APPLICATION NOTE

Atmel AVR2080: REB231FE2 – Hardware User's Manual

8-bit Atmel AVR Microcontrollers

Features

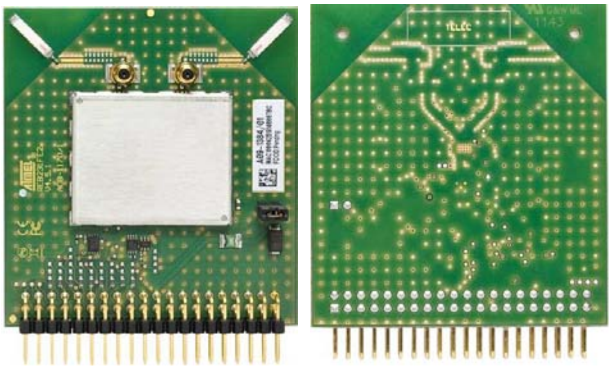
- High-performance, 2.4GHz, RF-CMOS Atmel AT86RF231 radio transceiver targeted for IEEE 802.15.4, ZigBee, and ISM applications
  - Industry leading 104dB link budget
  - Ultra-low current consumption
  - Ultra-low supply voltage (1.8V to 3.6V)
- High-performance, fully integrated 2.4GHz RF Front End Module SE2431L
- Hardware supported antenna diversity
- RF reference design and high-performance evaluation platform
- Interfaces to various Atmel microcontroller development platforms
- Board information EEPROM
  - MAC address
  - Board identification, features, and serial number
  - Crystal calibration values

Introduction

This manual describes the Atmel REB231FE2 radio extender board supporting increased TX output power and RX sensitivity as well as antenna diversity. The board is designed using the AT86RF231 radio transceiver in combination with the Skyworks SE2431L RF front end module (FEM). Detailed information is given in the individual sections about the board functionality, the board interfaces and the board design.

The REB231FE2 connects directly to the REB controller base board (REB-CBB), or can be used as an RF interface in combination with an Atmel microcontroller development platform. The REB231FE2 together with a microcontroller forms a fully functional wireless node.

Figure 1. Top and bottom view of the REB231FE2.



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1. Disclaimer

Typical values contained in this application note are based on simulations and testing of individual examples.

Any information about third-party materials or parts was included in this document for convenience. The vendor may have changed the information that has been published. Check the individual vendor information for the latest changes.

2. Overview

The radio extender board is assembled with an Atmel AT86RF231 radio transceiver [1], a Skyworks SE2431L FEM [9] and two ceramic antennas, demonstrating an increased link budget together with hardware-based antenna diversity, improving radio link robustness in harsh environments significantly [3].

The radio extender board was designed to interface to an Atmel microcontroller development platform. The microcontroller board in combination with the REB provides an ideal way to:

- Evaluate the outstanding radio transceiver performance, such as the excellent receiver sensitivity achieved at ultra-low current consumption
- Test the radio transceiver's comprehensive hardware support of the IEEE 802.15.4 standard
- Test the radio transceiver's enhanced feature set, which includes antenna diversity, AES, high data rate modes and other functions

The photograph in Figure 2-1 shows a development and evaluation setup using the REB-CBB [2] in combination with the Atmel REB231FE2 radio extender board.

Figure 2-1. The REB231F2 connected to a REB-CBB.

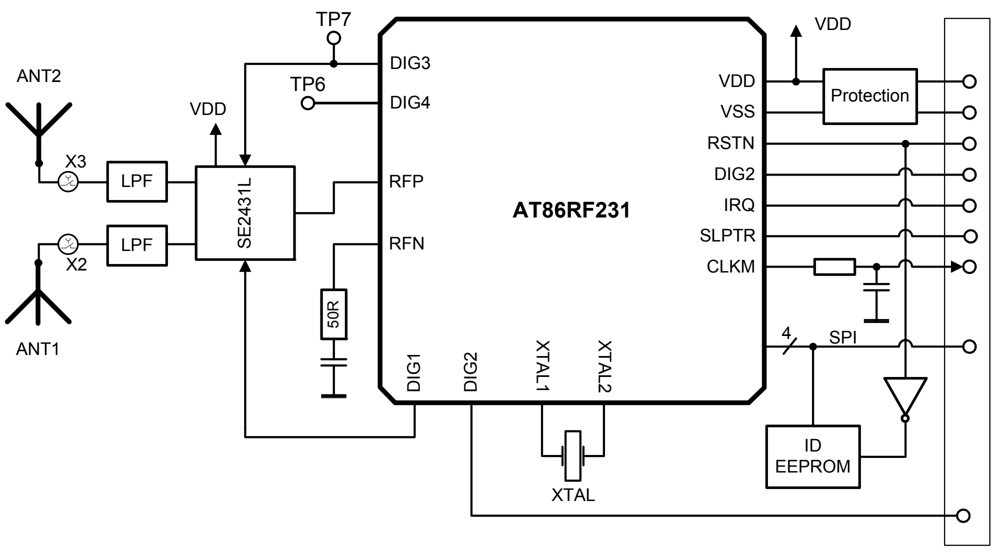
3. Functional description

The block diagram of the Atmel REB231FE2 radio extender board is shown in Figure 3-1. The power supply pins and all digital I/Os of the radio transceiver are routed to the 2 × 20-pin expansion connector to interface to a power supply and a microcontroller.

The Atmel AT86RF231 antenna diversity (AD) feature supports the control of two antennas (ANT0/ANT1). A digital control pin (DIG1) is used to control an external RF switch selecting one of the two antennas. During the RX listening period, the radio transceiver switches between the two antennas autonomously, without the need for microcontroller interaction, if the AD algorithm is enabled. Once an IEEE 802.15.4 synchronization header is detected, an antenna providing sufficient signal quality is selected to receive the remaining frame. This ensures reliability and robustness, especially in harsh environments with strong multipath fading effects.

Board-specific information such as board identifier, the node MAC address, and production calibration values are stored in an ID EEPROM. The SPI bus of the EEPROM is shared with the radio transceiver's interface.

Figure 3-1. REB231FE2 block diagram.



3.1 Interface connector specification

The REB is equipped with a 2 × 20-pin, 100mil expansion connector. The pin assignment enables a direct interface to the REB-CBB [2]. Further, the interface connects to the Atmel STK®500/501 microcontroller development platform to enable support for various Atmel 8-bit AVR® microcontrollers.

The REB is preconfigured to interface to the REB-CBB and STK501 with an Atmel ATmega1281.

If an Atmel ATmega644 is used as the microcontroller, the 0Ω resistors R10 through R18 must be removed and re-installed on the board manually as resistors R20 through R28 (see Appendix A.1).

Other microcontroller development platforms need to be interfaced using dedicated adapter boards.

3.1.1 REB-CBB (Atmel ATxmega256A3) and Atmel STK501 (Atmel ATxmega1281) configuration

Table 3-1. Default expansion connector mapping.

Pin#	Function	Pin#	Function
1	GND	2	GND
3	n.c.	4	n.c.
5	n.c.	6	n.c.
7	n.c.	8	n.c.
9	n.c.	10	n.c.
11	n.c.	12	n.c.
13	n.c.	14	n.c.
15	n.c.	16	n.c.
17	XT1 (MCLK)	18	n.c.
19	V_{CC}	20	V_{CC}
21	GND	22	GND
23	PB7 (open)	24	PB6 (open)
25	PB5 (RSTN)	26	PB4 (SLPTR)
27	PB3 (MISO)	28	PB2 (MOSI)
29	PB1 (SCLK)	30	PB0 (SEL)
31	PD7 (TP1)	32	PD6 (MCLK)
33	PD5 (TP2)	34	PD4 (DIG2)
35	PD3 (TP3)	36	PD2 (open)
37	PD1 (TP4)	38	PD0 (IRQ)
39	GND	40	EE#WP (write protect EEPROM)

3.1.2 Atmel ATmega644 configuration

Table 3-2. Expansion connector mapping when assembled for ATmega644.

Pin#	Function	Pin#	Function
1	GND	2	GND
3	n.c.	4	n.c.
5	n.c.	6	n.c.
7	n.c.	8	n.c.
9	n.c.	10	n.c.
11	n.c.	12	n.c.
13	n.c.	14	n.c.
15	n.c.	16	n.c.
17	XT1 (MCLK)	18	n.c.
19	V_{CC}	20	V_{CC}
21	GND	22	GND
23	PB7 (SCLK)	24	PB6 (MISO)

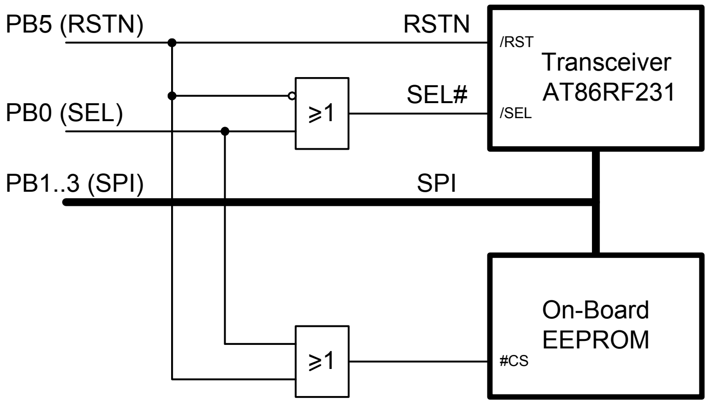
Pin#	Function	Pin#	Function
25	PB5 (MOSI)	26	PB4 (SEL)
27	PB3 (open)	28	PB2 (RSTN)
29	PB1 (MCLK)	30	PB0 (open)
31	PD7 (SLPTR)	32	PD6 (DIG2)
33	PD5 (TP2)	34	PD4 (open)
35	PD3 (TP3)	36	PD2 (IRQ)
37	PD1 (TP4)	38	PD0 (open)
39	GND	40	EE#WP (write protect EEPROM)

3.2 ID EEPROM

To identify the board type by software, an optional identification (ID) EEPROM is populated. Information about the board, the node MAC address and production calibration values are stored here. An Atmel AT25010B [8] with 128 × 8-bit organization and SPI bus is used because of its small package and low-voltage / low-power operation.

The SPI bus is shared between the EEPROM and the transceiver. The select signal for each SPI slave (EEPROM, radio transceiver) is decoded with the reset line of the transceiver, RSTN. Therefore, the EEPROM is addressed when the radio transceiver is held in reset (RSTN = 0) (see Figure 3-2).

Figure 3-2. EEPROM access decoding logic (Atmel ATmega1281 configuration).



The EEPROM data are written during board production testing. A unique serial number, the MAC address [(1)], and calibration values are stored. These can be used to optimize system performance.

Note: Final products do not require this external ID EEPROM. All data can be stored directly within the microcontroller's internal EEPROM.

Note: 1. MAC addresses used for this package are Atmel property. The use of these MAC addresses for development purposes is permitted.

Figure 3-3 shows a detailed description of the EEPROM data structure.

Table 3-3. ID EEPROM mapping.

Address	Name	Type	Description
0x00	MAC address	uint64	MAC address for the 802.15.4 node, little endian byte order
0x08	Serial number	uint64	Board serial number, little endian byte order
0x10	Board family	uint8	Internal board family identifier
0x11	Revision	uint8[3]	Board revision number ##.##.##
0x14	Feature	uint8	Board features, coded into seven bits 7 – Reserved 6 – Reserved 5 – External LNA 4 – External PA 3 – Reserved 2 – Diversity 1 – Antenna 0 – SMA connector
0x15	Cal OSC 16MHz	uint8	RF231 XTAL calibration value, register XTAL_TRIM
0x16	Cal RC 3.6V	uint8	Atmel ATmega1281 internal RC oscillator calibration value @ 3.6V, register OSCCAL
0x17	Cal RC 2.0V	uint8	Atmel ATmega1281 internal RC oscillator calibration value @ 2.0V, register OSCCAL
0x18	Antenna gain	Int8	Antenna gain [resolution 1/10dBi]. For example, 15 will indicate a gain of 1.5dBi. The values 00h and FFh are per definition invalid. Zero or -0.1dBi has to be indicated as 01h or FEh
0x20	Board name	char[30]	Textual board description
0x3E	CRC	uint16	16-bit CRC checksum, standard ITU-T generator polynomial $G16(x) = x^{16} + x^{12} + x^5 + 1$

Figure 3-3. Example EEPROM dump.

```
-----| EEPROM dump |--------------
0000 - 49 41 17 FF FF 25 04 00 D6 11 00 00 2A 00 00 00    IA...%......*...
0010 - 02 04 01 01 06 02 A8 A9 01 FF FF FF FF FF FF FF    ................
0020 - 52 61 64 69 6F 45 78 74 65 6E 64 65 72 32 33 31    RadioExtender231
0030 - 46 45 32 00 00 00 00 00 00 00 00 00 00 00 8D 9B    FE2.............
0040 - FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF    ................
0050 - FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF    ................
0060 - FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF    ................
0070 - FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF    ................
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3.3 Supply current sensing

A jumper, JP1, is placed in the supply voltage trace to offer an easy way for current sensing of active components one the Atmel REB231FE2, see Figure 3-4.

The power supply pins of the radio transceiver and FEM are protected against overvoltage stress and reverse polarity at the EXPAND1 pins (net CVTG, net DGND) using a Zener diode (D1) and a thermal fuse (F1) (see Appendix A.1). This is required because the Atmel STK500 will provide 5V as default voltage, and the board can also be mounted with reverse polarity.

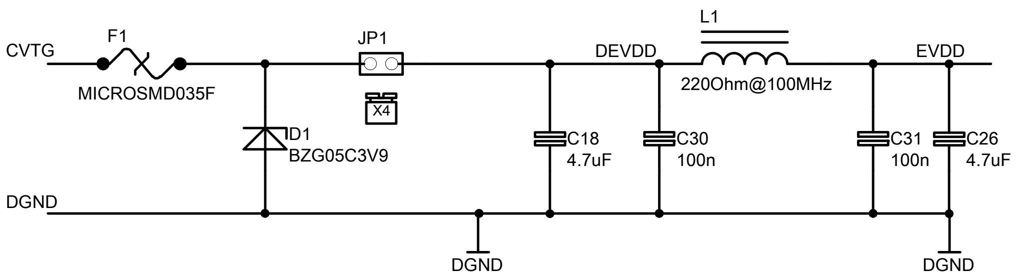
Depending on the actual supply voltage, the diode D1 can consume several milliamperes. This has to be considered when the current consumption of the whole system is measured. In such a case, D1 should be removed from the board.

To achieve the best RF performance, the analog (EVDD, AGND) and digital (DEVDD, DGND) supply are separated from each other by a CLC PI-element. Digital and analog ground planes are connected together on the bottom layer, underneath the radio transceiver IC. Further details are described in Chapter 4, page 10.

Note: All components connected to nets DEVDD/EVDD contribute to the total current consumption.

While in radio transceiver SLEEP state, most of the supply current is drawn by the 1MΩ pull-up resistor, R9, connected to the ID EEPROM and the EEPROM standby current.

Figure 3-4. Power supply routing.



3.4 Radio transceiver reference clock

The integrated radio transceiver is clocked by a 16MHz reference crystal. The 2.4GHz modulated signal is derived from this clock. Operating the node according to IEEE 802.15.4 [4], the reference frequency must not exceed a deviation of ±40ppm. The absolute frequency is mainly determined by the external load capacitance of the crystal, which depends on the crystal type and is given in its datasheet.

The radio transceiver reference crystal, Q1, shall be isolated from fast switching digital signals and surrounded by a grounded guard trace to minimize disturbances of the oscillation. Detailed layout considerations can be found in Section 4.2.

The REB uses a Siward CX4025 crystal with load capacitors of 10pF and 12pF. The imbalance between the load capacitors was chosen to be as close as possible to the desired resonance frequency with standard components. To compensate for fabrication and environment variations, the frequency can be further tuned using the radio transceiver register XOSC_CTRL (0x12) (refer to [1]). The REB production test guarantees a tolerance of within +20ppm and -5ppm. The correction value, to be applied to TRX register XOSC_CTRL (0x12), is stored in the onboard EEPROM (see Section 3.2).

The reference frequency is also available at pin CLKM of the radio transceiver and, depending on the related register setting; it is divided by an internal prescaler. CLKM clock frequencies of 16MHz, 8MHz, 4MHz, 2MHz, 1MHz, 250kHz or 62.5kHz are programmable (refer to [1]). The CLKM signal is filtered by a low-pass filter to reduce harmonic emissions within the 2.4GHz ISM band. The filter is designed to provide a stable 1MHz clock signal with correct logic level to a microcontroller pin with sufficiently suppressed harmonics. CLKM frequencies above 1MHz require a redesign of R8 and C36. In case of RC cut-off frequency adjustments, depending on the specific load and signal routing conditions, one may observe performance degradation of channel 26.

Note: Channel 26 (2480MHz) is affected by the following harmonics: 155 × 16MHz or 310 × 8MHz.

By default, CLKM is routed to a microcontroller timer input; check the individual configuration resistors in the schematic drawing. To connect CLKM to the microcontroller main clock input, assemble R3 with a 0Ω resistor.

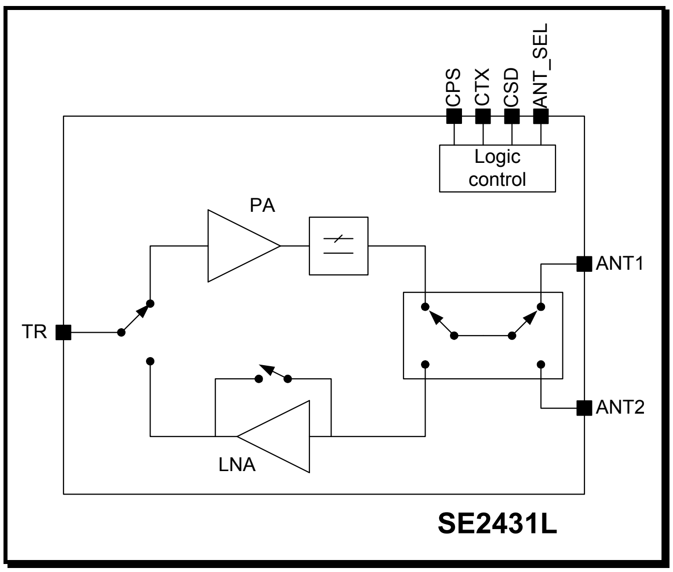
3.5 RF section

The Atmel AT86RF231 radio transceiver incorporates all RF and BB critical components necessary to transmit and receive signals according to IEEE 802.15.4 or proprietary ISM data rates.

To further improve system TX output power and RX sensitivity a FEM is connected to the radio transceiver.

The Skyworks SE2431L FEM [9] is a high performance, fully integrated module in a 3 × 4 × 0.9mm³ 24 pin QFN package. It incorporates a transmit power amplifier (PA) with harmonic filtering, a receive low noise amplifier (LNA) with optional bypass switch, transmit/receive (TR) switching and an antenna diversity switch. A block diagram of the SE2431L is shown in Figure 3-5.

Figure 3-5. SE2431L block diagram.



In transmit mode, nominal antenna port transmit output power is +20dBm for Atmel AT86RF231 sub-register setting TX_PWR = 0x0A at EVDD = 3.0V nominal supply voltage. Second and third harmonics levels are less than -42dBm/MHz. Transmit output power level is adjusted using the AT86RF231 TX output power, controlled via register bits TX_PWR.

The supply voltage can be increased to 3.6V to further increase transmit output power. There is provision on the PCB for C-L-C low pass filtering at the antenna ports to reduce harmonic levels at these higher output powers.

In receive mode, conducted sensitivity is better than -104dBm for 1% packet error rate. The SE2431L has a typical receive noise figure of 2dB which includes all RF switch input losses.

Referring to the Atmel REB231FE2 schematic in Appendix A.1, the RF interface consists of two antenna ports. By default two on-board ceramic antennas are connected allowing radiated measurements. Solder pads located along the tuning line allow for the optimization of antenna matching without the need for redesigning the PCB. Detailed information about the antenna diversity feature is given in [1] and [3].

Optionally two switched in-line MS-147 RF connectors, which disconnect the on-board antennas, allow conducted measurements. The SE2431L antenna ports are controlled by AT86RF231 pin DIG1 connected to SE2431L pin ANT_SEL.

The SE2431L operating mode is determined by control lines CTX, CPS and CSD. The default configuration connects CPS pin to EVDD via R31. This means that in receive mode the LNA will always be enabled for maximum sensitivity. Enabling low power RX bypass mode requires removing R31 and R32 populated with 0R resistor.

The PA is enabled when CTX is high and the LNA is enabled when CTX is low. When CSD, CTX and CPS pins are low, the SE2431L goes into low current standby mode (<1µA current consumption). CSD is connected to the AT86RF231 analog LDO regulator output (AVDD). AVDD is 1.8V for all AT86RF231 states except P_ON, SLEEP, RESET, and TRX_OFF. To enable/disable the SE2431L immediately and independently from individual radio transceiver states, an additional GPIO control line from the microcontroller is required.

The SE2431L has two analog power supply pins, VCC1 and VCC2, which power the internal analog circuitry. This supply is connected to the REB231FE2 EVDD supply voltage.

The interface between the AT86RF231 and the Skyworks SE2431L is single-ended 50Ω, optimized for high performance and low cost applications. The unused AT86RF231 RFN pin is terminated to ground with a 50Ω resistor and DC block.

Avoiding a balun helps minimizing the bill of materials cost. In transmit mode, the AT86RF231 transmit output power needs to be set higher compared to a differential TRX-FEM interface using a balun. In receive mode, the effective gain ahead of the AT86RF231 is 3dB less than the specified SE2431L LNA gain (12.5dB). The resulting loss in sensitivity is about 0.3…0.4dB.

Note: The latest revision of SE2431L FEM [9] does not require resistor R30 connected to SE2431L pin 5, leave this pin unconnected as stated in the datasheet.

4. PCB layout description

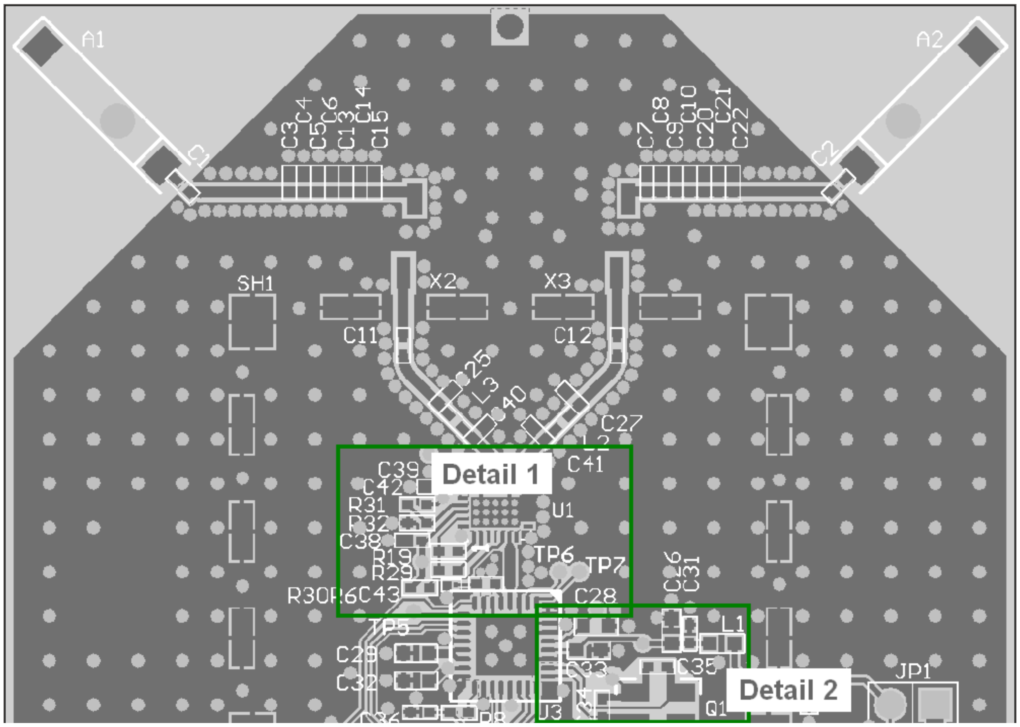
This section describes critical layout details to be carefully considered during a PCB design. The PCB design requires an optimal solution for the following topics:

- Create a solid ground plane for the antenna. The PCB has to be considered as a part of the antenna; it interacts with the radiated electromagnetic wave
- Around the SE2431L front end module layout, ensure good RF grounding, good thermal conduction, effective decoupling and correct microstrip impedances for RF tracks
- Isolate digital noise from the antenna and the radio transceiver to achieve optimum range and RF performance
- Isolate digital noise from the 16MHz reference crystal to achieve optimum transmitter and receiver performance
- Reduce any kind of spurious emissions below the limits set by the individual regulatory organizations

The Atmel REB231FE2 PCB design further demonstrates a low-cost, two-layer PCB solution without the need of an inner ground plane.

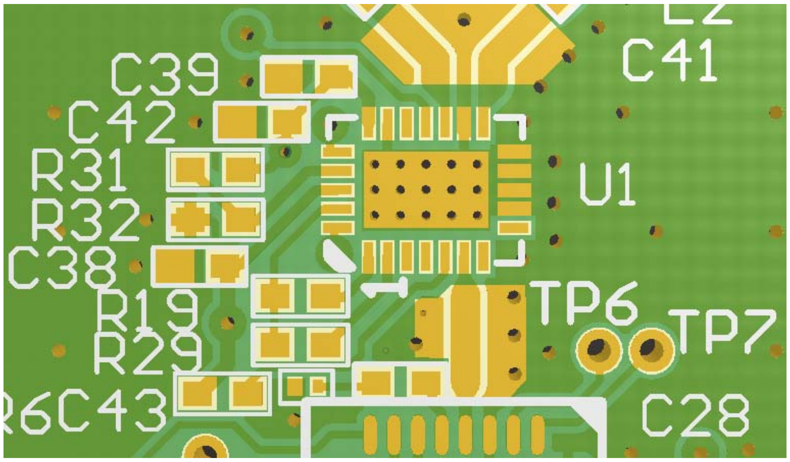
The drawing in Figure 4-1 show critical sections using numbered captions. Each caption number has its own subsection below with detailed information.

Figure 4-1. Board layout – RF section.



4.1 PCB detail 1 – balanced RF pin fan out

Figure 4-2. Board layout – SE2431L layout.



The SE2431L (U1) and associated circuitry follow a standard Skyworks Solutions recommended layout to achieve specified RF performance. The SE2431L requires a central PCB ground pad which is completely relieved of solder resist and has a grid of 15 ground vias [9]. This is essential to achieve good RF performance and adequate thermal conduction, especially in transmit mode. The solder paste mask has limited coverage for assembly purposes.

The RF tracks to SE2431L TR, ANT1 and ANT2 pins, and tracking to the antennas, are all 50Ω microstrip.

The 10pF decoupling capacitors C38 and C39 are placed close to the respective power supply pins. Grounded pins on the SE2431L are routed directly to the central ground pad.

4.2 PCB detail 2 – crystal routing

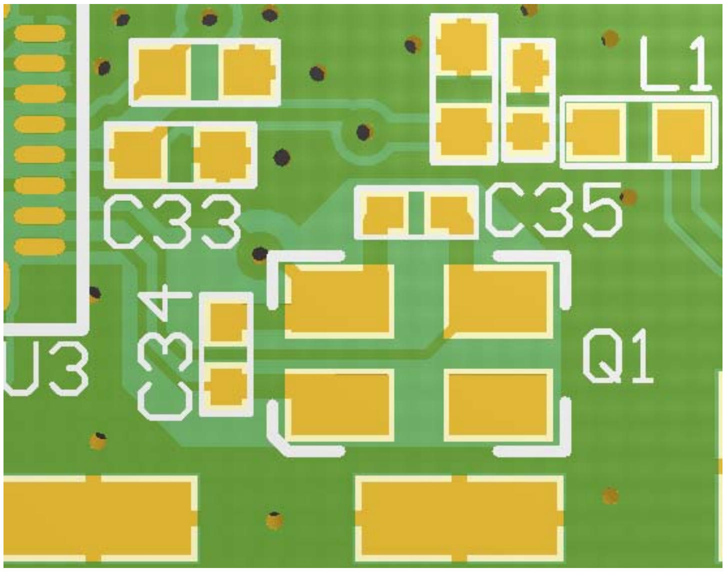
The reference crystal PCB area requires optimization to minimize external interference and to keep any radiation of 16MHz harmonics low.

The reference crystal and load capacitors C34/35 form the resonator circuit. These capacitors are to be placed close to the crystal. The ground connection in between the capacitors should be the crystal housing contact, resulting in a compact, robust and stable resonator.

The resonator block is enclosed within ground traces around it and a plane on the bottom side. Do not connect the resonator directly to the plane beneath the block. The only ground connection for the resonator block should be a trace in parallel with the two crystal lines that connects to TRX pin 27 or the paddle.

Based on recent experiments, the bottom ground connection shall be routed directly to the paddle or pin 27. The loop is not required. In addition, the open space underneath the crystal can be filled with copper. A small keep out trace next to the bottom ground connection can help to keep this connection separate and prevent the layout tool from flooding across this trace.

Figure 4-3. Board layout – XTAL section.

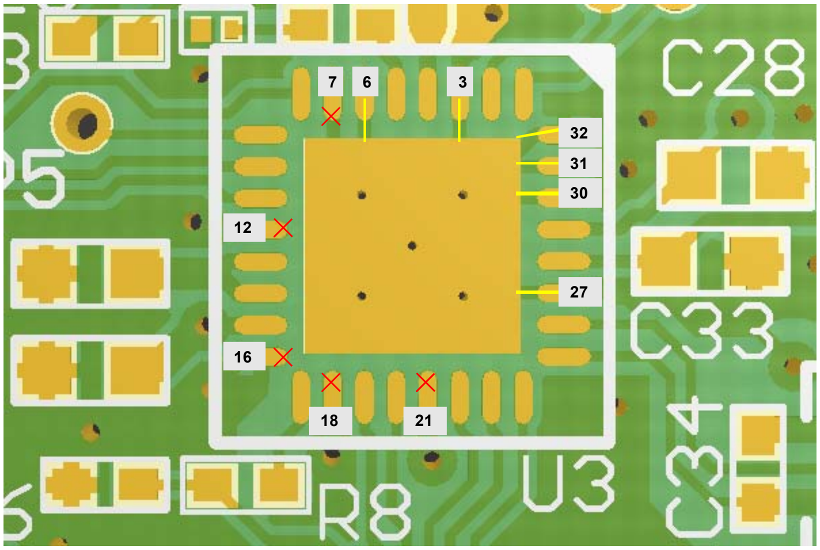


When designing applications for very harsh environments, for example where the radio transceiver is close to mains power lines and burst and surge requirements already dictate special provisions in the design, the above reference crystal design might not work well. In this case, the reference crystal ground is to be directly connected to top and bottom layers.

4.3 PCB – analog GND routing

Analog ground pins (3, 6, 27, 30, 31 and 32) and pin 7 are to be routed to the paddle underneath the IC. The trace width has to be similar to the pad width when connecting the pads, and increase, if possible, some distance from the pad.

Figure 4-4. Board layout – transceiver GND.



Each ground pin should be connected to the bottom plane with at least one via. Move the vias as close to the IC as possible. It is always desired to integrate the single-pin ground connections into polygon structures after a short distance. Top, bottom, and, on multilayer boards, the inner ground planes, should be tied together with a grid of vias. When ground loops are smaller than one tenth of the wavelength, it is safe to consider this as a solid piece of metal.

The soldering technology used allows the placement of small vias (0.15mm drill) within the ground paddle underneath the chip. During reflow soldering, the vias get filled with solder, having a positive effect on the connection cross section. The small drill size keeps solder losses within an acceptable limit. During the soldering process vias should be open on the bottom side to allow enclosed air to expand.

4.4 PCB – digital GND routing

Digital ground pins (12, 16, 18 and 21) are not directly connected to the paddle. Digital ground pins may carry digital noise from I/O pad cells or other digital processing units within the chip.

In case of a direct paddle connection, impedances of the paddle ground vias could cause a small voltage drop for this noise and may result in an increased noise level transferred to the analog domain.

4.5 PCB – GND plane

Besides the function to provide supply ground to the individual parts, the ground plane has to be considered as a counterpart for the antenna. Such an antenna base plate is considered a continuous metal plane.

For that reason, any unused surface should be filled with a copper plane and connected to the other ground side using sufficient through holes. Larger copper areas should also be connected to the other side layer with a grid of vias. This way, for an external electromagnetic field the board will behave like a coherent piece of metal.

When a trace is cutting the plane on one side, the design should contain vias along this trace to bridge the interrupted ground on the other side. Place vias especially close to corners and necks to connect lose polygon ends.

4.6 Ceramic antenna design and tuning

The antenna section follows an already existing similar implementation as described in Atmel AVR2043; REB231ED Radio Extender Board – Hardware User Manual; Rev. 8345A-AVR-05/11; Atmel Corporation. [10] application note. The application note provides detailed information about a design study, design-in and tuning.

5. Mechanical description

The Atmel REB231FE2 is manufactured using a low-cost, two-layer printed circuit board. All components and connectors are mounted on the top side of the board.

The format was defined to fit the EXPAND1 connector on the REB-CBB and Atmel AVR STK500 / STK501 microcontroller evaluation board. The upright position is chosen for best antenna performance.

Figure 5-1. Mechanical outline.

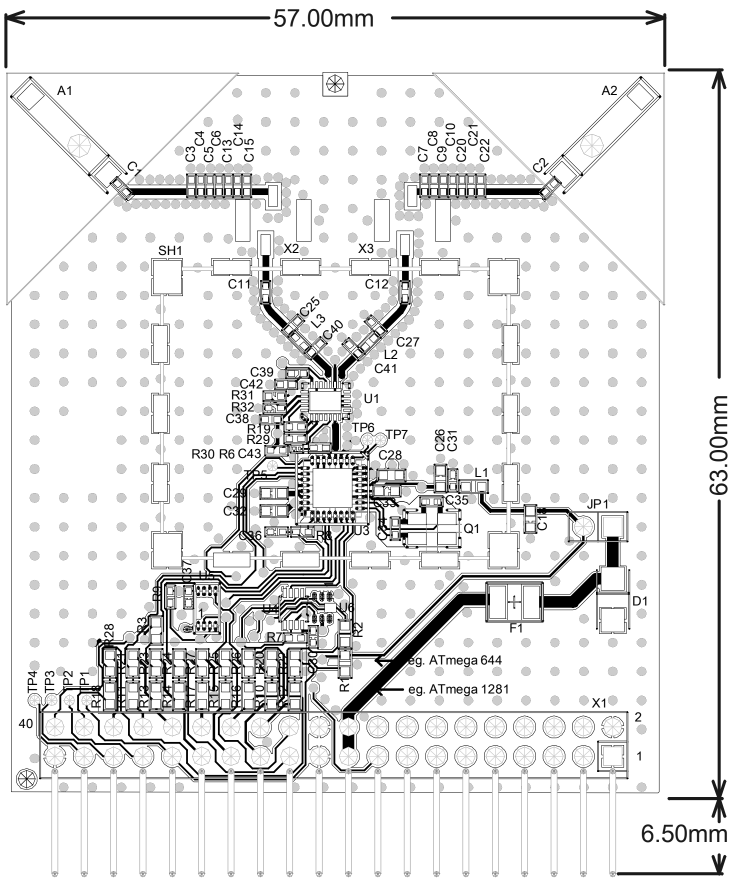


Table 5-1. REB231FE2 mechanical dimensions.

Dimension	Value
Width x	57mm
Height y	63mm

6. Electrical characteristics

6.1 Absolute maximum ratings

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the board. This is a stress rating only and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of this manual are not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability. For more details about these parameters, refer to individual datasheets of the components used.

Table 6-1. Absolute maximum rating.

No.	Parameter	Condition	Minimum	Typical	Maximum	Unit
7.1.1	Storage temperature range		-40		+85	°C
7.1.2	Humidity	Non-considerating			90	% r.H.
7.1.3	Supply voltage		-0.3		+3.6	V
7.1.4	EXT I/O pin voltage		-0.3		V_{CC} + 0.3	
7.1.5	Supply current from batteries	Sum over all power pins			-0.5	A
7.1.6	Battery charge current(1)					mA

Note: 1. Keep power switch off or remove battery from REB-CBB when external power is supplied.

6.2 Recommended operating range

Table 6-2. Recommended operating range.

No.	Parameter	Condition	Minimum	Typical	Maximum	Unit
7.2.1	Operating temperature range	Note(1)	-20		+70	°C
7.2.2	Supply voltage (V_{CC})	REB231FE2 and REB-CBB	0.2	3.0	3.6	V

Note: 1. Temperature range limited by crystal Q1, otherwise -40 … +85degC.

6.3 Current consumption

Test conditions (unless otherwise stated):

V_{DD} = 3.0V, f_{RF} = 2.45GHz, T_{OP} = 25°C, TX_PWR=0xA, X2 conducted

Table 6-3 lists typical Atmel REB231FE2 current consumption values for different operating modes. Current measurement is taken by replacing REB231FE2 jumper 'JP1' with an amperemeter, for REB-CBB figures refer to [2].

Table 6-3. Current consumption of REB231FE2 (JP1).

No.	Parameter	Condition	Minimum	Typical	Maximum	Unit
7.3.1	Supply current I_{DD,TRX_OFF}	CLKM off		0.44		mA
7.3.2	Supply current I_{DD,PLL_ON}	SE2431L enabled, RX mode		10.8		
7.3.3	Supply current I_{DD,RX_ON}	SE2431L LNA high gain		17.6		
7.3.4	Supply current I_{DD,TX_Pmin}	BUSY_TX (+5dBm)		40		
7.3.5	Supply current $I_{DD,TX\_Pdefault}$	BUSY_TX (+20dBm)		116		
7.3.6	Supply current I_{DD,TX_Pmax}	BUSY_TX (+23dBm)(1)		205		

Note: 1. V_{DD} = 3.6V, AT86RF231 sub-register TX_PWR = 0x0.

6.4 Transmitter characteristics

Test conditions (unless otherwise stated):

V_{DD} = 3.0V, f_{RF} = 2.45GHz, T_{OP} = 25°C, TX_PWR=0xA, X2 conducted

Table 6-4. Transmitter characteristics.

No.	Parameter	Condition	Minimum	Typical	Maximum	Unit
7.4.1	TX Output Power	Ch11 … 25, Ch26 (1)	+5	+20	+23.5(2)	dBm
7.4.2	Output Power Range			15	18	dB
7.4.3	Harmonics	average, worst case 4f0		-50	-44	dBm/MHz
7.4.4	Spurious Emissions			tbd.		dBm

Notes: 1. Ch26 requires TX output power back-off and duty cycle operation, see Notes for details.
2. V_{DD} = 3.6V, AT86RF231 sub-register TX_PWR = 0x0.

Notes:

- The Atmel REB231FE2 setup has been tested for compliance with FCC and ETSI, see Appendix B. To ensure compliance, the following regional specific settings are to be ensured
- FCC: Operating the transmitter at channel 26 requires limitation of TX output power to max. +13dBm and to ensure a duty cycle ≤25%
- FCC: Operating the setup at maximum possible TX output power for all other channels requires either an adjustment of the lowpass filters (C25, L3, C40 and C27, L2, C41), or alignment of the TX duty cycle
- ETSI: Operating the setup in Europe requires setting the Atmel AT86RF231 register TX_PWR to 0x0E maximum for all channels. This setting ensures compliance with ETSI EN 300 228 clause 4.3.2.2 Maximum Power Spectral Density (refer to [6])

6.5 Receiver characteristics

Test conditions (unless otherwise stated):

V_{DD} = 3.0V, f_{RF} = 2.45GHz , T_{OP} = 25°C, X2 conducted

Table 6-5. Receive characteristics.

No.	Parameter	Condition	Minimum	Typical	Maximum	Unit
7.5.1	Receiver Sensitivity	PER ≤1%, PSDU length 20 octets		-104		dBm
7.5.2	Maximum RX input level			-5(1)		
7.5.3	Spurious Emissions			-70		
7.5.4	RSSI/ED offset(2)(3)	SE2431L LNA in high gain mode		13		dB

Notes: 1. Calculated, based on AT86RF231 maximum RX input level – SE2431L maximum RX gain.
2. AT86RF231 RSSI value indicates RF input power PRF[dBm] = (RSSI_BASE_VAL-13) + 3×(RSSI-1), see [1] in Chapter References.
3. AT86RF231 ED value indicates RF input power PRF[dBm] = -104 + ED, see [1] in Chapter References.

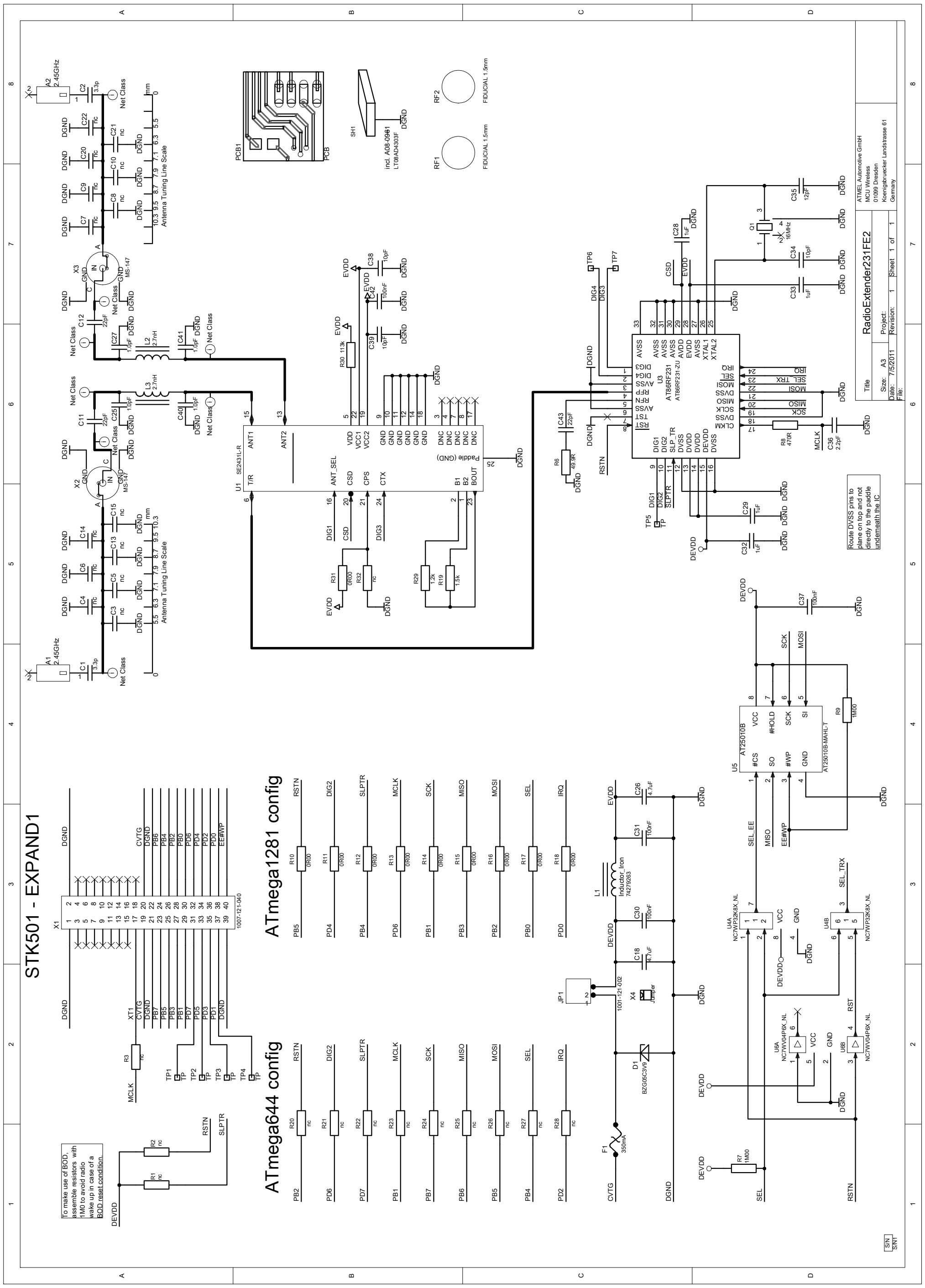
7. Abbreviations

AD	-	Antenna diversity
AES	-	Advanced encryption standard
BB	-	Baseband
REB-CBB	-	REB-Controller base board
ETSI	-	European Telecommunications Standards Institute
FCC	-	Federal Communications Commission
FEM	-	Front end module
ISM	-	Industrial, scientific and medical (frequency band)
LDO	-	Low-dropout
LNA	-	Low-noise amplifier
MAC	-	Medium access control
MCU	-	Microcontroller unit
PA	-	Power amplifier
PCB	-	Printed Circuit Board
PDI	-	Program/debug interface
PER	-	Packet error rate
R&TTE	-	Radio and Telecommunications Terminal Equipment (Directive of the European Union)
REB	-	Radio extender board
RF	-	Radio frequency
RSSI	-	Received signal strength indicator
RX	-	Receiver
SPI	-	Serial peripheral interface
TX	-	Transmitter
XTAL	-	Crystal

Appendix A. PCB design data

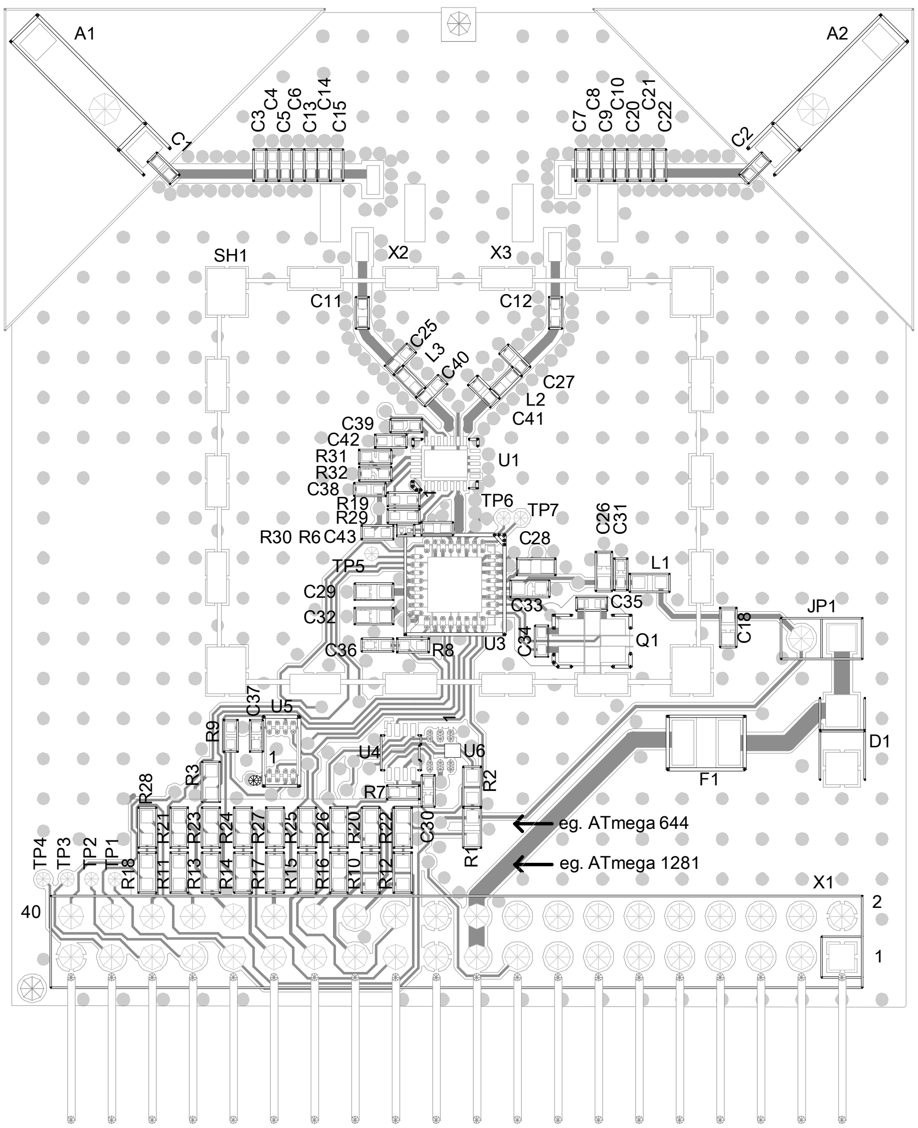
A.1 Schematic

Figure 7-1. Atmel REB231FE2 schematic.



7.2 Assembly drawing

Figure 7-2. Atmel REB231FE2 assembly drawing.



A.2 Bill of materials

Table 7-1. Bill of materials.

Qty.	Designator	Description	Footprint	Manuf. Part#	Manufacturer	Comment
2	X2, X3	RF connector MS147	SMA	CL358-150-5-06	Hirose	MS147
1	X1	Pin header 2×20 90 degree	JP_2x20_90°_ Top_Invers	1007-121-40	CAB	HEADER-20X2
1	U5	EEPROM	MiniMap-8-2X3	AT25010B-MAHL-T	Atmel	AT25010B
1	U4	Logic gate	MO-187	NV7WP32K8X	Fairchild	NC7WP32K8X
1	U3	802.15.4 2.4GHz radio transceiver	MLF-32	AT86RF231	Atmel	AT86RF231
1	U6	Dual INV, ULP	SC-70/6	NC7WV04P6X	Fairchild	NC7WV04
1	U1	RFFE	QFN24	SE2431L	Skyworks	SE2431L
9	R10, R11, R12, R13, R14, R15, R16, R17, R18	Resistor	0603H0.4		Generic	0Ω
1	R31	Resistor	0402		Generic	0Ω
1	R8	Resistor	0402A		Generic	470Ω
2	R7, R9	Resistor	0402A		Generic	1MΩ
1	R19	Resistor	0402A		Generic	1.5kΩ
1	R29	Resistor	0402A		Generic	1.2kΩ
1	R30	Resistor	0402A		Generic	113kΩ
1	R6	Resistor	0201A		Generic	49.9Ω
1	Q1	Crystal 16MHz	XTAL_4X2_5_ small	XTL551150NLE-16MHz-9.0R	Siward	CX-4025 16MHz
1	L1	SMT ferrite bead	0603H0.8	74279263	Würth	220Ω@100MHz
2	L2, L3	Chip Inductor	0402 (32306)	L0075S0083LQG15 HN	Murata	±0.3nH
1	JP1	Jumper 2-pol.	JP_2x1	1001-121-002	CAB	JP-2
1	F1	PTC fuse	1210	MICROSMD035F	Tyco	MICROSMD035F
1	D1	Z-Diode	DO-214AC	BZG05C3V9	Vishay	BZG05C3V9
1	C35	Capacitor	0402A		Generic C0G	12pF/5%
3	C34, C38, C39	Capacitor	0402A		Generic C0G	10pF/5%
4	C28, C29, C32, C33	Capacitor	0603H0.8		Generic X5R	1µF
4	C30, C31, C37, C42	Capacitor	0402A		Generic X7R	100n
3	C11, C12, C43	Capacitor	0402A		Generic C0G	22pF
1	C36	Capacitor	0402A		Generic C0G	2.2pF
2	C1, C2	Capacitor	0402A		Generic C0G	3.3pF
2	C18, C26	Capacitor	0603A	GRM1555C1H1R0 CA01	Generic X5R	4.7µF
4	C25, C27, C40, C41	Capacitor	0402A	2450AT45A100	Murata	1.0pF ±0.25pF
2	A1, A2	Ceramic antenna	ANT_AT45_45 deg		Johanson	2.45GHz

Appendix B. Radio certification

The Atmel REB231FE2, mounted on a REB controller base board (REB-CBB), has received regulatory approvals for modular devices in the United States and ensures compliance in European countries.

B.1 United States (FCC)

Compliance Statement (Part 15.19)

The device complies with Part 15 of the FCC rules. To fulfill FCC Certification requirements, an Original Equipment Manufacturer (OEM) must comply with the following regulations:

- The modular transmitter must be labeled with its own FCC ID number, and, if the FCC ID is not visible when the module is installed inside another device, then the outside of the device into which the module is installed must also display a label referring to the enclosed module
- This exterior label can use wording such as the following. Any similar wording that expresses the same meaning may be used

Contains FCC-ID: VNR-E31F2-X5B-00
This device complies with Part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) this device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

Use in portable exposure conditions (FCC 2.1093) requires separate equipment authorization. Modifications not expressly approved by this company could void the user's authority to operate this equipment (FCC Section 15.21).

Compliance Statement (Part 15.105(b))

This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to Part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- Reorient or relocate the receiving antenna
- Increase the separation between the equipment and receiver
- Connect the equipment into an outlet on a circuit different from that to which the receiver is connected
- Consult the dealer or an experienced radio/TV technician for help

Warning (Part 15.21)

Changes or modifications not expressly approved by this company could void the user’s authority to operate the equipment.

B.2 Europe

If the device is incorporated into a product, the manufacturer must ensure compliance of the final product to the European harmonized EMC and low-voltage/safety standards. A Declaration of Conformity must be issued for each of these standards and kept on file as described in Annex II of the R&TTE Directive.

The manufacturer must maintain a copy of the device documentation and ensure the final product does not exceed the specified power ratings, and/or installation requirements as specified in the user manual. If any of these specifications are exceeded in the final product, a submission must be made to a notified body for compliance testing to all required standards. The “CE“ marking must be affixed to a visible location on the OEM product. The CE mark shall consist of the initials "CE" taking the following form:

- If the CE marking is reduced or enlarged, the proportions given in the above graduated drawing must be respected
- The CE marking must have a height of at least 5mm except where this is not possible on account of the nature of the apparatus
- The CE marking must be affixed visibly, legibly, and indelibly

More detailed information about CE marking requirements you can find at "DIRECTIVE 1999/5/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL" on 9 March 1999 at Section 12.

Appendix C. References

[1] AT86RF231: Low Power, 2.4GHz Transceiver for ZigBee, IEEE 802.15.4, 6LoWPAN, RF4CE, SP100, WirelessHART and ISM Applications; Datasheet; Rev. 8111B-MCU Wireless-02/09; Atmel Corporation.

[2] Atmel AVR2042: REB Controller Base Board – Hardware User Guide; Application Note; Rev. 8334A-AVR-05/11; Atmel Corporation.

[3] AVR2021: AT86RF231 Antenna Diversity; Application Note; Rev. 8158B-AVR-07/08; Atmel Corporation.

[4] IEEE Std 802.15.4™-2006: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (LR-WPANs).

[5] FCC Code of Federal Register (CFR); Part 47; Section 15.35, Section 15.205, Section 15.209, Section 15.231, Section 15.247, and Section 15.249. United States.

[6] ETSI EN 300 328, Electromagnetic Compatibility and Radio Spectrum Matters (ERM); Wideband Transmission Systems; Data transmission equipment operating in the 2.4GHz ISM band and using spread spectrum modulation techniques; Part 1-3.

[7] ARIB STD-T66, Second Generation Low Power Data Communication System/Wireless LAN System 2003.03.26 (H11.12.14) Version 2.1.

[8] AT25010B: SPI Serial EEPROM; Datasheet; Rev. 8707C-SEEPR-6/11; Atmel Corporation.

[9] SE2431L: 2.4GHz ZigBee/802.15.4 Front End Module; SiGe Semiconductor; Datasheet; Rev 1.8; Aug-08-2010; Skyworks Solutions, Inc.

[10] Atmel AVR2043; REB231ED Radio Extender Board – Hardware User Manual; Rev. 8345A-AVR-05/11; Atmel Corporation.

Appendix D. Revision history

Version	Description
A08-1170/1	Initial release

Appendix E. EVALUATION BOARD/KIT IMPORTANT NOTICE

This evaluation board/kit is intended for use for **FURTHER ENGINEERING, DEVELOPMENT, DEMONSTRATION, OR EVALUATION PURPOSES ONLY.** It is not a finished product and may not (yet) comply with some or any technical or legal requirements that are applicable to finished products, including, without limitation, directives regarding electromagnetic compatibility, recycling (WEEE), FCC, CE or UL (except as may be otherwise noted on the board/kit). Atmel supplied this board/kit "AS IS," without any warranties, with all faults, at the buyer's and further users' sole risk. The user assumes all responsibility and liability for proper and safe handling of the goods. Further, the user indemnifies Atmel from all claims arising from the handling or use of the goods. Due to the open construction of the product, it is the user's responsibility to take any and all appropriate precautions with regard to electrostatic discharge and any other technical or legal concerns.

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