	$SVLD_{TH\_06}$ $SVLD_{TH\_07}$			2.05 2.25		V

Table 5.1 Power supply characteristics

5.1.2 Current consumption

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Non-BLE states (Unconnected):						
Standby State current	$I_{Standby}$	ABM8-26.000MHZ-10-D7G Xtal type with 10pF load capacitance		200		µA
Sleep State current	I_{Sleep}			19		µA
Deep-Sleep State current	$I_{Deep\text{-}Sleep}$	Memory retention		9		µA
OFF Mode current	I_{OFF}	Leakage of the switch device			0.5	µA
BLE states (Advertising, Scanning, Connected):						
BLE Active State Receive current	I_{Rx}			12.9		mA
BLE Active State Transmit current	I_{Tx_0dBm}	Version 002 output power P_{out_06} Version 022: output power P_{out_05}		12.1		mA
BLE Idle State current (Xtal-referenced)	$I_{BLE\_Idle\_Xtal}$	ABM8-26.000MHZ-10-D7G Xtal type with 10pF load capacitance		450		µA
BLE Idle State current (RC-referenced)	$I_{BLE\_Idle\_RC}$			60		µA
BLE Idle State current (Externally-referenced)	$I_{BLE\_Idle\_Ext}$	Only available in version 022		9		µA

Table 5.2 Current consumption

5.2 Digital interface characteristics

5.2.1 Digital Input/Output pins characteristics

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Input Low voltage	*VIL*		0		0.25 V_{CC2}	V
Input High voltage	*VIH*		0.75 V_{CC2}		V_{CC2}	V
Output High current	*IOH*	*VOH*= V_{CC2} - 0.3V	1			mA
Output Low current	*IOL*	*VOL*= 0.3V	1			mA

Table 5.3 Digital Input/Output pins characteristics

5.2.2 Digital interface timing characteristics

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
UART interface:						
Baud rate	$UART_{BdRate}$	Programmed as defined in section 9.11.	1.2		1843.2	KBd/s
SPI interface:						
SPI speed (bit rate)	$SPI_{bitRate}$				5000	Kb/s

Table 5.4 Digital interface timing characteristics

5.3 RF characteristics

All the RF parameters are measured using the reference design presented in section 2 and the component list on Table 2.1.

Measuring conditions and device configuration are specified in [2] (*Bluetooth* Low Energy RF-PHY Test Specifications) for PHY parameters and in [3] (*Bluetooth* 4.0 Link Layer Test Specifications) for LL parameters.

When applicable, exceptions for some parameters are compliant to what described in [1] (*Bluetooth* Core Specifications, volume 6, Part A).

5.3.1 General RF characteristics

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
RF operating frequency	f_c		2400		2484	MHz
Channel spacing	Δf_{ch}			2		MHz
On-air Data Rate	*DR*			1000		Kbps
Differential antenna port impedance	Z_{ANT}			200+j0		Ω

Table 5.5 General RF characteristics

5.3.2 Xtal oscillator characteristics

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Xtal oscillator frequency	f_0	Quartz crystal as specified in Table 5.7		26		MHz
Xtal oscillator frequency deviation	df_0/f_0	Including frequency tolerance, stability over temperature and aging of the quartz crystal and total tolerance of the external capacitances. Refer to section 9.2.			±50	ppm

Table 5.6 Xtal oscillator characteristics

Quartz crystal general specifications

These are the general specifications for the quartz crystal required by the EM9301 Xtal oscillator. Additional specifications must be given for each particular quartz to ensure that the total frequency deviation is within the oscillator specification. Please refer to section 9.2 for additional information on the Xtal specifications.

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Resonance frequency with a parallel load capacitance C_L	f_0			26.000		MHz
Load Capacitance	C_L		8		18	pF
Series or “motional” resistance	R_m		10		200	Ω
Quality factor	Q_{Xtal}		10k		500k	
Operation mode				Fundamental		

Table 5.7 Quartz crystal general specifications

5.3.3 RF timing characteristics

The following timings are highly dependent on the quartz crystal quality factor. Typical values are stated based on the Abracon ABM8-26.000MHZ-10-D7G Xtal with 10pF load capacitance.

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Start-up time version 002 (Off to Standby State)	$t_{st.up}$			15.5		ms
Start-up time version 022 (Off to Standby State)	$t_{st.up}$			3.2		ms
Sleep → Standby State	$t_{Sleep\_Standby}$			2.6		ms
Deep-Sleep → Standby State	$t_{Deep\text{-}Sleep\_Stdby}$			2.7		ms

Table 5.8 RF timing characteristics

5.3.4 Transmitter characteristics

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Output power versions 001 & 002	P_{out_07} P_{out_06} P_{out_05} P_{out_04} P_{out_03} P_{out_02} P_{out_01} P_{out_00}	The power level is programmed as described in section 9.9. The default value is P_{out_06} (0dBm) Low-loss balun and impedance matching network required.		3 0 -3 -6 -9 -12 -15 -18		dBm
Output power version 022	P_{out_07} P_{out_06} P_{out_05} P_{out_04} P_{out_03} P_{out_02} P_{out_01} P_{out_00}	The power level is programmed as described in section 9.9. The default value is P_{out_05} (0dBm) Low-loss balun and impedance matching network required.		4 2 0 -3 -9 -12 -15 -18		dBm
RF Power accuracy	P_{out}/P_{out_xx}			±3		dB
Deviation from the channel center frequency	Δf_c	[5]			±150	KHz
Frequency drift for any packet length	Δf_{c_pkt}	[5]			50	KHz
Drift rate	$\Delta f_c/\Delta T$	[5]			400	Hz/µs
Modulated frequency deviation	Δf_{mod}	[6]		±250		KHz
In-band spurious emission, power transmitted outside the selected channel, at a frequency offset f_{offs}	$P_{out}(f_c+f_{offs})$	[5] $\lvert f_{offs} \rvert$ = 2 MHz $\lvert f_{offs} \rvert$ ≥ 3MHz			-20 -30	dBm
Spurious emission at an out-of-band frequency f	$P_{out}(f)$	[7] [8] f= 30MHz–88MHz f= 88MHz–230MHz f= 230MHz–470 MHz f= 470MHz–862MHz f= 862MHz–960MHz f= 960MHz–2396MHz f= 2487.5MHz–12750MHz			-57.3 -54.0 -51.3 -54.0 -51.3 -43.4 -43.4	dBm

Table 5.9 Transmitter characteristics

[5] As defined in [1]: *Bluetooth* Core Specifications, Version 4.0, volume 6, Part A, section 3. Measuring conditions and signal specifications are described in [2]: *Bluetooth* Low Energy RF-PHY Test Specifications, Version 4.0.1. These parameters are highly related to a correct PCB and matching-network design.

[6] Frequency deviation corresponding to a 10101010 modulation sequence is at least 80% of the frequency deviation corresponding to a 00001111 sequence. Positive frequency deviations represent a logic level '1' and negative frequency deviations represent a logic level '0' as defined in [1]: *Bluetooth* Core Specifications, Version 4.0, volume 6, Part A, section 3.1.

[7] Measuring conditions and signal specifications are described in [4]: ETSI EN 300 440-1 Version 1.6.1, [5]: ETSI EN 300 328 Version 1.8.1, and [6]: FCC Regulations Part 15. These parameters are highly related to a correct PCB and matching-network design.

[8] For frequencies higher than 1000MHz the spurious emission limits refer to average power. 50% worst-case duty cycle (BT connection mode) is assumed for the measurements. c.f. FCC Regulations Part 15, §15.35(b).

5.3.5 Receiver characteristics

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Sensitivity level	P_{in_min}	0.1% BER Compliant with *Bluetooth* V4.0		-80		dBm
Maximum input power	P_{in_max}	0.1% BER Compliant with *Bluetooth* V4.0		-5		dBm
In-band blocking for a wanted signal level of -67dBm Minimal Carrier-to-Interferer ratio required to maintain communication	$P_C/P_I\ (f_{offs})_{min}$	[9] Co-channel interference			+21	dB
		Interferer at $\lvert f_{offs} \rvert$ = 1MHz			+15	
		Interferer at $\lvert f_{offs} \rvert$ = 2MHz			-17	
		Interferer at $\lvert f_{offs} \rvert \geq$ 3MHz			-27	
		Interferer at image freq. f_{offs} = -4.4MHz			-9	
		Interference at adjacent frequencies to image f_{offs} = -4.4 MHz ± 1MHz			-15	
Out-of-band blocking for a wanted signal level of -67 dBm Interferer level at the frequency *f* that disturbs communication	$P_I(f)_{max}$	[9] *f*= 30–2000MHz	-30			dBm
		f= 2000–2399 MHz	-35			
		f= 2484–3000 MHz	-35			
		f= 3000–12750 MHz	-30			
Spurious emission at frequency *f*	$P_{out\_Rx}(f)$	[7] *f*= 30MHz–88MHz			-57.3	dBm
		f= 88MHz–1000MHz			-57.0	
		f= 1000MHz–12750MHz			-47.0	

Table 5.10 Receiver characteristics

[9] As defined in [1]: *Bluetooth* Core Specifications, Version 4.0. *Bluetooth* SIG, 30.03.2012, volume 6, Part A, section 4. Measuring conditions and signal specifications are described in [2]: *Bluetooth* Low Energy RF-PHY Test Specifications, Version 4.0.1, *Bluetooth* SIG, 18.07.2011. These parameters are highly related to a correct PCB and matching-network design.

6. Functional description

6.1 EM9301 start up

This section describes the EM9301 start-up procedure of the chip; it is intended to be informational only since the process is independent of any external action. The application shall however select the preferred communication interface by means of the pin SEL:

SEL = 1 => SPI

SEL = 0 => UART

6.1.1 Start-up sequence

When a 3V battery is connected to the EM9301, an internal RC oscillator starts up providing a clock with fixed duty cycle to the power check circuit. After the power check indicates enough voltage on VDD, the quartz crystal (Xtal) oscillator is enabled and when its start-up procedure is completed, the main logic switches then to the Xtal clock reference.

6.1.2 End of the boot-up procedure

Once the Xtal oscillator clock is available to the digital part of the controller, the EM9301 enters in Standby State using the Standby Power Mode and an event is sent to the host through the selected communication interface. Refer to section 5.3.2 for a description of how to send commands and read events to and from the EM9301. The definitions of power modes and operating states are given in sections 0 and 6.2.

At the end of the boot sequence, EM9301 returns an HCI event EM_STANDBY_STATE to the host to notify that the system has entered in Standby State. Refer to [1] for more details on standard BLE events. If for any reason the first HCI event is corrupted after start up, for example if the host needs a long time to initialize or if the SEL signal is not stable at start-up time, it is recommended that the host generates an additional reset as described in section 6.4 to ensure proper start up.

When the boot-up sequence ends, the EM9301 is ready to communicate through HCI. EM9301 power modes

EM9301 works in two main power modes which are automatically chosen based on the selected chip state described in section 6.2. These modes depend on the operating state are not directly selectable by the external application.

6.1.3 Standby Mode

In this power mode the Xtal oscillator is up and running and supplies the main system clock. The internal RC oscillator is also active.

6.1.4 Xtreme Mode

In Xtreme Mode, the Xtal oscillator is turned off but the internal RC oscillator is kept on. The complete controller status is kept in memory and if no BLE Idle State is being used, the supply voltage of the logic is lowered to reduce leakage currents.

6.1.5 Quiescent Mode

Quiescent Mode is only available for the EM9301. In this mode the two internal oscillators (Xtal and RC) are quiescent. The complete controller status is maintained and the supply voltage of the logic is lowered to reduce leakage currents.

6.2 EM9301 operating states

This section describes the operating states of the EM9301 and how to switch between them.

6.2.1 State diagram

Figure 6.1 shows a simplified state diagram of the EM9301. Each bubble corresponds to one EM9301 operating state and the bubble color represents the power mode associated to the specific chip mode. The arrows indicate how the transitions from one state to the other can be achieved. Note that some operations in some states are only allowed for HCI over SPI transport layer, some others are achieved only by BLE firmware.

The power modes as well as the state of the Xtal and RC oscillators and the supply configuration corresponding to each operating state can be found in Table 6.1.

As described in section 6.1, EM9301 becomes functional at the end of the start-up procedure. After that initial step, the EM9301 automatically enters the Standby State. A change of state is allowed through the HCI commands and the time needed to switch from one state to the other is summarized in the timing table of section 5.3.

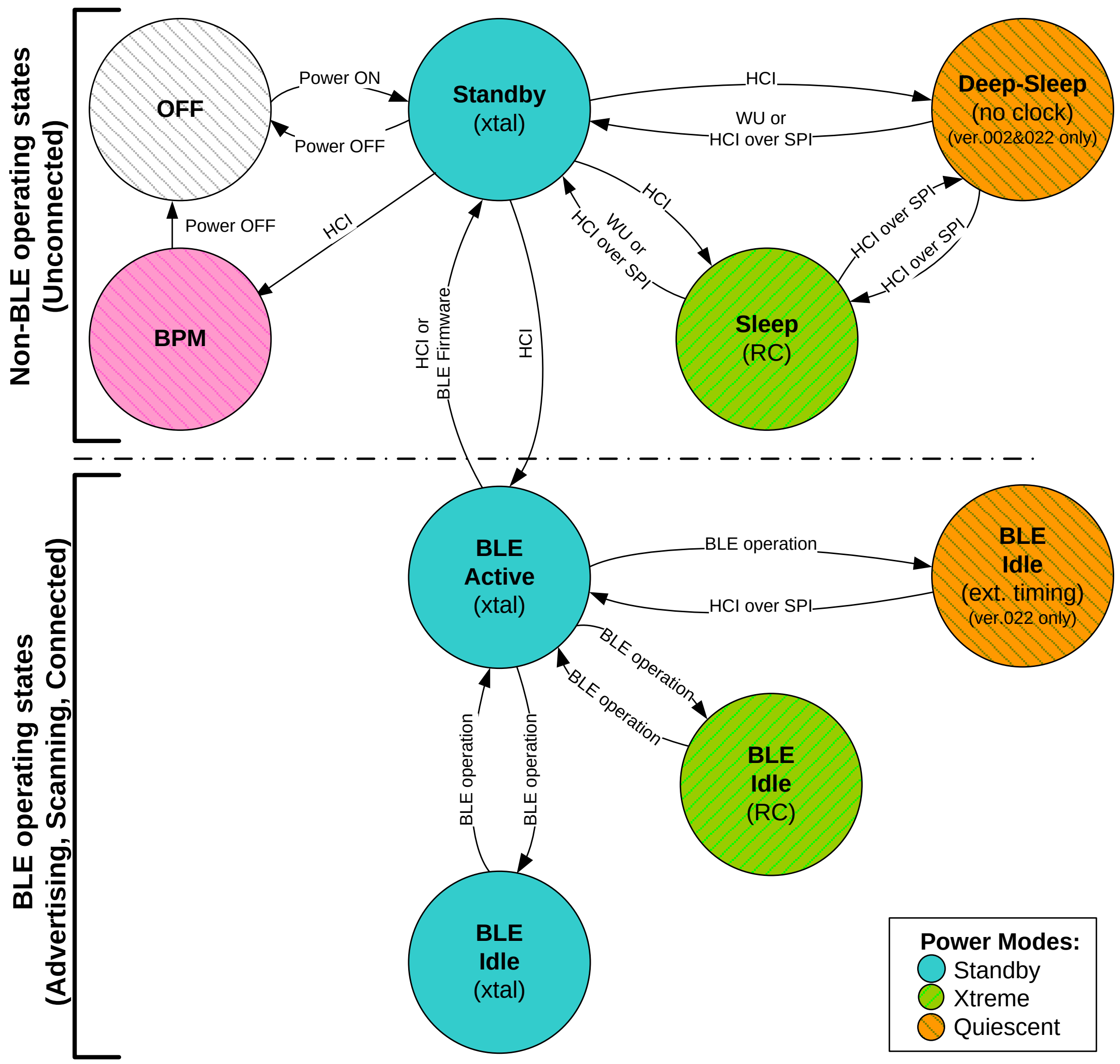


Figure 6.1 EM9301 state diagram

Operating state	Power mode	Xtal oscillator	RC oscillator	RF state	Logic supply voltage
Deep-Sleep	Quiescent	OFF	OFF	OFF	1.4V
Sleep	Xtreme	OFF	ON	OFF	1.4V
Standby	Standby	ON	ON	OFF	1.8V
BLE Active	Standby	ON	ON	ON	1.8V
BLE Idle	Standby	ON	ON	OFF	1.8V
	Xtreme	OFF	ON	OFF	1.8V
	Quiescent	OFF	OFF	OFF	1.4V

Table 6.1 EM9301 operating states and power modes

6.2.2 Standby State

Standby is the state where the EM9301 enters per default after power up. When this state is entered, the HCI event EM_STANDBY_STATE is reported to the host. The power mode for this configuration is Standby Mode, as defined in section 6.1.3. The HCI system is available and the host can communicate with the controller using the transport layer selected during the start-up sequence by the SEL pin. In this state the chip is able to receive and decode any HCI command sent by the host as well as send any event back to the host using either the UART or the SPI transport layer. The clock source of the EM9301 logic is given by the Xtal oscillator. The RF core is off and the internal logic is in Halt Mode, waiting for a HCI command from the host.

6.2.3 Sleep State

The Sleep State is an EM9301 low-power state. The power mode for this configuration is Xtreme Mode as defined in sections 6.1.3 and 6.1.4. RF operation cannot be activated from this state. When the EM9301 exits from this state it goes to Standby State. The HCI system is available but with limited functionality depending on the transport layer chosen:

- If UART has been chosen as transport layer, no HCI commands shall be sent. The system can be waked up by setting the pin WU to High. Once this is done, the system will restart all internal oscillators and automatically go to Standby State asserting the EM_STANDBY_STATE event.
- If SPI has been chosen as transport layer, EM9301 is capable of executing a limited set of HCI commands. In particular, all commands which enable RF communications are not allowed in this mode. In addition, when the EM9301 is in Sleep State the SPI interface requires that the CSN pin is toggled after each byte. The flow control described in 7.4.2 ensures that no overflow occurs in the communication. The HCI command EM_SET_OPERATING_STATE can be used to switch to the Standby State.

6.2.4 Deep-Sleep State

This is the EM9301 state with the lowest power consumption. The power mode for this configuration is Quiescent Mode, as defined in section 6.2.4. In this mode both oscillators, Xtal and RC, are turned off. The RF core cannot be activated. The HCI system is available but only to wake up the system, no other HCI commands are accepted. When the system wakes up the default state is Standby. Depending on the transport layer chosen, the system can be waked up as follows:

- If UART has been chosen as transport layer, the system can be waked up setting the pin WU to ‘1’. Once this is done, the system will restart all internal oscillators and automatically go to Standby State asserting the EM_STANDBY_STATE event.
- If SPI has been chosen, the system can be waked up by sending an HCI command. Only a limited set of HCI commands is supported in this state. In particular all the commands which enable RF communications are not allowed. Once a command has been received, the EM9301 switches automatically to Sleep State and tries to execute the command. The command EM_SET_OPERATING_STATE can be used to switch between the Standby and Deep-Sleep states. If Standby State is chosen the system will restart all internal oscillators and go to Standby State asserting the EM_STANDBY_STATE event. If Deep-Sleep State has been chosen, no special HCI event is sent but the EM9301 returns to the Deep-Sleep State.

6.2.5 BLE Active State

BLE Active is the state in which the EM9301 communicates with other BLE devices. It can be entered only from the Standby State, which is the starting state for any *Bluetooth* Low Energy operation (scanning, advertising, and connection). The power mode during BLE Active State is Standby Mode, as defined in section 6.1.3.

In this state the HCI system is fully available and the host can communicate with the controller using the selected transport layer. During this phase the clock source is the crystal oscillator and the internal RC oscillator can be calibrated. The RF core is dynamically activated in order to optimize power consumption. The internal logic is in Halt Mode, waiting for any HCI command from the host. When the on-air link is active, it is recommended to reduce the host-controller communications in order to avoid possible noise coupling.

6.2.6 BLE Idle State

BLE Idle is a special state defined in the *Bluetooth* Low Energy standard to reduce the power consumption by means of duty cycling. EM9301 offers three possible configurations for this mode: one employing the crystal oscillator, a second using the RC oscillator and a third making use of external timing.

The EM9301 controls automatically the transitions between BLE Active and BLE Idle State, the host cannot influence them directly. When external timing in the host MCU is used (EM9301 version 022) the time requested by the EM9301 has to be respected.

Per default the BLE Idle State employs the Standby Power Mode and the Xtal oscillator. The use of the Xtreme Power Mode (RC oscillator) or of the Quiescent Power Mode (external timing) can be enabled by the HCI command EM_POWER_MODE_CONFIGURATION as described in section 9.10. Note that if the Xtreme Power Mode is used, all requirements regarding current consumption described in section 6.2.1 and defined in Table 5.2 Current consumption shall be taken into account

In this configuration the RF core is turned off and the HCI system is active and able to receive any command.

- If UART has been chosen as transport layer, only the Xtal oscillator (Standby Power Mode) can be chosen.
- If the transport layer is SPI, the Xtal oscillator (Standby Power Mode), the RC oscillator (Xtreme Power Mode) can be selected. The EM9301 version 022 allows in addition the use an external timer (Quiescent Power Mode) as described in section 6.3.1.

6.3 Optimizations of power consumption on EM9301 version 022

6.3.1 BLE Idle State using external time reference (version 022 only)

In EM9301 version 022 the current consumption during the BLE Idle State can be further reduced by using the Quiescent Power Mode instead of the Standby or Xtreme power modes (described in section 6.2.6).

When the Quiescent Power Mode is used there is no clock running on the EM9301 and the timing of the BLE transactions has to be performed by the host MCU. Figure 6.2 shows the concept of using the Quiescent Power Mode during the BLE Idle State.

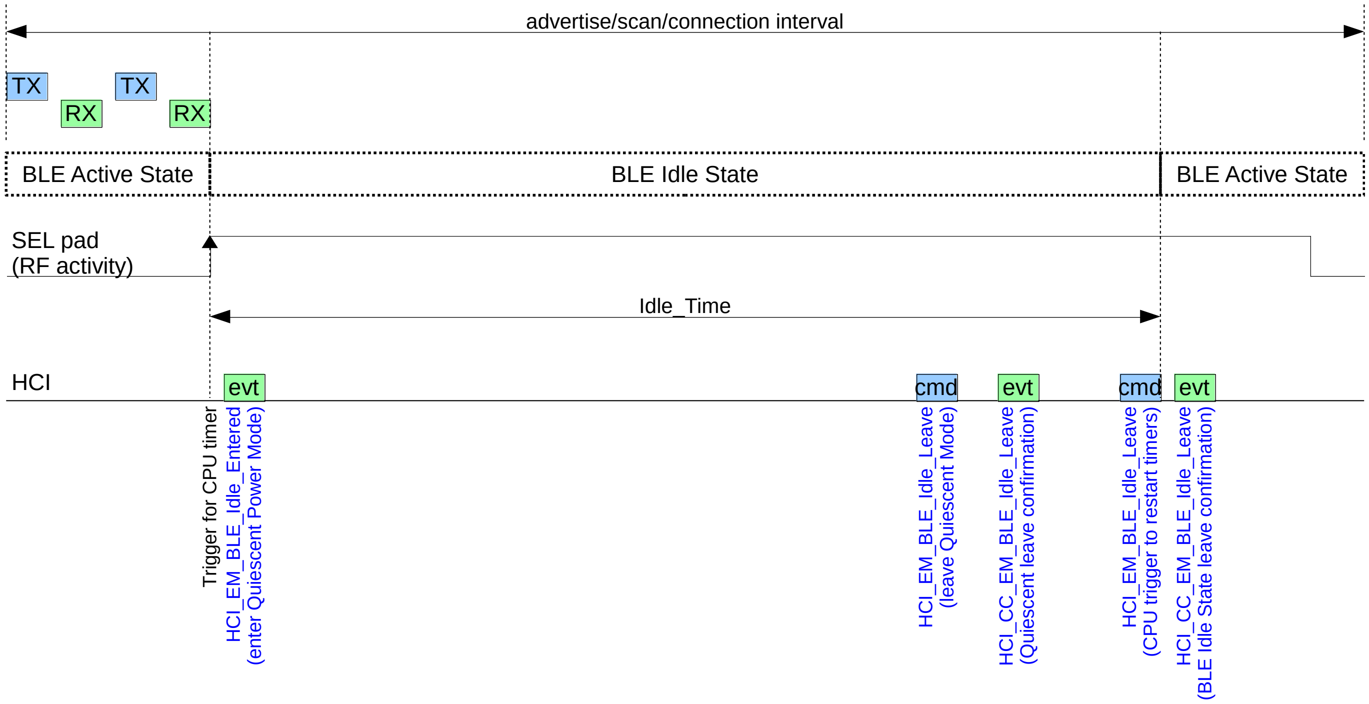


Figure 6.2: BLE Idle State using external time reference (version 022 only)

The host MCU can use the HCI command EM_POWER_MODE_CONFIGURATION as described in section 9.10 to enable the use of the Quiescent Power Mode during BLE Idle and the EM_SET_BLE_IDLE_PARAMETERS command described in section 9.19 to configure the timing parameters.

The HCI event EM_BLE_IDLE_ENTERED and two EM_BLE_IDLE_LEAVE commands are used to synchronize the Idle timing.

In this configuration the EM9301 SEL pad becomes a digital output which signalizes the RF activity (as described in section 6.3.3) and it is used as a trigger for the external MCU to start the timing of part of the BLE Idle phase. The MCU shall have one GPIO connected to the EM9301 SEL pad to be used for timing synchronization.

Description of the communication between EM9301 and the host MCU:

1. Once the RF packet exchange is finished, the EM9301 generates a trigger edge on the SEL pad which shall be used by the MCU to start its internal Idle timer. The timer shall be started with minimum delay (~us). The target value of the Idle timer is not know at this moment thus the Idle timer shall be pre-configured to count to some default value which should be bigger than the communication interval (e.g. 1000ms).
2. Shortly after the trigger edge the EM9301 sends the HCI event EM_BLE_IDLE_ENTERED informing to the host MCU how long the EM9301 will stay in Quiescent Power Mode. The duration is given by the Idle_Time parameter. The target value of the MCU Idle timer shall be changed to the value indicated in the HCI event.
3. Approximately 7500us before the MCU Idle timer reaches its target value (communicated in the EM_BLE_IDLE_ENTERED event) the MCU shall send a first EM_BLE_IDLE_LEAVE command to wake up the EM9301. Once the EM9301 is woken up it switches to the Standby Power Mode and sends an HCI Command Complete event to inform the MCU that the synchronization can be performed [10].
4. Once the MCU Idle timer reaches the target value, the MCU shall send a second HCI command EM_BLE_IDLE_LEAVE to synchronize the timing in the EM9301. The end of this second EM_BLE_IDLE_LEAVE command shall be sent at the same instant at which the MCU Idle timer reaches the target value. The synchronization point for the EM9301 timer is the time when the last byte of the HCI command is received.
5. Once the second EM_BLE_IDLE_LEAVE command is processed by the EM9301 an HCI Command Complete event is sent to the host MCU and short time after the SEL pad toggles to signalize that the RF activity starts again.

Host MCU Idle timer precision and current consumption

The overall timing precision provided by the host MCU (SEL pad edge to the end of the second EM_BLE_IDLE_LEAVE command) shall fulfill all BT requirements for protocol timing; in particular the timing accuracy has to be better than +/-500ppm and the instantaneous timing shall not deviate more than 16us from the average timing. The overall (MCU + EM9301) cumulative timing error shall be always within the range +/-16us from the average timing.

As the timing accuracy of the EM9301 is +/-2us, the MCU has to be within the +/-14us range.

The HCI command EM_SET_BLE_IDLE_PARAMETERS (described in section 9.19) can be used to configure the timing parameters. The command allows to set the Sleep Clock Accuracy (SCA) of the external timing system, the minimum length of the Idle time, and to independently enable/disable the use of external timing and Quiescent Power Mode for each BLE role by means of an enable mask.

The current consumption of the host MCU should also be optimized: a low power mode and a low power timer should be used and the SPI transactions should be optimized.

To reduce the power consumption during the timing synchronization phase, the host MCU can optimize the time between sending the first and the second EM_BLE_IDLE_LEAVE HCI commands in the following way:

- first the MCU starts with a default value (7500us) and once the first EM_BLE_IDLE_LEAVE is sent and the Command Complete event is received the MCU can calculate the remaining time to the end of the BLE Idle State;
- if this time is bigger than a given margin (e.g. 1000us) the time needed for wake-up and synchronization (time between the two EM_BLE_IDLE_LEAVE commands) can be reduced. The time reduction can be then used for the next advertise/scan/connection event.

The minimum Idle time required to transfer the timing to the Host MCU and to enter into the Quiescent Power Mode is configurable by the command EM_SET_BLE_IDLE_PARAMETERS as described in section 9.19. Depending on the host power consumption during the BLE Idle State and during the timing synchronization phases the value of this minimum required time can be optimized. The default value is 25ms and if the EM9301 calculates the Idle time being less than 25ms then the external timer won't be used. In that case the SEL pad edge is still generated (RF activity signalization) but the HCI event EM_BLE_IDLE_ENTERED is not sent.

6.3.2 Configurable RF auto-calibration system (version 022 only)

There are two blocks in the RF system which need to be calibrated before usage and recalibrated if the operating temperature changes by more than 5°C: the VCO (Voltage-Controller Oscillator) in the frequency synthesizer and the GFSK (Gaussian Frequency Shift Keying) modulator.

[10] After sending the first EM_BLE_IDLE_LEAVE HCI command is not allowed to send any other HCI command before finishing the timing synchronization which is done by a second EM_BLE_IDLE_LEAVE command otherwise the timing synchronization is not performed correctly.

The EM9301 implements an auto-calibration system which is launched before any BLE operation to obtain initial calibration values and then periodically to adjust for the temperature changes. The two processes are called “RF initialization” and “RF periodic auto calibration”

The EM9301 version 022 allows to

- Enable or disable the RF initialization
- Enable or disable the RF periodic auto calibrations
- Read and write the calibration values

With these features the host MCU can disable the calibrations that are not needed and reduce the overall power consumption.

In some systems the temperature does not change and the RF calibration is needed only once. In other systems the host MCU can monitor the temperature and launch the calibration only when the temperature changes by more than 5°C.

RF Initialization control
RF initialization differs from the periodic RF auto calibration in the fact that during RF initialization the RF auto calibration is performed several times and the results are averaged while the periodic RF auto calibration consist of a maximum of one auto calibration per second.

The HCI command EM_SET_RF_INITIALIZATION_CONFIG described in section 9.16 allows controlling the RF initialization which is performed per default before any BLE operation. The RF initialization can be disabled, enabled or launched once to obtain new calibration values. The number of auto calibration iteration can also be controlled.

By using the commands EM_READ_RF_CALIBRATION_VALUES and EM_WRITE_RF_CALIBRATION_VALUES described in sections 9.17 and 9.18 the host MCU can read and write calibration values into the RF system.

These commands are provided to optimize the power consumption on systems sensitive to start-up time and consumption during the start-up phase.

RF periodic auto calibration control
During BLE operation (advertiser, scanner, connection) the RF system is periodically auto calibrated to update the calibration values in case there is a temperature change. When the periodic auto calibration is enabled one RF auto calibration is performed before any BLE event that occurs after one second from the preceding auto calibration. The obtained auto-calibration value is averaged with the last 3 foregoing values.

The HCI command EM_SET_RF_AUTOCAL_CONFIG defined in section 9.15 controls the periodic auto calibration system. With this command the periodic auto calibration can be disabled / enabled with this command or one auto calibration can be programmed to be launched before the next BLE RF event.

The host MCU can control the periodic RF auto calibration and reduce the power consumption in power sensitive systems.

6.3.3 RF activity signalization (version 022 only)

Some systems with very small batteries need to avoid high current peaks to prevent battery damage. The EM9301 version 022 implements an “RF activity” signal which can prevent the host MCU not to execute current hungry activities simultaneously with the EM9301 RF activity.

This RF activity signalization can be enabled by the HCI command EM_SET_RF_ACTIVITY described in section 9.13.

When this signalization is enabled the SEL pad becomes an EM9301 digital output and signalizes RF activity as depicted in Figure 6.3: it goes low around 500us before the first Tx or Rx transaction of a BLE event and goes high around 30us after the last transaction. The host MCU needs to be connected to the SEL pad to monitor the RF activity.

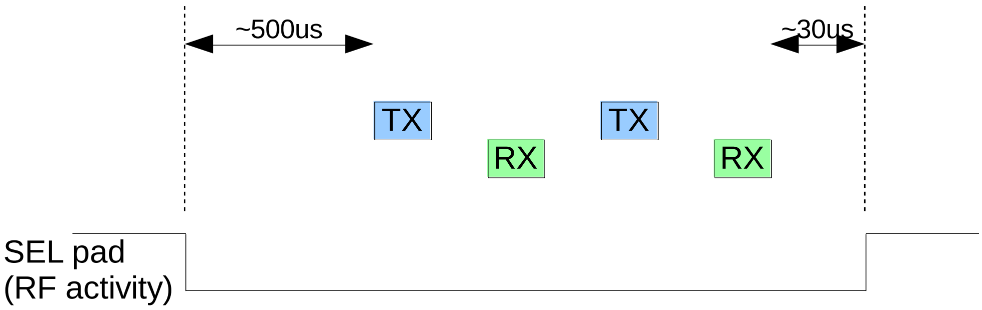


Figure 6.3: RF activity signalization (version 022 only)

6.3.4 Crystal oscillator start-up time optimization (version 022 only)

The start-up time of the 26MHz crystal oscillator can vary in a wide range depending on the particular quartz characteristics. The *Bluetooth* system requires precise timing and for that reason the crystal oscillator needs to be started soon enough before any BLE event to be sure that the 26MHz clock is available for RF operation.

The EM9301 version 022 implements an automatic measurement of the crystal oscillator start-up time and optimizes the time given to the oscillator each time it starts, reducing the overall power consumption.

In order to account for environmental changes (temperature) affecting the start-up time, the EM9301 starts the oscillator 1ms in advance. On systems with a stable environment the host MCU can reduce that margin by setting a fix start-up time value for the crystal oscillator. The command EM_SET_XTAL_STARTUP_TIME described in section 9.14 can be used for this purpose.

6.4 EM9301 reset structure

EM9301 has the following sources of reset:

1) Power-On Reset (POR). This occurs after each power up of the EM9301. When the start-up procedure is finished an EM_STANDBY_STATE event is reported to the host, indicating that the EM9301 has entered in Standby State. During POR RST pad shall be pull to logic 0.
2) RST pad. The host can reset EM9301 by pulling up the pin RST for at least 1ms. In this situation EM9301 will reboot the firmware and an event EM_STANDBY_STATE is sent as soon as EM9301 has entered into the Standby State. The pad RST shall be pull to logic ‘0’ during POR.
3) HCI reset. The host can reset the BLE functions of EM9301 by sending the standard *Bluetooth* command HCI_RESET as described in [1].

7. Host/Controller Interface (HCI)

EM9301 includes a Host/Controller Interface as defined in the *Bluetooth* Core Specifications [1], volume 2, part E. Table 7.1 summarizes the command formats and Table 7.2 the event formats. This section is added only for completeness as there are no differences with respect to the definitions given by the *Bluetooth* SIG. The set of available commands is limited to the ones defined for the *Bluetooth* Low Energy devices. More detailed description of commands and events as well as all HCI related information can be found in [1].

Byte #	Parameter	Size	Description
1	Packet_ID	1	Packet ID: Packet Identifier • For HCI Command PacketID = 0x01
2-3	OpCode	2	OpCode is a unique identification of the command It includes: • OpCode Group Field (OGF) of 6 bit. Code 0x3F is reserved for Vendor command • OpCode Command Field (OCF) of 10 bit. Opcode = (OGF << 10) + OCF
4	Parameter_Total_Length	1	Lengths of all of the parameters contained in the given command packet (aka len).
	Parameter_0		Each command has a specific number of parameters associated with it. These parameters and the size of each of the parameters are defined for each command. Each parameter is an integer number of octets in size.
	. . .		
	Parameter_N		

Table 7.1 HCI Command formats

Byte #	Parameter	Size	Description
1	Packet_ID	1	Packet ID: Packet Identifier • For HCI Events PacketID = 0x04
2	EventCode	1	Each event is assigned by a code used to uniquely identify different types of events. Range: 0x00-0xFF (The event code 0xFF is reserved for the event code used for vendor-specific debug events. In addition, the event code 0xFE is also reserved for Bluetooth Logo Testing)
3	Parameter_Total_Length	1	Lengths of all of the parameters contained in the given command packet.
	Parameter_0		Each command has a specific number of parameters associated with it. These parameters and the size of each of the parameters are defined for each command. Each parameter is an integer number of octets in size.
	. . .		
	Parameter_N		

Table 7.2 HCI event formats

As an example, a 3 byte long word with a value 0x123456 is sent in the sequence: 0x56 0x34 0x12 in little endian representation.

In addition to standard commands, a set of HCI proprietary commands for dealing with the power modes and some parameters linked to RF performances are supported. The complete list of supported proprietary HCI commands is available in section 0.

EM9301 supports two different transport layers for HCI according to the level of the pin SEL:

1) SEL = 0: UART interface as defined in [1], volume 4, part A
2) SEL = 1: SPI interface with proprietary flow control

7.1 List of supported HCI commands

HCI command name	OGF	OCF	OpCode	Notes
Set Event Mask	0x03	0x001	0x0C01	
Reset	0x03	0x003	0x0C03	
Read Local Version Information	0x04	0x001	0x1001	
Read Local Supported Commands	0x04	0x002	0x1002	
Read Local Supported Features	0x04	0x003	0x1003	
Read BD_ADDR	0x04	0x009	0x1009	
LE Set Event Mask	0x08	0x001	0x2001	
LE Read Buffer Size	0x08	0x002	0x2002	
LE Read Local Supported Features	0x08	0x003	0x2003	
LE Set Random Address	0x08	0x005	0x2005	
LE Read Supported States	0x08	0x01C	0x201C	
LE Read White List Size	0x08	0x00F	0x200F	
LE Clear White List	0x08	0x010	0x2010	
LE Add Device To White List	0x08	0x011	0x2011	
LE Remove Device From White List	0x08	0x012	0x2012	
LE Set Advertising Parameters	0x08	0x006	0x2006	
LE Set Advertising Data	0x08	0x008	0x2008	
LE Set Scan Response Data	0x08	0x009	0x2009	
LE Set Advertise Enable	0x08	0x00A	0x200A	c
LE Read Advertising Channel TX Power	0x08	0x007	0x2007	
LE Set Scan Parameters	0x08	0x00B	0x200B	
LE Set Scan Enable	0x08	0x00C	0x200C	c
LE Create Connection	0x08	0x00D	0x200D	c
LE Create Connection Cancel	0x08	0x00E	0x200E	
Disconnect	0x01	0x006	0x0406	
LE Connection Update	0x08	0x003	0x2013	
LE Set Host Channel Classification	0x08	0x014	0x2014	
LE Read Channel Map	0x08	0x015	0x2015	
LE Read Remote Used Features	0x08	0x016	0x2016	
Read Transmit Power Level	0x03	0x02D	0x0C2D	
Read Remote Version Information	0x01	0x01D	0x041D	
Read RSSI	0x05	0x0005	0x1405	a
LE Encrypt	0x08	0x017	0x2017	
LE Rand	0x08	0x018	0x2018	
LE Start Encryption	0x08	0x019	0x2019	
LE Long Term Key Request Reply	0x08	0x01A	0x201A	
LE Long Term Key Request Negative Reply	0x08	0x01B	0x201B	
LE Receiver Test	0x08	0x01D	0x201D	c
LE Transmitter Test	0x08	0x01E	0x201E	c
LE Test End	0x08	0x01F	0x201F	

Table 7.3 List of supported HCI commands

Notes : see next page

7.1.1 Vendor specific HCI commands

HCI command	OGF	OCF	OpCode	Notes
EM_WRITE_DATA	0x3F	0x000	0XFC00	
EM_READ_DATA	0x3F	0x001	0XFC01	
EM_SET_PUBLIC_ADDRESS	0x3F	0x002	0XFC02	
EM_SET_OPERATING_STATE	0x3F	0x003	0XFC03	
EM_SVLD	0x3F	0x004	0XFC04	
EM_SET_RF_POWER_LEVEL	0x3F	0x005	0XFC05	
EM_POWER_MODE_CONFIGURATION	0x3F	0x006	0XFC06	
EM_SET_UART_BAUD_RATE	0x3F	0x007	0XFC07	
EM_BLE_IDLE_LEAVE	0x3F	0x009	0XFC09	b
EM_SET_RF_ACTIVITY	0x3F	0x00A	0XFC0A	b
EM_SET_XTAL_STARTUP_TIME	0x3F	0x00B	0XFC0B	b
EM_SET_RF_AUTOCAL_CONFIG	0x3F	0x00C	0XFC0C	b
EM_SET_RF_INITIALIZATION_CONFIG	0x3F	0x00D	0XFC0D	b,c
EM_READ_RF_CALIBRATION_VALUES	0x3F	0x00E	0XFC0E	b
EM_WRITE_RF_CALIBRATION_VALUES	0x3F	0x00F	0XFC0F	b
EM_SET_BLE_IDLE_PARAMETERS	0x3F	0x010	0XFC10	b
EM_TRANSMITTER_TEST	0x3F	0x011	0XFC11	b,c
EM_TRANSMITTER_TEST_END	0x3F	0x012	0XFC12	b

Table 7.4 Vendor specific HCI commands

Notes :

a) Typical RSSI accuracy is ±8 dB
b) Only supported by EM9301 version 022
c) During starting BLE activity or RF calibration HCI commands should not be queued. In other words next HCI command can be sent only if previous was completely proceeded (Command Complete/Status event was received for previously sent HCI command). This is only valid for EM9301 version 022.

7.2 List of supported HCI events

HCI event name	Event Code	Subevent Code	Notes
Command Complete	0x0E	----	
Command Status	0x0F	----	
LE Advertising Report	0x3E	0x02	a
LE Connection Complete	0x3E	0x01	
Disconnection Complete	0x05	----	
LE Connection Update Complete	0x3E	0x03	
LE Read Remote Used Features Complete	0x3E	0x04	
Read Remote Version Information Complete	0x0C	----	
Number Of Completed Packets	0x13	----	
LE Long Term Key Request	0x3E	0x05	
Encryption Change	0x08	----	
Encryption Key Refresh Complete	0x30	----	
Hardware Error	0x10	----	

Table 7.5 Supported HCI events

7.2.1 Vendor specific HCI events

HCI event name	Event Code	Subevent Code	Notes
EM_STANDBY_STATE	0xFF	0x01	
EM_BLE_IDLE_ENTERED	0xFF	0x02	

Table 7.6 Vendor specific HCI events

Notes :

a) Typical RSSI accuracy is ±8 dB

7.3 HCI UART transport layer

EM9301 includes a 2-pin UART compatible for communication protocol with 16450, 16550 and 16750 standards. The baud rate can be set by the host by sending the related HCI command (refer to section 9.11). The default baud rate is 115.2 kbps. When the UART interface is used, the SCK pin shall be tied to VSS.

7.3.1 UART interface

The UART interface is given by the following pins:

- UART_RX: UART receiver line
- UART_TX: UART transmitting line

7.3.2 UART Settings

The HCI UART Transport Layer uses the following settings for RS232:

- Baud rate : configurable via HCI
- The default baud rate is 115.2 kbps. The default value is set by the Power-On Reset (POR) or by the RST pin.
- Number of data bits: 8
- Parity bit: no parity
- Start bit: 1 start bit
- Stop bit: 1 stop bit
- Flow control: Not used

7.4 HCI SPI transport layer

EM9301 features a proprietary HCI SPI transport layer which allows the host/controller system to reach a lower power consumption by using lower clock frequencies. The HCI commands sent and events received over the SPI transport layer are identical to the ones sent/received over UART transport layer.

EM9301 supports only slave mode SPI. EM9301 HCI events are signalized to the host thought the assertion of the IRQ pin. When this occurs, the host shall send a clock so that event can be read. Pin IRQ is also used to inform the host that the EM9301 has data coming from RF communication to send. The procedures to read events or data are exactly the same.

7.4.1 SPI interface

EM9301 includes a 5-wire, 8-bit, MSB-first, Motorola-compatible with CPOL=0 and CPHA=0, SPI interface. Only half-duplex transport is supported.

The SPI interface is defined through the following pins:

- CSN: Chip select signal. This signal is active low and it is mandatory, even when only one slave device is connected to the host.
- SPI_SCK: SPI clock signal. When CSN is active, the host shall send to the controller a multiple of 8 clock cycles (and bits) during each SPI transaction. When CSN is not active, EM9301 ignores any signal sent to this pin. This allows the host to set a clock signal to serve other devices.
- SPI_MOSI: host-to-controller transfer data line. The host shall generate data on the negative edge and sample data on the positive edge of SPI_SCK signal. SPI data shall be sent in byte format, with most significant bit (MSB) first.
- SPI_MISO: controller-to-host transfer data line. When CSN is active, the controller generates data on the negative edge and sample data on the positive edge of SPI_SCK signal. When CSN is inactive, the controller sets this output in tri-state mode. SPI data is sent in byte format, with most significant bit (MSB) first.
- IRQ: interrupt request. This signal is set by the controller when an event needs to be sent to the host. This signal is active high.

7.4.2 SPI flow control

EM9301 features a proprietary flow control for all communications over SPI, both from host to controller and from controller to host. Each SPI transaction shall be done for 8 bits of data.

Host-to-controller flow

When the host needs to communicate with the controller, the following flow shall be followed:

1) The host sets MOSI signal to '1'
2) The host shall activate CSN after 100ns
3) The host shall poll MISO line. The first polling shall be done at least 100 ns after CSN is activated.
4) If MISO = '0' then the controller reception buffer is full and the host is not allowed to start the transaction.
5) If MISO = '1' then the controller reception buffer is not full and the host can start the transaction. After each set of 8 rising edge of SPI_SCK, the host shall poll MISO line to check whether the controller reception buffer is not full. The first polling can be done on the first SPI_SCK falling edge.

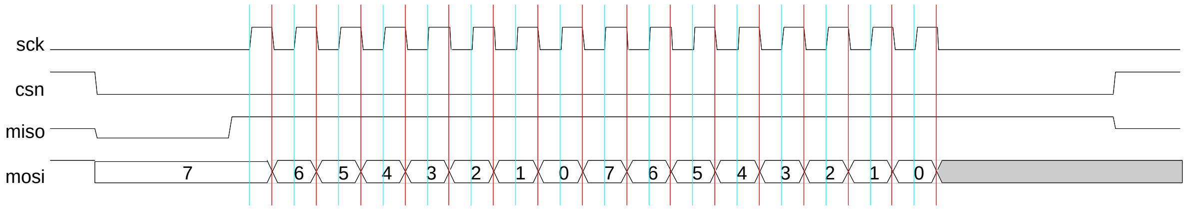


Figure 7.1 SPI writing transaction, with a wait state at start of the transaction

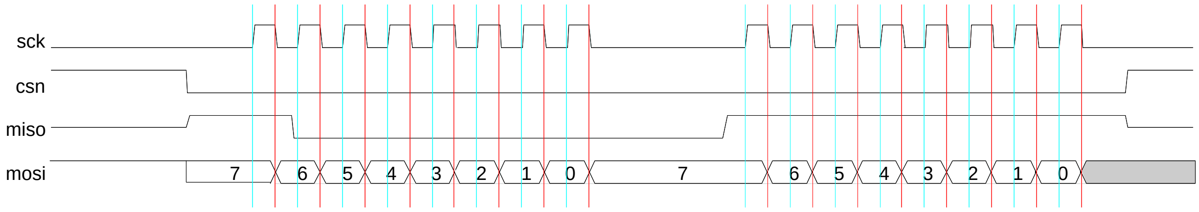


Figure 7.2 SPI writing transaction with a wait state after the first byte received

Controller-to-host flow

When the controller needs to communicate with the host, the following flow is followed:

1) The controller sets IRQ line to '1'. This means that the controller has at least 1 byte of data to transmit.
2) The host shall pull down MOSI signal.
3) The host shall activate CSN and after 100 ns
4) The host starts a SPI transaction by sending a data byte equal to 0x00
5) The host reads data sent by the controller on MISO line.
6) If IRQ is set to '0' during an SPI transaction then the controller has no other data to transmit. Once all bit of the transaction are read, the host can stop sending a clock
7) If EM9301 is in the Xtreme Power Mode, multi-transactions cannot be used and the host can read only one byte. If there are more bits to read, CSN has to be deactivated and activated again after reading one byte.

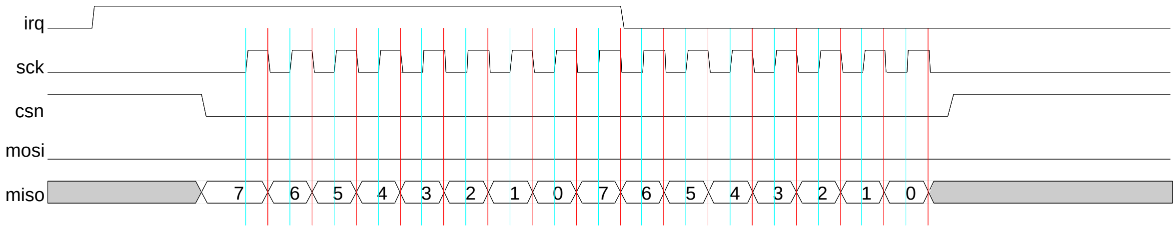


Figure 7.3 SPI read transaction with a empty buffer after the second byte

8. Peripherals information

EM9301 includes several internal peripherals to fulfill all requirements of the BLE standard. This section provides a short description of them to give a better overview of the system.

8.1 AES encryption/decryption accelerator

The EM9301 includes a hardware encryption/decryption accelerator based on the Advanced Encryption System (AES) standard. For further information about AES please refer to the official page of NIST (http://csrc.nist.gov/CryptoToolkit/aes/).

This block provides the following functions:

1) BLE encryption Key calculation
2) BLE Message Integrity Code (MIC) calculation
3) BLE Encryption stream generation
4) Host data encryption by means of the standard HCI_LE_Encrypt command

8.2 Random Number Generator (RNG)

EM9301 features a RNG block which is used to generate a 128 bit long, non-deterministic bit stream. The Host can use this block by means of the standard HCI_LE_Rand command.

8.3 Supply Voltage Level Detector (SVLD)

EM9301 offers the possibility of monitoring the supply voltage of the system (V_{CC2}). The host can launch a Supply Voltage Level Detector (SVLD) measurement by sending the HCI command EM_SVLD as defined in section 9.8.

The measure compares the supply voltage level with a predefined voltage level described in Table 8.1 and specified in section 5.1. After the measurement is completed, an event is reported to the host as described in section 9.8.

Note that a SVLD measurement can only be performed in the Standby Power Mode and that all threshold voltages have to be considered with a precision of ±10%.

Monitored power supply	SVLD threshold [11]	Function
VCC2	$SVLD_{TH\_06}$	Battery-low detection
	$SVLD_{TH\_07}$	Battery-low detection, early warning

Table 8.1 Function of SVLD thresholds

[11] The actual threshold voltage values are specified in **Error! Reference source not found.** and Table 5.1.

9. Application design guidelines

This chapter provides some design guidelines and constraints given for proper application design. For further information, please consider the related application notes or contact an EM Microelectronic-Marin representative.

9.1 Antenna port

The EM9301 features a fully differential 200Ω+j0Ω antenna port for the received or emitted signals at the pins ANTP and ANTN. The selected input/output impedance allows the implementation of a folded dipole antenna directly connected to the antenna port which does not require any external matching components. Use of other type of antennas is granted by implementing of a matching network with few external components. The following general guideline can be used to achieve best result in terms of RF performances:

1) Use at least a two-layer PCB and dedicate the bottom layer to one common ground plane covering all external components and the chip itself. Connect the attach area pin of the package to the ground plane.
2) Keep the EM9301 ANTP/ANTN symmetry on the PCB by keeping symmetry in components and via placement as well as line-routing.
3) Use only 100Ω transmission lines (200Ω differential) between the EM9301 RF output pins and the antenna / matching network input.
4) Try to minimize RF trace lengths.
5) Respect also a 3mm clearance to ground close to RF transmission lines and/or matching network components. In particular, respect clearance to ground for antenna structure (varies with antenna topology).
6) Do not put a ground plane below antenna structure to avoid gain loss and directivity modification.

9.1.1 Folded dipole antenna

The antenna port of the EM9301 can be directly connected to a folded dipole antenna as depicted in the layout example of Figure 9.1. This antenna example was implemented on a two-layer 0.8mm-thick FR4 PCB and has the advantage of providing 200Ω impedance and omni-directionality on one plane. Please refer to the EM application notes for further information on this and other antenna implementations for the EM9301 BLE controller.

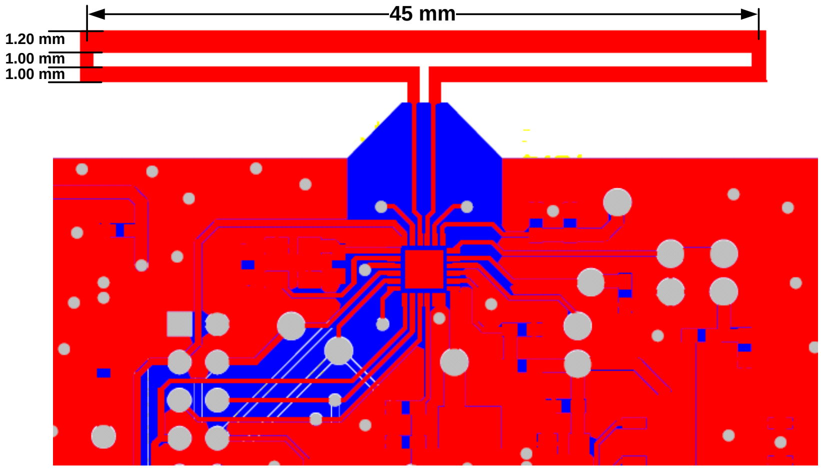


Figure 9.1 Layout example of a folded dipole antenna.

9.2 Xtal oscillator

EM9301 integrates a low-power, low-noise, fast-starting crystal oscillator designed for using a wide variety of low-cost and widely-spread 26MHz quartz crystals. This flexibility is achieved by the integration of an amplitude-control circuit which ensures optimal low-power and low-noise operation. Figure 9.2 shows a simplified block diagram of the EM9301 Xtal oscillator.

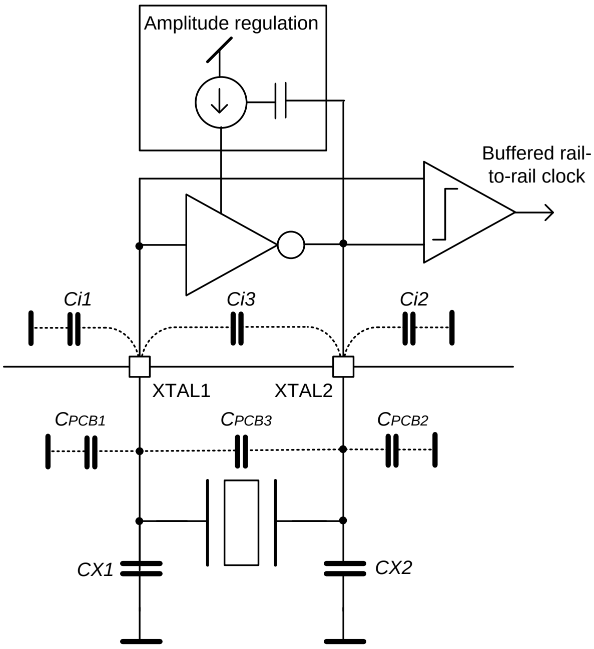


Figure 9.2 Xtal oscillator block diagram

This oscillator provides the reference clock for RF and digital operation on the EM9301 and has to meet the following requirements: low phase noise, low current consumption, fast start-up time, and *Bluetooth* frequency precision. The first three requirements are guaranteed by the oscillator and post-amplifier architectures; the frequency precision depends on the tolerances of the specific quartz crystal and on the variations of the internal and external capacitances on the nodes XTAL1 and XTAL2.

9.2.1 Frequency deviation

Bluetooth operation needs a frequency precision of 50ppm and the specifications for the quartz crystal as well as for the external capacitors CX1 and CX2 are driven by this requirement. Given the big variety of quartz crystals suitable to be used with the EM9301, some considerations have to be taken into account in order to comply with the *Bluetooth* precision requirement.

The total possible frequency deviation will be the addition of the following possible tolerances:

1. Quartz frequency tolerance
2. Quartz frequency deviation with temperature
3. Quartz aging tolerance
4. Frequency deviation due to the tolerances of the external capacitances CX1 and CX2 and of the parasitic capacitances.

The first three influences can be specified when ordering the quartz crystal and the fourth one has to be calculated. Please refer to the EM Microelectronic-Marin application notes for a calculation guide.

9.2.2 Reference quartz crystals

Two quartz crystals are given as reference: ABM8-26.000MHZ-10-D7G and ABM8-26.000-16-D7X from Abracon Corporation (www.abracon.com). The EM9301 typical characteristics are measured using the ABM8-26.000MHZ-10-D7G quartz. The total possible frequency deviation using any of the proposed quartz is within ±50ppm in the temperature range from -40°C to +85°C.

For the ABM8-26.000MHZ-10-D7G with 10pF specified load capacitance the total deviation can be calculated as follows: ±35ppm total frequency tolerance due to the quartz + ±13ppm frequency tolerance due to the external capacitance tolerance of 5% and to the parasitic capacitance tolerance of 30% = ±48ppm < ±50ppm.

For the ABM8-26.000-16-D7X crystal with 16pF specified load capacitance the total deviation can be calculated as follows: ±40ppm total frequency tolerance due to the quartz + ±8ppm frequency tolerance due to the external capacitance tolerance of 5% and to the parasitic capacitance tolerance of 30% = ±48ppm < ±50ppm.

9.3 Power supplies

In order to avoid any interference on the RF communication, all EM9301 Power supplies need to be properly decoupled. In general all decoupling capacitors defined in Figure 1.3 need to be as close as possible to the relative pin. Special caution needs to be taken for the decoupling on AVDD_PA (Power supply for the power amplifier) and VDD (power supply for the digital part). It is mandatory to put the decoupling capacitors as close as possible to the pin. All ground connections have to be as short as possible using as many vias directly to the ground plane as possible. Avoid sharing vias between different signals.

Vendor HCI commands

This section describes the proprietary HCI commands which can be used to setup special features of the EM9301. As defined in [1], the OGF reserved for vendor specific commands/event is 0x3F.

9.4 EM_WRITE_DATA

This HCI command is used to write data's into a registers. Note that some registers are partially or totally write protected. This command shall be used only for specific requirements as it can degrade performances and damage the device.

Opcode is : 0xFC00

Command parameters:

Parameter	**Size**	**Description**
Address	2	Register address.
Content	N	Data's to be written in the address of N byte size

Return parameters:

Parameter	**Size**	**Description**
Status	1	Standard *Bluetooth* error codes

Returned events:
Command Complete Event.

9.5 EM_READ_DATA

This HCI command is used to read registers.

Opcode is : 0xFC01

Command parameters:

Parameter	**Size**	**Description**
Address	2	Register address.
Count	1	Quantity of bytes to read.

Return parameters:

Parameter	**Size**	**Description**
Status	1	Standard *Bluetooth* error codes
Data	N	Register content over N requested bytes

Returned events:
Command Complete Event.

9.6 EM_SET_PUBLIC_ADDRESS

Set device public address

Opcode is : 0xFC02

Command parameters:

Parameter	Size	Description
Address	6	Device public address

Return parameters:

Parameter	Size	Description
Status	1	Standard *Bluetooth* error codes

Returned events:
Command Complete Event.

9.7 EM_SET_OPERATING_STATE

This command set the device operating state

Opcode is : 0xFC03

Command parameters:

Parameter	Size	Description
Operating State	1	0x00 = Standby State 0x01 = Sleep State 0x02 = Deep-Sleep State 0x04-0xFF = Reserved

Return parameters:

Parameter	Size	Description
Status	1	Standard *Bluetooth* error codes

Returned events:
The following event sequence, depending on the transition, is returned:

1) From Standby State to Sleep/Deep-Sleep State only the Command Completed Event is returned.
2) From Sleep/Deep-Sleep State to Standby State, a command status is sent after checking integrity of the command. Once the Standby State has been entered completely an EM_STANDBY_STATE event is returned to the host to report that the action has been completely done.

9.8 EM_SVLD

A measurement of the Supply Voltage Level Detector (SVLD) can be performed in Standby State and during BLE operation if the power mode for the BLE Idle State is the Standby Mode. The level tolerance is ±10%.
Opcode is : 0xFC04

Command parameters:

Parameter	**Size**	**Description**
Level	1	0x00 = Not used 0x01 = Not used 0x02 = Not used 0x03 = Not used 0x04 = Not used 0x05 = Not used 0x06 = $SVLD_{TH\_06}$ 0x07 = $SVLD_{TH\_07}$ 0x08-0xFF = Reserved
Source	1	0x00 = Not used 0x01 = VCC2 0x02 = VBAT 0x03-0xFF = Reserved

Return parameters:

Parameter	**Size**	**Description**
Status	1	Standard *Bluetooth* error codes
Result	1	0x00 = voltage is above the level 0x01 = voltage is below the level

Returned events:
Command Complete Event.

9.9 EM_SET_RF_POWER_LEVEL

Defines the Tx power level.

Opcode is : 0xFC05

Command parameters:

Parameter	**Size**	**Description**
Level	1	0x00 = *Pout_00* 0x01 = *Pout_01* 0x02 = *Pout_02* 0x03 = *Pout_03* 0x04 = *Pout_04* 0x05 = *Pout_05* (default for version 022) 0x06 = *Pout_06* (default for versions 001 & 002) 0x07 = *Pout_07* 0x08-0xFF = Reserved

Return parameters:

Parameter	Size	Description
Status	1	Standard *Bluetooth* error codes

Returned events:
Command Complete Event.

9.10 EM_POWER_MODE_CONFIGURATION

Enable/disable transition to BLE Idle State

Opcode is : 0xFC06

Command parameters:

Parameter	Size	Description
Power_Mode_Config	1	0x00 = BLE Idle State using Standby Power Mode (Xtal oscillator, default). 0x01 = BLE Idle State using Xtreme Power Mode (RC oscillator) 0x02 = BLE Idle State using Quiescent Power Mode (external timing) (version 022 only). 0x03-0xFF = Reserved.

Return parameters:

Parameter	Size	Description
Status	1	Standard *Bluetooth* error codes

Returned events:
Command Complete Event.

9.11 EM_SET_UART_BAUD_RATE

Select the UART baud rate

Opcode is : 0xFC07

Command parameters:

Parameter	Size	Description
Baud_Rate	1	0x00 = 1 200Bd 0x01 = 2 400Bd 0x02 = 4 800Bd 0x03 = 9 600Bd 0x04 = 14 400Bd 0x05 = 19 200Bd 0x06 = 28 800Bd 0x07 = 38 400Bd 0x08 = 57 600Bd 0x09 = 76 800Bd 0x0A = 115 200Bd (default) 0x0B = 230 400Bd 0x0C = 460 800Bd 0x0D = 921 600Bd 0x0E = 1 843 200Bd 0x0F – 0xFF reserved

Return parameters:

Parameter	Size	Description
Status	1	Standard *Bluetooth* error codes

Returned events:
Command Complete Event.

EM9301 changes the baud rate after sending the Command Complete event. This command shall be used only if no other event is in the controller HCI buffer. For this reason is highly advised to use this command only after power up or reset.

9.12 EM_BLE_IDLE_LEAVE

Wake up and timing trigger to leave BLE Idle State.

This HCI command is accepted only in EM9301 version 022.

Opcode is : 0xFC09

Command parameters:
None

Return parameters:

Parameter	Size	Description
Status	1	Standard *Bluetooth* error codes

Returned events:
Command Complete Event.

9.13 EM_SET_RF_ACTIVITY

Controls the RF activity signalization.

This HCI command is accepted only in EM9301 version 022.

Opcode is : 0xFC0A

Command parameters:

Parameter	Size	Description
RF_Active_Signal_Enable	1	0x00 = RF activity signalization disabled (default). 0x01 = RF activity signalization enabled. 0x02-0xFF = Reserved.

Return parameters:

Parameter	Size	Description
Status	1	Standard *Bluetooth* error codes

Returned events:
Command Complete Event.

9.14 EM_SET_XTAL_STARTUP_TIME

Crystal oscillator start-up time setting.

This HCI command is accepted only in EM9301 version 022.

Opcode is : 0xFC0B

Command parameters:

Parameter	Size	Description
XTAL_Startup_Time	2	0 = Automatic XTAL start-up time measurement. 1-1499 = Reserved. 1500-10000 = valid value of XTAL start-up time in [us] (manual mode). 10001-65535 = Reserved.

Return parameters:

Parameter	Size	Description
Status	1	Standard *Bluetooth* error codes

Returned events:
Command Complete Event.

9.15 EM_SET_RF_AUTOCAL_CONFIG

Set RF periodic auto calibration mode.

This HCI command is accepted only in EM9301 version 022

Opcode is : 0xFC0C

Command parameters:

Parameter	Size	Description
RF_Autocal_Mode	1	0x00 = RF periodic auto-calibration disabled. 0x01 = RF periodic auto-calibration enabled. 0x02 = One-shot RF auto-calibration. 0x03-0xFF = Reserved.

Return parameters:

Parameter	Size	Description
Status	1	Standard *Bluetooth* error codes

Returned events:
Command Complete Event.

9.16 EM_SET_RF_INITIALIZATION_CONFIG

Set RF initialization mode and parameters.

This HCI command is accepted only in EM9301 version 022

Opcode is : 0xFC0D

Command parameters:

Parameter	Size	Description
RF_Initialization_Mode	1	0x00 = Disable RF initialization. This code disables RF initialization which would be otherwise done before each BLE operation. 0x01 = Enable RF initialization. This code enables RF initialization to be done before each BLE operation (default). 0x02 = One shot RF initialization. This code immediately starts RF initialization. 0x03-0xFF = Reserved.
RF_Initialization_Iters	1	0x00 = 1 iteration. 0x01 = 2 iterations. 0x02 = 4 iterations (default). 0x03 = 8 iterations. 0x04 – 0xFF = Reserved.

Return parameters:

Parameter	Size	Description
Status	1	Standard *Bluetooth* error codes

Returned events:
Command Complete Event.

9.17 EM_READ_RF_CALIBRATION_VALUES

Read RF calibration values.

This HCI command is accepted only in EM9301 version 022

Opcode is : 0xFC0E

Command parameters:
None.

Return parameters:

Parameter	Size	Description
Status	1	Standard *Bluetooth* error codes
VCO_Cal	1	Currently used calibration value for VCO.
Modulator_Cal	1	Currently used calibration value for GFSK modulator.

Returned events:
Command Complete Event.

9.18 EM_WRITE_RF_CALIBRATION_VALUES

Write RF calibration values.

This HCI command is accepted only in EM9301 version 022

Opcode is : 0xFC0F

Command parameters:

Parameter	Size	Description
VCO_Cal	1	Allowed range: 0x00-0x0F. Calibration value for VCO.
Modulator_Cal	1	Allowed range: 0x00-0x3F. Calibration value for GFSK modulator.

Return parameters:

Parameter	Size	Description
Status	1	Standard *Bluetooth* error codes

Returned events:
Command Complete Event.

9.19 EM_SET_BLE_IDLE_PARAMETERS

Set the BLE Idle parameters.

This HCI command is accepted only by the EM9301 version 022 and only if there is no BLE activity (no advertising, scanning or connection).

Opcode is : 0xFC10

Command parameters:

Parameter	**Size**	**Description**
External_SCA	1	Sleep clock accuracy of external timing source used during BLE Idle State. 0x00 = 251 - 500 ppm (default). 0x01 = 151 - 250 ppm. 0x02 = 101 - 150 ppm. 0x03 = 76 - 100 ppm. 0x04 = 51 - 75 ppm. 0x05 = 0 - 50 ppm. 0x06-0xFF = Reserved.
BLE_Idle_Length_Min	2	Minimum length of BLE Idle State when using external timing. 0 – 14 = Reserved. 15 – 10240 = valid value of BLE Idle minimum length in [ms]. 10241 – 65535 = Reserved. Default value: 25 (25 ms).
BLE_Idle_State_Mask	1	The bits 0 to 3 select the BLE roles which are allowed to use the Deep-Sleep Power Mode and external timing when entering BLE Idle State: Bit 0 : Advertiser mask Bit 1 : Scanner and initiator mask Bit 2 : Slave connection mask Bit 3 : Master connection mask Bits 4-7 = reserved. Default value: 0x0F (all BLE roles selected).

Return parameters:

Parameter	**Size**	**Description**
Status	1	Standard *Bluetooth* error codes

Returned events:
Command Complete Event.

9.20 EM_TRANSMITTER_TEST

Start vendor transmitter test modes.

This HCI command is accepted only by the EM9301 version 022 and only if there is no BLE activity (no advertising, scanning or connection).

Opcode is : 0xFC11

Command parameters:

Parameter	Size	Description
Test_Mode	1	0x00 = EM transmitter test mode. This mode is similar to the standard BLE transmitter test mode with the difference that the number of transmitted packets is returned as event parameter when the test is stopped by the EM_TRANSMITTER_TEST_END command 0x01 = CM (continuously modulated) transmitter test mode 0x02 = CW0 (continuous wave at bit ‘0’) transmitter test mode 0x03 = CW1 (continuous wave at bit ‘1’) transmitter test mode 0x04 = CWC (continuous wave at center frequency) transmitter test mode 0x05 – 0xFF = Reserved.
Channel	1	0x00 – 0x27 = *Bluetooth* Low Energy RF channel (0 - 39) Frequency range: 2402 to 2480 [MHz]; f_n = 2402 + 2 n [MHz] 0x28 – 0xFF = Reserved.
Length_Of_Test_Data	1	0x00 – 0x25 = Length in bytes of payload data in each packet for EM and CM test mode 0x26 – 0xFF = Reserved.
Packet_Payload	1	Packet payload type for EM and CM transmitter test modes 0x00 = Pseudo-Random bit sequence 9 0x01 = Pattern of alternating bits ‘11110000’ 0x02 = Pattern of alternating bits ‘10101010’ 0x03 = Pseudo-Random bit sequence 9 0x04 = Pattern of All ‘1’ bits 0x05 = Pattern of All ‘0’ bits 0x06 = Pattern of alternating bits ‘00001111’ 0x07 = Pattern of alternating bits ‘01010101’ 0x08 – 0xFF = Reserved.

Return parameters:

Parameter	Size	Description
Status	1	Standard *Bluetooth* error codes

The RF output power for all the test modes started by this command is set by EM_SET_RF_POWER_LEVEL command.

The range of validity for the Length_Of_Test_Data and Packet_Payload parameters is checked in all cases but the parameters are used only in the EM and CM test modes.

Returned events:
Command Complete Event.

9.21 EM_TRANSMITTER_TEST_END

Stop vendor transmitter test modes.

This HCI command is accepted only by the EM9301 version 022 and only if there is no BLE activity (no advertising, scanning or connection).

Opcode is : 0xFC12

Command parameters:
None.

Return parameters:

Parameter	Size	Description
Status	1	Standard *Bluetooth* error codes
Number_Of_Packets	2	Number of transmitted packets in the EM and CM transmitter test modes.

Returned events:
Command Complete Event.

10. Vendor HCI events

This section defines the EM9301 Vendor events. There is no special event mask defined for vendor events in the EM9301. This means that the host cannot avoid receiving vendor events.

10.1 EM_STANDBY_STATE

This event reports that the device has correctly entered Standby State. This event is sent after POR, after wake-up by WU pin if UART is selected, and when the operating state changed from Sleep/Deep-Sleep to Standby.

The associated Event code is 0xFF.

Event parameters:

Parameter	Size	Description
EM_Event_Code	1	0x01

10.2 EM_BLE_IDLE_ENTERED

This event is reported only from EM9301 version 022.

The associated Event code is 0xFF.

Event parameters:

Parameter	Size	Description
EM_Event_Code	1	0x02
Idle_Time	3	3 bytes long parameter specifying how long BLE Idle State should be active in [us] (external MCU should wake up some time before and synchronize timing after this time).

10.3 Additional Hardware Error Event codes

Hardware Error Event is a standard *Bluetooth* event. EM9301 defines additional parameter codes as following:

Code	Description
0x00	No error
0x01	HCI synchronization lost
0x02	RF initialization fail (auto-calibration)
0x03	RF system error
0x04	CPU reset (watchdog)
0x05	CPU reset (bus error)
0x06	Crystal oscillator start-up error (only version 022)
0x80	Programming mode entered

Table 10.1 Additional Hardware Error Event codes

These hardware error event codes may occur if a strong perturbation is affecting the normal functioning of the EM9301. If one of these codes is received, it is recommended to check the presence of perturbations on the circuit interfaces, including the power supply and the antenna.

11. Versions and ordering information

The EM9301 is available in two different versions as summarized in the table below. All versions have the same pin-out.

Version	Description /Features	Applications / Comments
002	• BLE controller • Xtreme power mode • Deep-Sleep operating state	Wireless applications relying on 3V-type batteries (e.g. watches) or in which an external LDO is available (e.g. USB dongle)
022	• BLE controller • Operating supply voltage down to 1.9V • Xtreme power mode • Deep-Sleep operating state • External timing capability • Power consumption optimized	Ultra low power wireless applications relying on 3V-type batteries (e.g. watches) or in which an external LDO is available (e.g. USB dongle)

Table 11.1 EM9301 versions

11.1 Ordering information

Ordering Code	Description	Packaging	Container
EM9301V02LF24B+	BLE controller version 002	QFN24	Tape
EM9301V22LF24B+	BLE controller version 022	QFN24	Tape
EM9301V02WW7	BLE controller version 002	Wafer	Wafer container
EM9301V22WW7	BLE controller version 022	Wafer	Wafer container

Table 11.2 Ordering information

11.2 Package marking

This section reports the package marking information's. Additional marking letters and numbers are used for lot traceability.

9	3	0	1	0
0	2			

Table 11.3 EM9301 package marking for version 002

9	3	0	1	0
2	2			

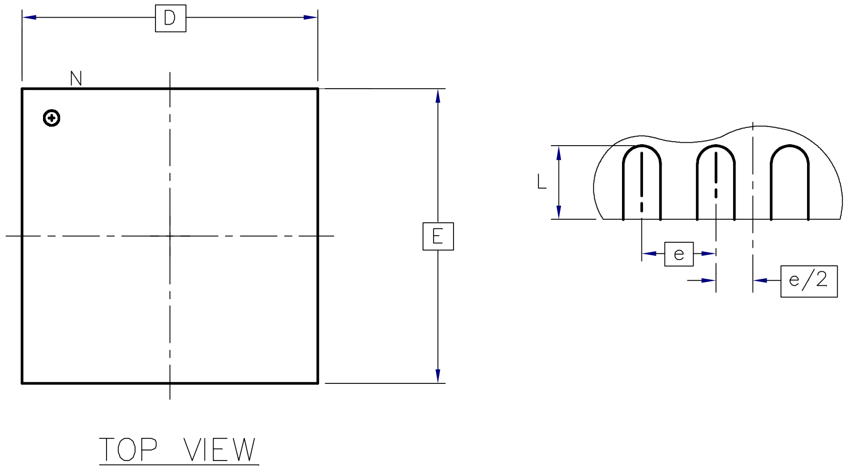
Table 11.4 EM9301 package marking for version 022

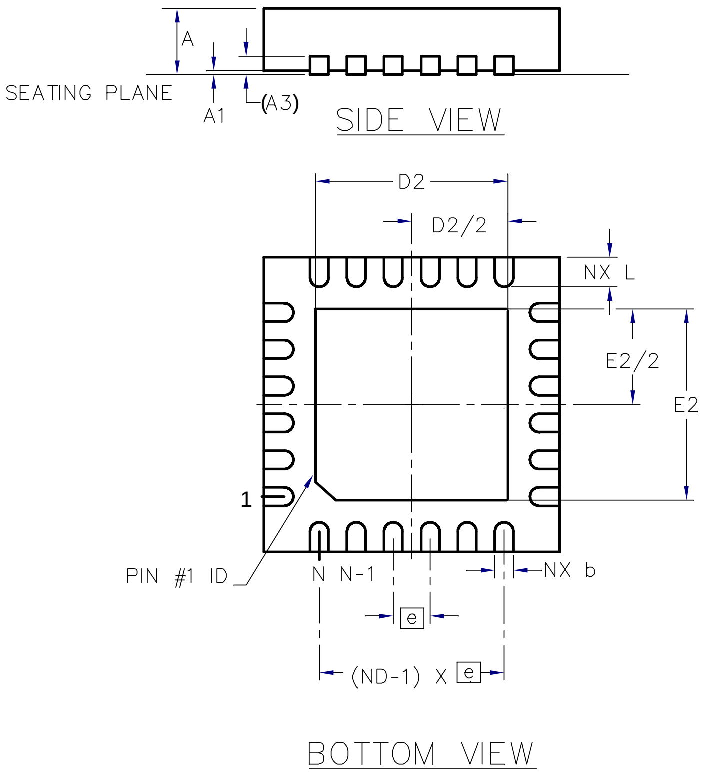
11.3 Firmware update

The EM9301 behavior is programmed in an internal memory. Some parts of this firmware (up to 6KB) can be changed to modify the system behavior. Please refer to the EM Microelectronic-Marin SA application notes for a detailed procedure to upload a firmware update.

12. Package information

EM 9301 is available in a QFN24 5mm x 5mm package. The package information is summarized in Figure 12.1.





mm	MIN	NOM	MAX
A	0.70	0.75	0.8
A1	0.00	0.035	0.05
A3	0.203 REF		
D	5.0 BSC		
E	5.0 BSC		
N	24		
ND	6		
L	0.35	0.40	0.45
b	0.25	0.3	0.35
D2	3.40	3.50	3.60
E2	3.40	3.50	3.60
e	0.65 BSC		

Figure 12.1 Package information