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 0.8V. This feature is achieved thanks to an embedded high-efficiency DC/DC converter which provides the required voltage to the integrated low-power RF core. Moreover, the DC/DC converter is designed to support an external load current and can be used to supply low-power microcontrollers or sensor interfaces.

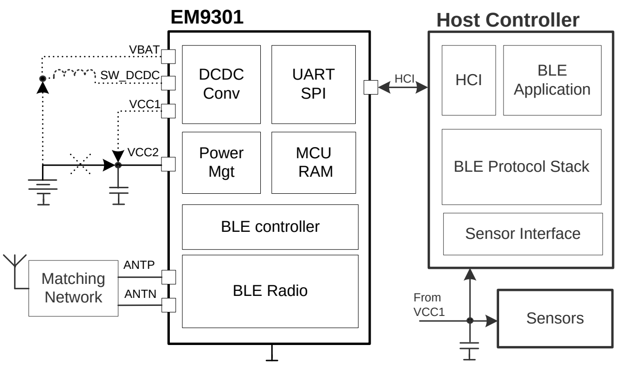
EM9301 can also be ordered without DC/DC converter for all applications where a supply voltage from a 3V battery or from any other source is available in the system. In this case, the bill of materials is further reduced, since no coil for the DC/DC converter is needed.

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 V4.0. 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* Low Energy companion chip.

Typical Application Schematic



*Not all connections shown. Dotted lines correspond to the DCDC version of EM9301.

[1] *Bluetooth* is a trademark owned by the *Bluetooth* Special Interest Group (SIG).

Main Features

- Master and slave BLE controller compliant to *Bluetooth* specification V4.0
- DCDC version operating directly from a single 1.5V battery and noDCDC version from a 3V battery
- Functional down to 0.8V in case of DCDC version to improve battery life time
- Low average current consumption in case of noDCDC version allowing the use of low-cost 3V batteries
- Based on widely-spread, low-cost 26MHz quartz
- 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 +3dBm 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

Typical Current consumptions

12mA	Tx current at 0dBm output power
13mA	Rx current
200µA	in Idle Mode
20µA	in Sleep Mode (noDCDC version)
9µA	in Deep-Sleep Mode (noDCDC version)

Typical Applications

- Remote sensing
- Wireless mouse and keyboard
- Wireless sensors for watches
- Wireless sport equipment
- Alarm and security systems

Pin Assignment

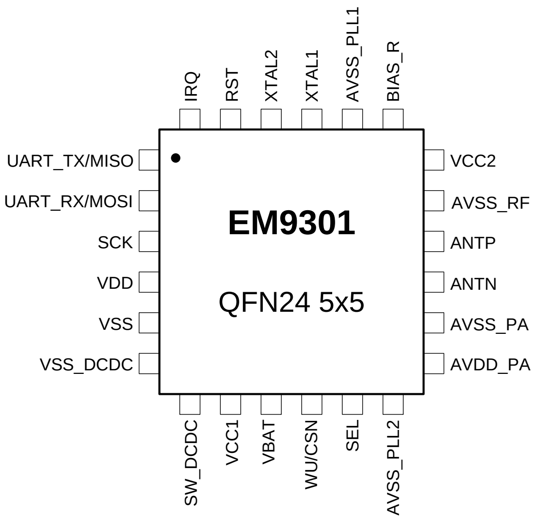


Table of contents

List of tables

List of figures

1. Introduction

The EM9301 is a low-power and low-voltage *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 +3dBm) 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 two hardware versions:

1) DCDC version which allows operation on a single 1.5V battery cell

2) noDCDC version which allows operation on a wide set of 3V batteries

The DCDC version includes a high-efficiency step-up converter capable of providing the power supply for the EM9301 itself and for other external components like a microcontroller or a discrete sensor. The minimum battery voltage can be as low as 0.8V during normal operation and the DC/DC output voltage can be selected by the host. Furthermore, the DC/DC converter can be re-configured into a proprietary mode called Xtreme Mode, where a fixed voltage is available for a limited output load current. This mode is specially suited for applications with low RF duty cycle.

Additionally, 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.

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.

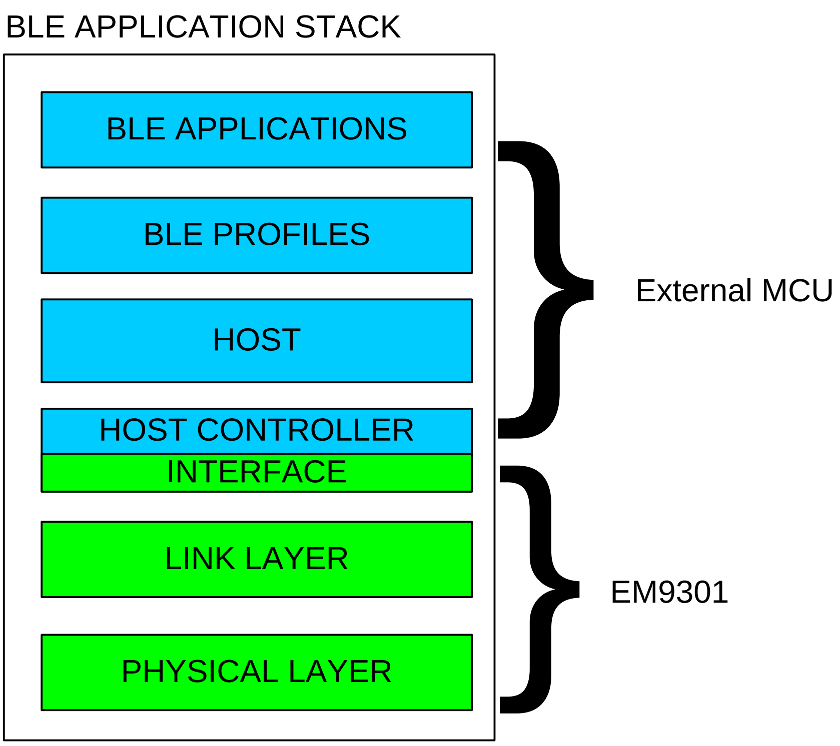


Figure 1.1 BLE stack

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 4.0, *Bluetooth* SIG, 30.06.2010

[2] *Bluetooth* Low Energy RF-PHY Test Specifications, Version 4.0.1, *Bluetooth* SIG, 18.07.2011

[3] *Bluetooth* 4.0 Link Layer Test Specifications, Version 4.0.3, *Bluetooth* SIG, 30.03.2012

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

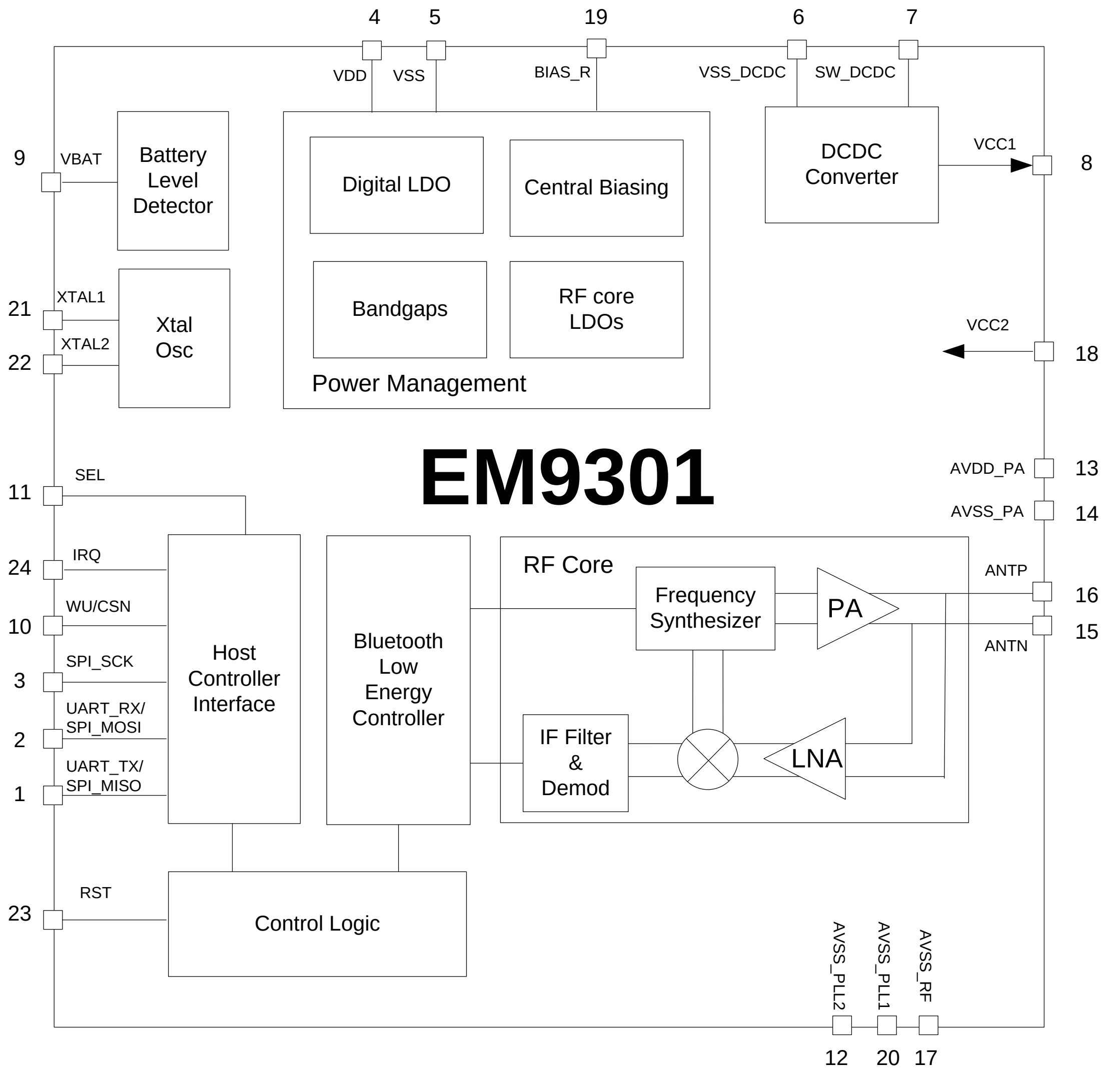


Figure 1.2 Simplified EM9301 block diagram

1.3 Pins description

Pin Nr	Name	Type	Description
0		Ground	Die paddle [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 [2]
6	VSS_DCDC	Ground	Negative supply for DC/DC converter [2]
7	SW_DCDC	Power	Input pin for the DC/DC converter coil
8	VCC1	Power	Output of DC/DC converter for DCDC version
9	VBAT	Analog	Power supply pin for DCDC version
10	WU / CSN	Digital Input	UART Wake Up from Sleep/Deep-Sleep Mode / SPI chip select.
11	SEL	Digital Input	Interface selection (0 = UART, 1 = SPI).
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	Analog	Pin for bias setting resistor
20	AVSS_PLL1	Ground	Negative supply of PLL [2]
21	XTAL1	Analog	Xtal oscillator ports
22	XTAL2	Analog	
23	RST	Digital Input	Reset.
24	IRQ	Digital Output	SPI Interrupt Request

Table 1.1 EM9301 pins description

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 a configuration schematic 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.

[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.

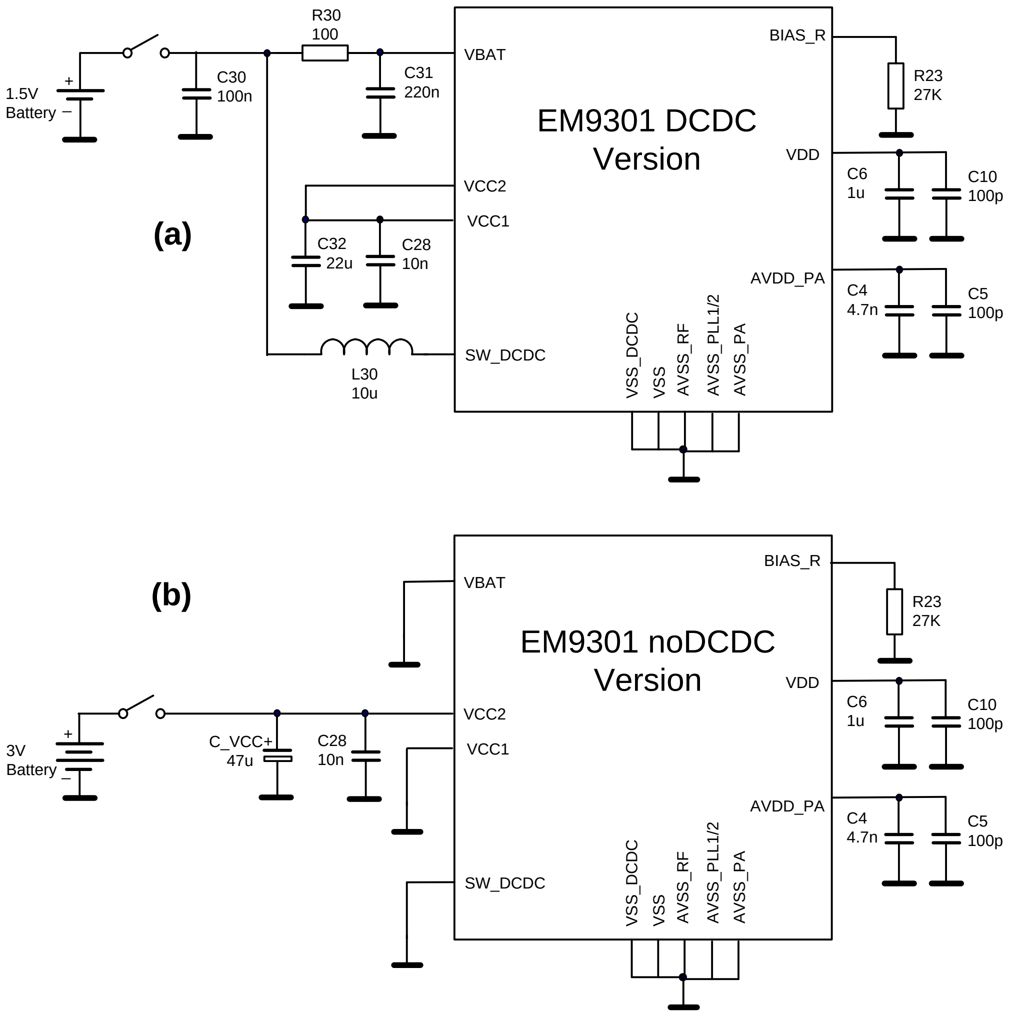


Figure 1.3 EM9301 power configurations: (a) DCDC version; (b) noDCDC version

Name	Description
VCC2	EM9301 main power supply. In the DCDC version this pin is directly connected to VCC1. In the noDCDC version this pin is connected to an external power supply (e.g. a 3V battery) as shown in 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 only used in the DCDC version. It is the main supply voltage for the DC/DC converter and can be connected to a single cell battery (e.g. a 1.5V battery). In order to avoid possible noise injection, a low pass filter as depicted in Figure 1.3(a) (R30 and C31) shall be included.
VCC1	This pin is only used in the DCDC version. It is the output of the integrated DC/DC converter and shall be connected externally to VCC2 and to a decoupling capacitor as depicted in Figure 1.3(a) (C32).
SW_DCDC	This pin is only used in the DCDC version. It is the coil input to the integrated DC/DC converter and shall be connected with the lowest possible resistance to the external coil as depicted in Figure 1.3(a) (L30).

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%
Component required only for the EM9301 noDCDC version:			
C_VCC	47uF	1206	VCC2 decoupling capacitor, ±20%, 10V
Components required only for the EM9301 DCDC version:			
C30	100nF	0402	VBAT decoupling capacitor, ±20%, 25V
C31	220nF	0603	VBAT filter capacitor, ±10%, 50V
C32	22uF	0805	DC/DC storage capacitor, ±20%, 25V, ESR <0.1Ω
L30	10uH	-	DC/DC coil, ±20%, recommended ESR <0.12Ω
R30	100Ω	0402	VBAT filter resistor, ±10%

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

2. Reference design

Figure 2.1 shows the schematic and Figure 2.2 the printed-circuit-board (PCB) layout of the reference design. The PCB consists of a 0.8mm-thick FR4 substrate with 35µm-thick copper layers on the top and bottom sides.

2.1 Bill Of Materials (BOM)

A list of recommended components to be used on the reference design is given in Table 2.1. Please note that the power supply components are given in Table 1.3.

Component	Value	Footprint	Description
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, ±5%
C22	15pF	0402	Xtal oscillator capacitor, ±5%
Balun and impedance matching network:			
L1	3.3nH	0402	Balun inductor, ±0.1nH, Q@2.44GHz>40
L2	3.3nH	0402	Balun inductor, ±0.1nH, Q@2.44GHz>40
L3	1.8nH	0402	Impedance matching inductor, ±0.1nH, Q@2.44GHz>30
L4	1.5nH	0402	Filter inductor, ±0.1nH, Q@2.44GHz>30
C24	1.2pF	0402	Balun capacitor, ±0.05pF, Q@2.44GHz>100
C25	1.2pF	0402	Balun capacitor, ±0.05pF, Q@2.44GHz>100
C26	1.2pF	0402	Impedance matching capacitor, ±0.05pF, Q@2.44GHz>100
C27	1.2pF	0402	Filter capacitor, ±0.05pF, Q@2.44GHz>100
R40	0 Ω	0402	Spare impedance matching component

Table 2.1 Recommended component list for the EM9301 reference design

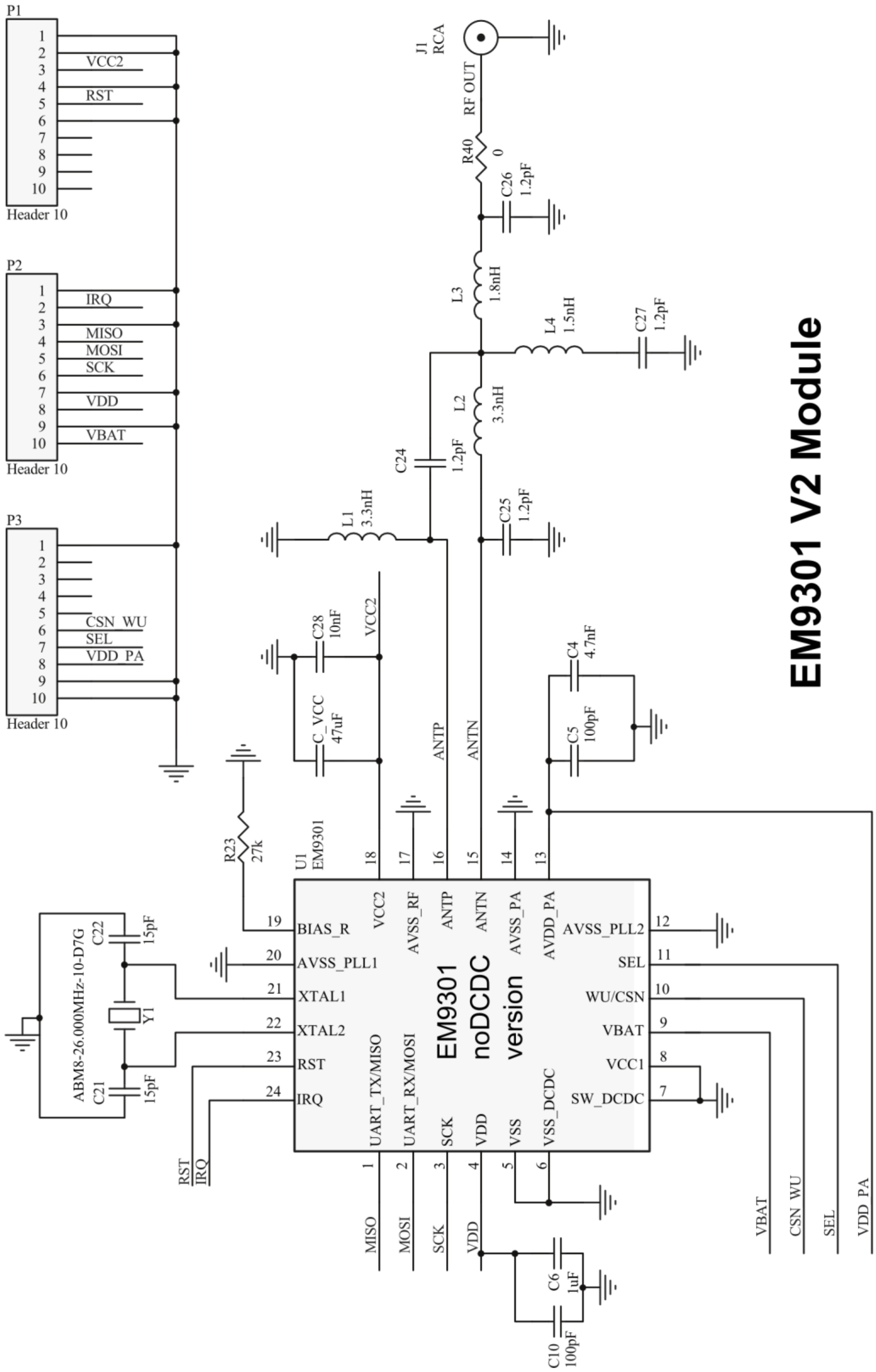


Figure 2.1 Reference design schematic (EM9301 noDCDC version)

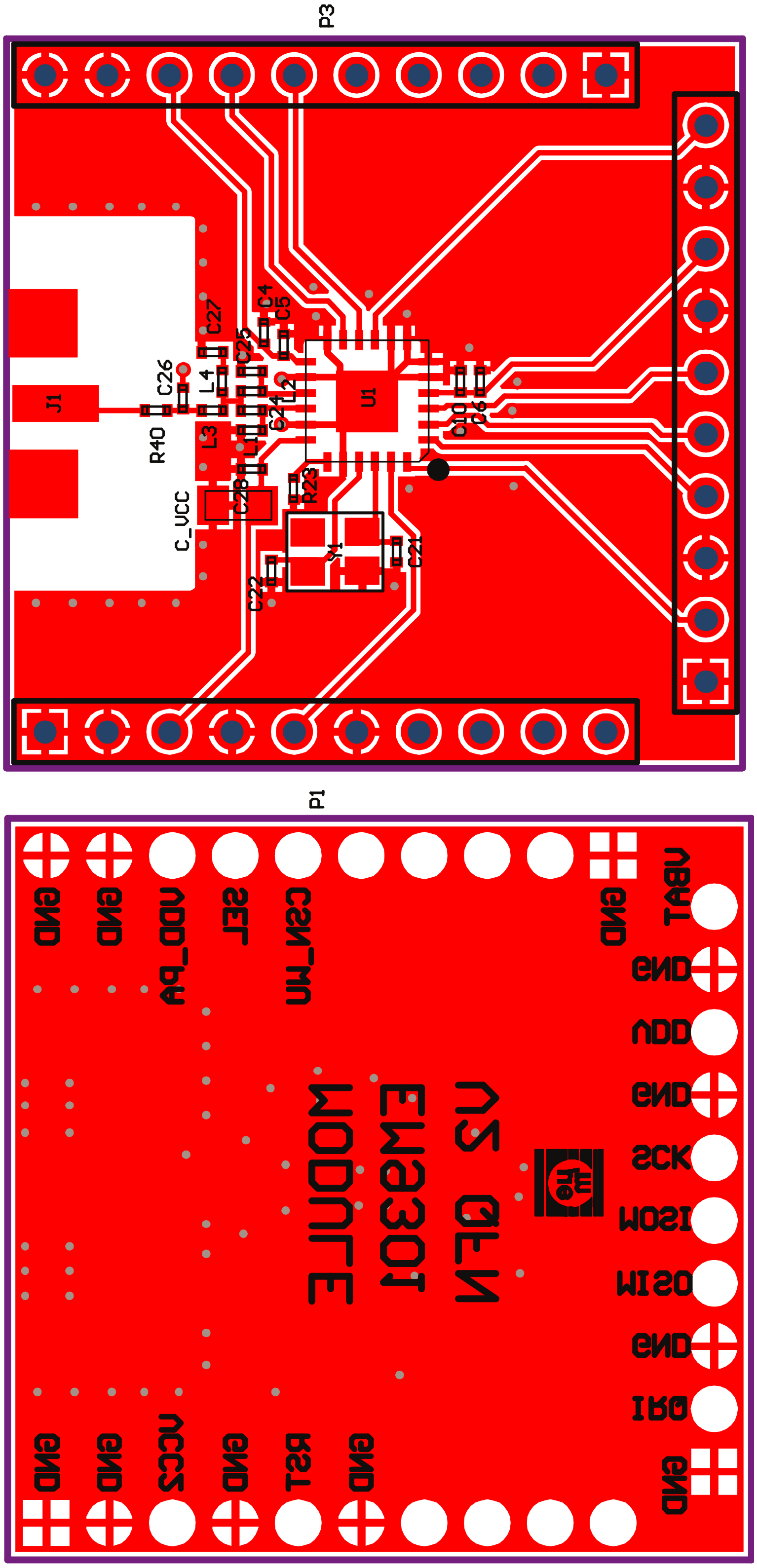


Figure 2.2 Reference design PCB top and bottom layout (EM9301 noDCDC version)

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
DC/DC converter supply voltage	V_{BAT}	-0.2	2.0	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 referred to GND according to Mil-Std-883, method 3015.7	V_{ESD}	-2000	+2000	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
Battery voltage EM9301 DCDC version [5]	V_{BAT}	0.8	1.8	V
Supply voltage EM9301 noDCDC version [5]	V_{CC2}	2.3	3.6	V
Operating temperature range	T_{op}	-40	+85	°C

Table 4.1 General operating conditions

[4] Ground pins defined in Table 1.1.

[5] The operating battery and supply voltages are is given for 25°C. In the full temperature range the battery voltage limits are 0.8V and 1.8V for the DCDC version and the supply voltage limits are 2.5V and 3.6V for the noDCDC version.

5. Electrical characteristics

The power and operating modes are defined in sections 6.2 and 6.3 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.
- For the EM9301 DCDC version the parameters are measured using the schematic on Figure 1.3(a) with the component list showed on Table 1.3, the battery voltage V_{BAT} is assumed to be 1.5V, the supply voltage V_{CC2}=2.2V, the external load in Standby Mode I_{Lext}=10mA, and the external load in Xtreme Mode I_{Lext}=500µA.
- For the EM9301 noDCDC version the parameters are measured using the schematic on Figure 1.3(b) 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 DCDC version power supply characteristics (preliminary)

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
DC/DC converter start-up voltage	$V_{BAT\_startup}$		1		1.8	V
DC/DC converter start-up time	$t_{DCDC\_st.up}$	Output settled to within ripple specification			100	ms
DC/DC Output Voltages in Standby Mode	V_{CC1_00} V_{CC1_01} V_{CC1_02} V_{CC1_03}	Voltage value selectable by HCI command	1.9 2.0 2.2 2.4	2.1 2.2 2.4 2.6	2.3 2.4 2.6 2.8	V
DC/DC Output Voltage in Xtreme Mode	V_{CC1_XT}	I_{Lext} < 1µA		2.0		V
Ripple on Output Voltage	$Vrip_{VCC1\_Stdby}$ $Vrip_{VCC1\_XT}$	Standby Mode Xtreme Mode			50 100	mVpp
External load applicable on VCC1	I_{Lext_Stdby} I_{Lext_XT}	Standby Mode Xtreme Mode			100 0.5	mA
DC/DC converter efficiency	η_{Stdby} η_{XT}	Standby Mode, I_{Lext} =30mA, V_{BAT}=1.2V Xtreme Mode, I_{Lext} = 30µA, V_{BAT} = 1.2V		88 55		%
Supply Voltage Level Detector (SVLD) threshold Levels	$SVLD_{TH\_00}$ $SVLD_{TH\_01}$ $SVLD_{TH\_02}$ $SVLD_{TH\_03}$			0.82 0.92 1.12 1.25		V
Battery Protection Mode (BPM) current consumption on VBAT	I_{BPM}				75	µA

Table 5.1 DCDC version power supply characteristics (preliminary)

5.1.2 noDCDC version 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 5.2 noDCDC version power supply characteristics

5.1.3 Current consumption

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Deep-Sleep Mode current	$I_{Deep\text{-}Sleep}$			9		µA
Sleep Mode current	I_{Sleep}			19		µA
Idle Mode current	I_{Idle}	ABM8-26.000MHZ-10-D7G Xtal type with 10pF load capacitance		200		µA
BLE Transmit Mode current	I_{Tx_06}	Output power = P_{out_06}		12.1		mA
BLE Receive Mode current	I_{Rx}			12.9		mA
BLE Sleep Mode current (Xtal-referenced)	$I_{BLE\_Sleep\_Xtal}$	ABM8-26.000MHZ-10-D7G Xtal type with 10pF load capacitance		450		µA
BLE Sleep Mode current (RC-referenced)	$I_{BLE\_Sleep\_RC}$			60		µA

Table 5.3 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 5.4 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 10.6.	1.2		1843.2	KBd/s
SPI interface:						
SPI speed (bit rate)	$SPI_{bitRate}$				5000	Kb/s

Table 5.5 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 5.6 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 5.8		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 5.7 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 5.8 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 (power up to Idle Mode)	$t_{st.up}$			15.5		ms
Sleep → Idle Mode	t_{Sleep_Idle}			2.6		ms
Deep-Sleep → Idle Mode	$t_{Deep\text{-}Sleep\_Idle}$			2.7		ms

Table 5.9 RF timing characteristics

5.3.4 Transmitter characteristics

Parameter	Symbol	Conditions		Min	Typ	Max	Unit
Output power	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 10.4. Low-loss balun and impedance matching network required.			3 0 -3 -6 -9 -12 -15 -18		dBm
RF Power accuracy	P_{out}/P_{out_xx}				±3		dB
Deviation from the channel center frequency	Δf_c	[6]				±150	KHz
Frequency drift for any packet length	Δf_{c_pkt}	[6]				50	KHz
Drift rate	$\Delta f_c/\Delta T$	[6]				400	Hz/µs
Modulated frequency deviation	Δf_{mod}	[7]			±250		KHz
In-band spurious emission, power transmitted outside the selected channel, at a frequency offset f_{offs}	$P_{out}(f_c+f_{offs})$	[6]	$\lvert f_{offs} \rvert$ = 2 MHz $\lvert f_{offs} \rvert$ ≥ 3MHz			-20 -30	dBm
Spurious emission at an out-of-band frequency f	$P_{out}(f)$	[8] [9]	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 5.10 Transmitter characteristics

[6] 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.

[7] 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.

[8] 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.

[9] 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	$P_C/P_I\ (f_{offs})_{min}$	[10] 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	$P_I(f)_{max}$	[10] *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*	$P_{out\_Rx}(f)$	[8] *f*= 30MHz–88MHz			-57.3	dBm
		f= 88MHz–1000MHz			-57.0	
		f= 1000MHz–12750MHz			-47.0	

Table 5.11 Receiver characteristics

[10] 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 for both versions 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

It is recommended that the communication interface be well defined at boot-up time. To assure this, the SEL pin shall be tied to VCC2 or to VSS with a low impedance (<10kΩ).

6.1.1 Start-up sequence: DCDC version

When a 1.5V battery is connected to the EM9301 DCDC version as described in section 1.4, an internal RC oscillator starts up providing a clock with fixed duty cycle to the power check circuit and to the embedded DC/DC converter, which starts to raise the voltage on pin VCC1.

The DC/DC converter includes a soft-start circuitry which is aimed to limit both the coil current and the voltage at the VCC1 pin. This ensures that all voltage levels inside and outside the chip do not exceed the maximum rates which could lead to a destruction of the EM9031 or any external component. Any unnecessary on-chip load is avoided in that phase (i.e. the RF-core circuitry cannot be enabled in this phase) and only the power-management control part and some bias circuitry are enabled.

The digital voltage regulator output (VDD), which is supplied by VCC2, is monitored by a power-check detector circuit. As soon as the power-check detector signals a sufficient voltage on VDD, the quartz crystal (Xtal) oscillator starts up. After the Xtal oscillator start-up procedure is completed, the full DC/DC converter regulation circuitry and the main logic will use the Xtal signal as reference clock and the output voltage is kept to the default value. The DC/DC converter starts to work either in CCM (Continuous Current Mode) or in Burst Mode according to the load present on the VCC1 pin.

6.1.2 Start-up sequence: noDCDC version

When a 3V battery is connected to the EM9301 noDCDC version as described in section 1.4, 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.

6.1.3 End of the boot-up procedure

Once the Xtal oscillator clock is available to the digital part of the controller, the EM9301 enters in Idle Mode and an event is sent to the host through the selected communication interface (refer to section 5.3.2 for the complete description how to send commands and read events from the EM9301).

At the end of the boot sequence, EM9301 returns an event EM_POWER_MODE_IDLE to the host to notify that the system has entered in Idle Mode. 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 DC/DC converter can be fully loaded and the EM9301 is ready to communicate through HCI. To avoid interference on the RF communication it is advised to minimize any external load on the DC/DC converter output while the EM9301 is in an on-air mode.

6.2 EM9301 power modes

EM9301 works in three main power modes which are automatically chosen based on the selected chip state described in section 6.3. These modes are not directly selectable by the external application.

6.2.1 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. In case of DCDC version, the DC/DC converter is in CCM (Continuous Current Mode) or Burst Mode, depending on the load at the VCC1 pin.

6.2.2 Xtreme Mode (DCDC version)

In Xtreme Mode for the DCDC version the Xtal oscillator is turned off and the DC/DC converter continues to operate using a low-frequency internal RC oscillator. The complete controller status is kept in memory and if no BLE Sleep Mode is being used, the supply voltage of the logic is lowered to reduce the power consumption due to leakage currents.

The main regulation circuitry of the DC/DC converter is disabled and replaced by a simple regulation loop working in Burst Mode. The voltage on VCC1 is maintained at a fixed value V_{CC1_XT}[11] with a ripple having a period which depends on the actual load. In this condition the ripple amplitude on VCC1 is typically degraded to $Vrip_{VCC1\_XT}$[11].

EM9301 can still supply external circuits in this mode, but the maximum load is reduced to I_{Lext_XT}[11]. For this reason, it is strongly recommended to put the external host controller into its lowest consumption mode and limit the current consumption of any external sensor.

6.2.3 Xtreme Mode (noDCDC version)

In Xtreme Mode for the noDCDC version 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 Sleep Mode is being used, the supply voltage of the logic is lowered to reduce leakage currents. The DC/DC circuitry is completely deactivated.

6.2.4 Deep-Sleep Mode (noDCDC version only)

Deep-Sleep Mode is only available for the EM9301 noDCDC version. 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.

6.3 EM9301 operating modes

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

6.3.1 State diagram

Figure 6.1 shows a simplified state diagram of the EM9301. Each bubble corresponds to one EM9301 operating mode and the bubble color represents the power mode associated to the specific chip mode. The arrows indicate how the transaction 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 mode 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 this initial step, EM9301 automatically enters the Idle Mode. A change of mode 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.

[11] The actual voltage and current values are specified in Table 5.1.

Figure 6.1 EM9301 state diagram

Operating mode	Power mode	Xtal oscillator	RC oscillator	RF state	Logic supply voltage	DC/DC converter operation and maximal external load
EM9301 DCDC version:						
Sleep	Xtreme	OFF	ON	OFF	1.2V	Burst Mode only; $I_{Lext} < I_{Lext\_XT}$ [11]
Idle	Standby	ON	ON	OFF	1.8V	CCM or Burst Mode; $I_{Lext} < I_{Lext\_Stdby}$ [11]
BLE Active	Standby	ON	ON	ON	1.8V	CCM or Burst Mode; $I_{Lext} < I_{Lext\_Stdby}$ [11]
BLE Sleep	Xtreme	OFF	ON	OFF	1.8V	Burst Mode only; $I_{Lext} < I_{Lext\_XT}$ [11]
	Standby	ON	ON	OFF	1.8V	CCM or Burst Mode; $I_{Lext} < I_{Lext\_Stdby}$ [11]
EM9301 noDCDC version:						
Deep-Sleep	Deep-Sleep	OFF	OFF	OFF	1.4V	NA
Sleep	Xtreme	OFF	ON	OFF	1.4V	NA
Idle	Standby	ON	ON	OFF	1.8V	NA
BLE Active	Standby	ON	ON	ON	1.8V	NA
BLE Sleep	Xtreme	OFF	ON	OFF	1.8V	NA
	Standby	ON	ON	OFF	1.8V	NA

Table 6.1 EM9301 operating and power modes

6.3.2 Idle Mode

Idle is the mode where the EM9301 enters per default after power up. When this mode is entered, the HCI event EM_POWER_MODE_IDLE is reported to the host. The power mode for this configuration is Standby Mode, as defined in section 6.2.1. The HCI system is available and the host can communicate with the controller using the selected transport layer. Using the HCI, the chip is able to receive and decode any command sent by the host as well as send any event back to the host using either UART or SPI transport layers, according to the value of SEL pin. 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.

6.3.3 Sleep Mode

Sleep Mode is an EM9301 low-power mode. The power mode for this configuration is Xtreme Mode as defined in sections 6.2.2 and 6.2.3. RF operation cannot be activated from this state. When the EM9301 exits from this mode, it goes to Idle Mode. 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 Idle state asserting the EM_POWER_MODE_IDLE event.
- If SPI has been chosen as transport layer, EM9301 is capable of executing a limited set of HCI commands with a limited speed. In particular all commands which enable RF communications are not allowed in this mode. The flow control described in 7.2.2 ensures that no overflow occurs in the communication. The HCI command EM_SET_POWER_MODE can be used to switch to Standby Mode.

6.3.4 Deep-Sleep Mode (only for noDCDC version)

Deep-Sleep Mode is the mode with the lowest power consumption. The power mode for this configuration is Deep-Sleep, as defined in section 6.3.4. 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 HCI commands are accepted. When the system wakes up, the default mode is Idle. 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 Idle Mode asserting the EM_POWER_MODE_IDLE event.
- If SPI has been chosen, the system can be waked up by sending any HCI command. Only a limited set of HCI commands is supported in this mode and with limited speed. In particular all the commands which enable RF communications are not allowed. Once a command has been received, EM9301 switches automatically to Sleep Mode and try to execute the command. The command EM_SET_POWER_MODE can be used to switch either to Idle or to Deep-Sleep Mode. In the first case the system will restart all internal oscillators and automatically go to Idle Mode asserting the EM_POWER_MODE_IDLE event. If Deep-Sleep Mode has been chosen, no special HCI event is sent but the EM9301 returns to Deep-Sleep Mode.

6.3.5 BLE Active Mode

BLE Active is the mode where the EM9301 is able to communicate to other BLE devices. It can be entered only from Idle Mode. This mode represents the starting state for any *Bluetooth* Low Energy operation (scanning, advertising, and connection). The power mode for this configuration is Standby, as defined in section 6.2.1. The HCI system is available and the host can communicate with the controller using the selected transport layer. HCI is able to receive and decode any command sent by the host as well as send any event back to the host using either UART or SPI transport layers, according to the value of SEL pin. Xtal is the clock source of EM9301 logic. The internal RC oscillator is calibrated during this phase. The RF core can be activated and controlled in order to optimize power consumption. The internal logic is in Halt Mode, waiting for a HCI command from the host. When the on-air link is active, it is highly recommended to reduce the host-controller communications in order to avoid possible noise coupling.

6.3.6 BLE Sleep Mode

BLE Sleep is a special mode defined in the *Bluetooth* Low Energy standard to reduce the power consumption by means of duty cycling. EM9301 offers two possible configurations for this mode: one employing the Xtal oscillator and the other using the RC oscillator. When the Xtal oscillator is used, the high precision of the Xtal allows the EM9301 to act as a master, slave, advertiser or scanner device. When the EM9301 is a slave, advertiser or scanner device, the RC oscillator can be chosen, and the power consumption can be significantly reduced because the Xtreme power mode is used in that case.

The EM9301 controls automatically the transitions between BLE Active and this mode, the host cannot influence them directly.

The use of the RC oscillator can be enabled by the HCI command EM_POWER_MODE_CONFIGURATION as described in section 10.5. Note that if the Xtreme power mode is used, all requirements regarding current consumption described in section 6.2.2 and defined in Table 5.1 shall be taken into account, in particular the maximum load applicable at the VCC1 pin: I_{Lext_XT}.

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 can be chosen.
- If the transport layer is SPI, the Xtal oscillator or the RC oscillator can be selected.

6.3.7 Battery Protection Mode (DCDC version only)

EM9301 features a special mode which protects weak batteries from leaking their chemistry by limiting the amount of long-term constant current. This mode is called Battery Protection Mode (BPM). BPM is activated by the proprietary HCI command EM_SET_POWER_MODE and sends the chip into a state where all electronics, except an internal resistive load, is switched off. It is important to know, that the BPM mode can only be left by changing the battery.

BPM is of particular importance at the start up of the system when a weak battery is applied since it can prevent excessive steady state current due to an improperly start up of the DC/DC converter. It is recommended to perform a power check after the start-up sequence is finished (see 6.1.1) to check if sufficient battery voltage is available. If this is not the case the EM9301 shall be sent into BPM.

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_POWER_MODE_IDLE event is reported to the host, indicating that the EM9301 has entered in Idle Mode. 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_POWER_MODE_IDLE is sent as soon as EM9301 has entered in Idle Mode. Pad RST shall be pull to logic 0 during POR.
3) HCI reset. Sending the standard *Bluetooth* command HCI_RESET, the host can reset the BLE functions of EM9301 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.
4	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 7.1 HCI Command formats

Byte #	Parameter	Size	Description
1	Packet_ID	1	Packet ID: Packet Identifier • For HCI Events PacketID = 0x04
2	EventCode	1	OpCode is a unique identification of the command/event. It includes: • OpCode Group Field (OGF) of 6 bit. Code 0x3F is reserved for Vendor command • OpCode Command Field (OCF) of 10 bit.
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

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 10.

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 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 10.6). The default baud rate is 115.2 kbps. When the UART interface is used, the SCK pin shall be tied to VSS.

7.1.1 UART interface

The UART interface is given by the following pins:

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

7.1.2 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

7.2 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.

7.2.1 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.

7.2.2 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.

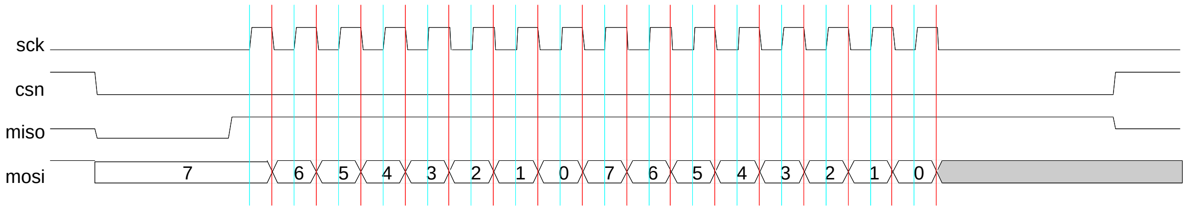


Figure 7.1 SPI writing transaction, with a wait state at start of the transaction

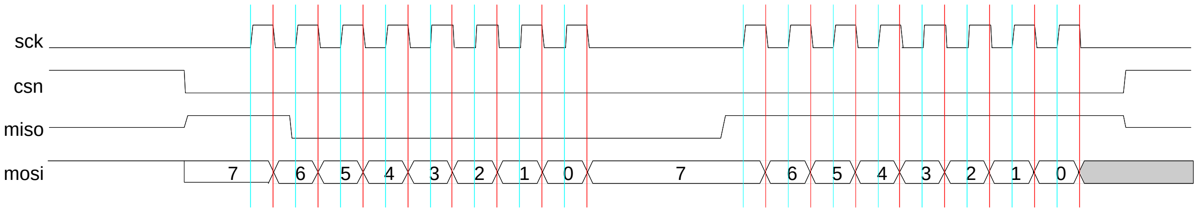


Figure 7.2 SPI writing transaction with a wait state after the first byte received

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 EM901 is in Sleep 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.

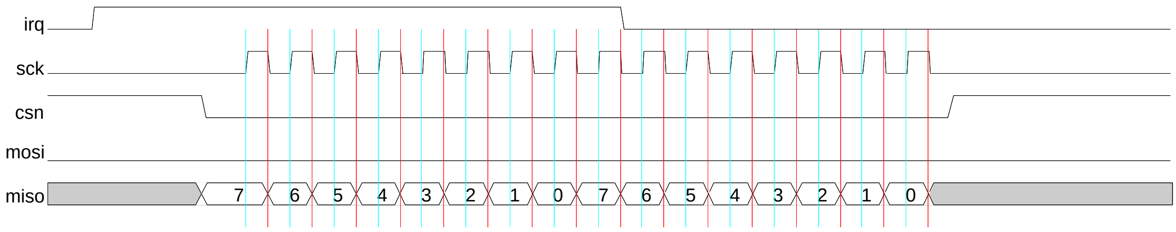


Figure 7.3 SPI read transaction with a empty buffer after the second byte

8. Peripherals information

EM9301 includes several internal peripherals to fulfill all requirements of the BLE standard. Although none of these peripherals are available for host use, 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

8.2 Random Number Generator (RNG)

EM9301 features a RNG block which is used to generate a non deterministic bit stream as required in [1]. The result of this block is a non deterministic 32 bit stream.

8.3 Supply Voltage Level Detector (SVLD)

EM9301 offers the possibility of monitoring the supply voltage of the system (V_{BAT} for the DCDC version and V_{CC2} for the no DCDC version). The host can launch a Supply Voltage Level Detector (SVLD) measurement by sending the HCI command EM_SVLD as defined in section 10.3.

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 10.3.

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

Monitored power supply	SVLD threshold [12]	Function
EM9301 DCDC version:		
VBAT	$SVLD_{TH\_00}$	BPM mode, battery monitoring
	$SVLD_{TH\_01}$	BPM early warning
	$SVLD_{TH\_02}$	Battery-low detection
	$SVLD_{TH\_03}$	Battery-low detection, early warning
EM9301 noDCDC version:		
VCC2	$SVLD_{TH\_06}$	Battery-low detection
	$SVLD_{TH\_07}$	Battery-low detection, early warning

Table 8.1 Function of SVLD thresholds

[12] The actual threshold voltage values are specified in Table 5.1 and Table 5.2.

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.

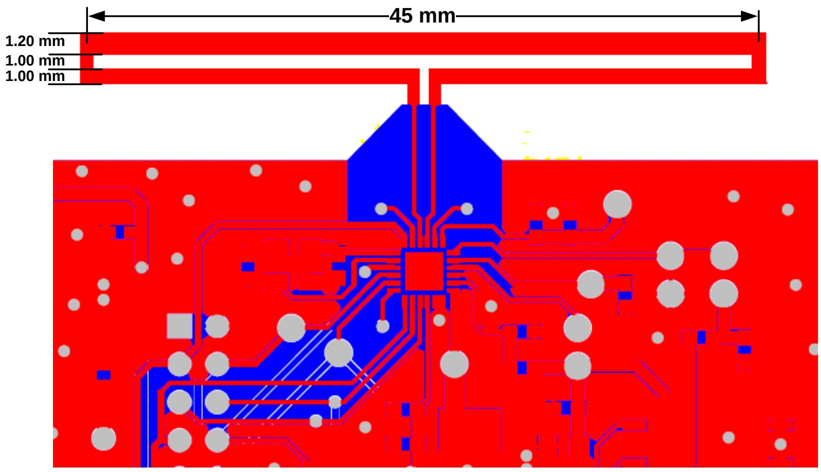


Figure 9.1 Layout example of a folded dipole antenna.

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.

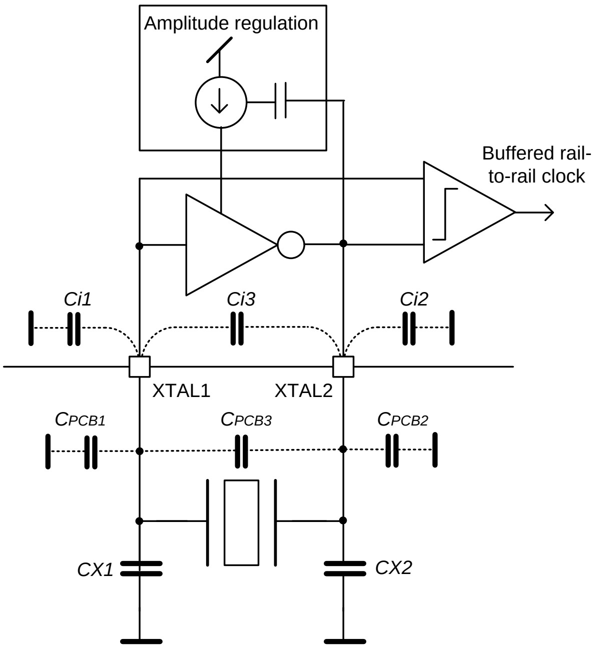


Figure 9.2 Xtal oscillator block diagram

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 DC/DC converter and 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.

For the DCDC version, the series routing resistance of all DCDC related pins (see Table 1.2 for a detailed description) can have a strong impact on the EM9301 DC/DC converter efficiency. Therefore, the trace length of all lines going to DCDC pins and in particular the one between the external coil and the EM9301 DCDC_SW pin should be minimized.

10. 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.

Table 10.1 lists the EM9301 proprietary HCI commands, which are then described in the following subsections.

HCI Command	OCF	Description
EM_SET_PUBLIC_ADDRESS	0x02	Set device public address
EM_SET_POWER_MODE	0x03	Select power mode
EM_SVLD	0x04	Run SVLD measurement
EM_SET_RF_POWER_LEVEL	0x05	Select Tx power level
EM_POWER_MODE_CONFIGURATION	0x06	Enable/disable transition to BLE Sleep Mode
EM_SET_UART_BAUD_RATE	0x07	Set UART baud rate
EM_SET_DCDC_VOLTAGE	0x08	Select the DC/DC converter output voltage

Table 10.1 Vendor HCI commands

10.1 EM_SET_PUBLIC_ADDRESS

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.

10.2 EM_SET_POWER_MODE

Command parameters:

Parameter	Size	Description
Power Mode	1	0x00 = Idle 0x01 = Sleep 0x02 = Deep-Sleep (Available only for noDCDC version) 0x03 = BPM (Available only for DCDC version) 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 Idle Mode to Sleep/Deep-Sleep Mode only the Command Completed Event is returned.
2) From Sleep/Deep-Sleep Mode to Idle Mode, a command status is sent after checking integrity of the command. Once Idle state has been entered completely an EM_POWER_MODE_IDLE event is returned to the host to report that the action has been completely done.

10.3 EM_SVLD

A measurement of the Supply Voltage Level Detector (SVLD) can be preformed in Idle Mode and, if the transition to BLE Sleep Mode using RC clock is disabled, also in BLE Active Mode. The level tolerance is ±10%.

Command parameters:

Parameter	Size	Description
Level	1	0x00 = $SVLD_{TH\_00}$ - valid only for DCDC version 0x01 = $SVLD_{TH\_01}$ - valid only for DCDC version 0x02 = $SVLD_{TH\_02}$ - valid only for DCDC version 0x03 = $SVLD_{TH\_03}$ - valid only for DCDC version 0x04 = Not used 0x05 = Not used 0x06 = $SVLD_{TH\_06}$ - valid only for noDCDC version 0x07 = $SVLD_{TH\_07}$ - valid only for noDCDC version 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.

10.4 EM_SET_RF_POWER_LEVEL

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* 0x06 = *Pout_06* 0x07 = *Pout_07* 0x08-0xFF = Reserved

Return parameters:

Parameter	Size	Description
Status	1	Standard *Bluetooth* error codes

Returned events:
Command Complete Event.

10.5 EM_POWER_MODE_CONFIGURATION

Command parameters:

Parameter	**Size**	**Description**
sleep_Mode_Enable	1	0x00 = Transition to BLE Sleep Mode using RC oscillator disabled 0x01 = Transition to BLE Sleep Mode using RC oscillator enabled 0x02-0xFF = Reserved

Return parameters:

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

Returned events:
Command Complete Event.

10.6 EM_SET_UART_BAUD_RATE

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.

10.7 EM_SET_DCDC_VOLTAGE

Command parameters:

Parameter	Size	Description
Output voltage	1	0x00 = V_{CC1_00} 0x01 = V_{CC1_01} (Default) 0x02 = V_{CC1_02} 0x03 = V_{CC1_03} 0x04 – 0xFF = Reserved

Return parameters:

Parameter	Size	Description
Status	1	Standard *Bluetooth* error codes

Returned events:
Command Complete Event.

11. 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.

11.1 EM_POWER_MODE_IDLE

This Event reports that the device has correctly entered Idle Mode. This event is sent after POR, after wake-up by WU pin if UART is selected, and when the power mode changed from Sleep/Deep-Sleep to Idle.

The associated Event code is 0xFF.

Event parameters:

Parameter	Size	Description
EM_Event_Code	1	0x01

11.2 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 (bus error)

Table 11.1 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.

12. Versions and ordering information

The EM9301 is available in two different versions as summarized in the table below. Both versions have the same pin-out. In the noDCDC version the internal DC/DC converter is disabled by means of hardware.

	Version	Description /Features	Applications / Comments
1	DCDC version	• BLE controller with embedded DC/DC converter • Possibility to supply external components • Xtreme power mode • BPM mode to prevent fluid losses in battery	Wireless applications designed for 1.5V-type batteries (e.g. wireless mouse).
2	noDCDC version	• BLE controller without DC/DC converter • Xtreme power mode • Deep-Sleep operating mode	Wireless applications relying on 3V-type batteries (e.g. watches) or in which an external LDO is available (e.g. USB dongle)

Table 12.1 EM9301 versions

12.1 Ordering information

Ordering Code	Description	Packaging	Container
EM9301V01LF24D+	BLE controller with DCDC	QFN24	Tray
EM9301V02LF24D+	BLE controller without DCDC	QFN24	Tray
EM9301V01LF24B+	BLE controller with DCDC	QFN24	Bundle
EM9301V02LF24B+	BLE controller without DCDC	QFN24	Bundle
EM9301V01WW7	BLE controller with DCDC	Wafer	Wafer container
EM9301V02WW7	BLE controller without DCDC	Wafer	Wafer container
EMDVK9301	Evaluation Kit		

Table 12.2 Ordering information

12.2 Package marking

This section reports the package marking for EM9301 version 1 (DCDC version) and for EM9301 version 2 (noDCDC version). Additional marking letters and numbers are used for lot traceability.

9	3	0	1	0
0	1			

Table 12.3 EM9301 package marking for version 1 (DCDC version)

9	3	0	1	0
0	2			

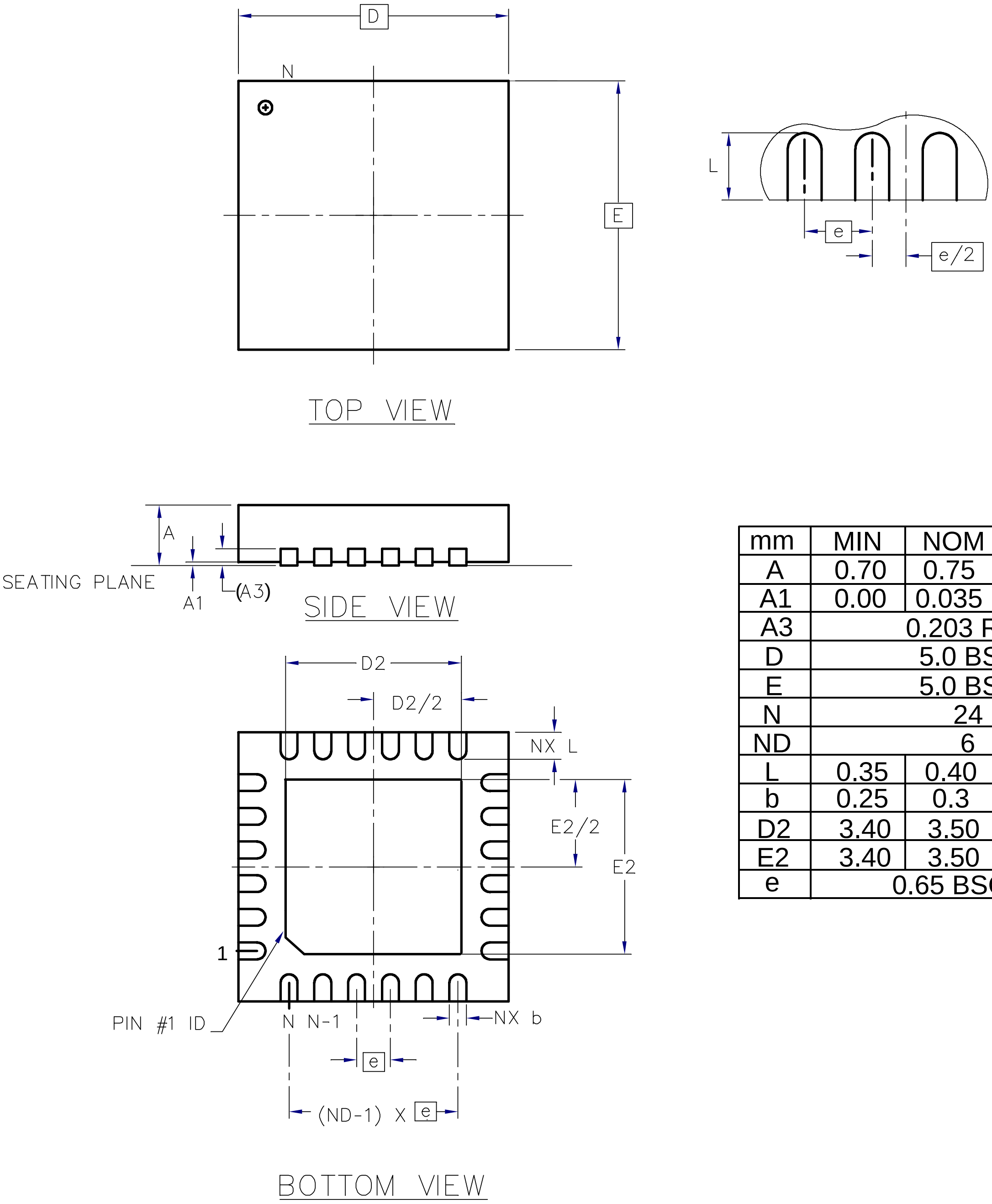
Table 12.4 EM9301 package marking for version 2 (noDCDC version)

12.3 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.

13. Package information

EM 9301 is available in a QFN24 5mm x 5mm package. The package information is summarized in Figure 13.1.



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 13.1 Package information